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Teamwork in Acute Care Teams:

Coordination Processes, Assessment, and Training

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Summary

Effective team coordination in medical teams, especially when under time pressure, is essential for patient safety. This dissertation is composed of four articles that address three distinct but closely related aspects of group research and its application to acute care teams: Group coordination processes, their measurability through behavioral observation, and the application of research findings to the design of appropriate (simulation) training.

Article 1 (Implicit Coordination: A Systematic Review and a New Approach) and **Article 2** (Moving from Explicit to Implicit Coordination in Acute Care Teams: The Role of Verbal Communication and Coordination Requirements) examine a specific coordination mechanism, called implicit coordination, that is seen to be beneficial especially in teams performing a complex task in a time-critical environment such as acute care teams. The goal of these articles is to better understand this coordination mechanism and to be able to use the findings for training purposes.

Article 3 (Rules for Coding Scheme Development: DIY) shows how coordination can be made measurable - the prerequisite for studying coordination mechanisms in the first place. This article is aimed at both practitioners and researchers.

Article 4 (The Patient Who Fell Out of Bed: A Simulation Scenario Combining Technical and Non-Technical Skills for Multidisciplinary ICU Teams in a Non-Standard Emergency Situation) demonstrates how knowledge about team processes can be used for simulation-based training, specifically how training scenarios are developed. The result of this article is a detailed description of a challenging training scenario for experienced physicians and nurses in medical, technical, and teamwork skills developed primarily for practice.

Résumé

La coordination efficace des équipes médicales, en particulier lorsqu'elles sont soumises à une pression temporelle, est essentielle pour la sécurité des patients. Cette thèse est composée de quatre articles qui examinent trois aspects distincts mais tous liés à la recherche sur les groupes et à leur application aux équipes de soins aigus: Les processus de coordination de groupe, leur mesurabilité par l'observation du comportement, et l'application des résultats de la recherche à la conception d'une formation (simulation) appropriée.

L'article 1 (Implicit Coordination: A Systematic Review and a New Approach) et **l'article 2** (Moving from Explicit to Implicit Coordination in Acute Care Teams : The Role of Verbal Communication and Coordination Requirements) examinent un mécanisme de coordination spécifique appelé coordination implicite, qui est considéré comme bénéfique en particulier pour les équipes effectuant une tâche complexe dans un environnement à temporalité critique, comme c'est le cas des équipes de soins aigus. L'objectif de ces articles est de mieux comprendre ce mécanisme de coordination et de pouvoir utiliser les résultats à des fins de formation.

L'article 3 (Rules for Coding Scheme Development: DIY) montre comment la coordination peut être rendue mesurable - la condition préalable à l'étude des mécanismes de coordination en premier lieu. Cet article s'adresse à la fois aux praticiens et aux chercheurs.

L'article 4 (The Patient Who Fell Out of Bed: A Simulation Scenario Combining Technical and Non-Technical Skills for Multidisciplinary ICU Teams in a Non-Standard Emergency Situation) montre comment les connaissances sur les processus d'équipe peuvent être utilisées pour la formation basée sur la simulation, et plus précisément comment les scenarii de formation sont développés. Le résultat de cet article est une description détaillée d'un scénario de formation complexe pour les médecins et les infirmiers expérimentés en matière de compétences médicales, de compétences techniques et de travail en équipe, développé principalement pour la pratique.

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Abstract

This dissertation is composed of four articles that address three distinct but closely related aspects of group research and their application in acute care teams: group coordination processes, their measurability via behavioral observation and the application of research findings to the design of appropriate (simulation) training.

Article 1 (IMPLICIT COORDINATION: A SYSTEMATIC REVIEW AND A NEW APPROACH) is a systematic literature review that summarizes articles that have examined a specific form, that of implicit coordination, in a variety of teams performing a common task. Since empirical results on implicit coordination are not always conclusive, the goal of the review was to identify possible reasons for such discrepancies and to present an extended model of implicit coordination to clarify and expand the understanding of implicitness in coordination processes.

Article 2 (MOVING FROM EXPLICIT TO IMPLICIT COORDINATION IN ACUTE CARE TEAMS: THE ROLE OF VERBAL COMMUNICATION AND COORDINATION REQUIREMENTS) is an observational simulation study that analyzes in detail a defining aspect of implicit coordination; the reduced need or lack of verbal communication (Entin & Serfaty, 1999; Kolbe et al., 2013; Rico et al., 2008), as well as the role of task demands in medical groups repeatedly confronted with the same task. This process from explicit to more implicit coordination was examined using quantitative and qualitative indicators of the change of verbal communication. The quantitative communication indicators studied were the number of words, the number of communication units, the percentage of tasks coordinated without verbal communication, and a quantitative indicator of grounding/chunking (Bangerter & Clark, 2003; Clark & Brennan, 1991; Miller, 1956), i.e., number of words per communication unit. The ambiguity of communication over time was analyzed as a qualitative indicator of the grounding process.

Article 3 (RULES FOR CODING SCHEME DEVELOPMENT: DIY) focuses on the process of developing coding schemes for assessing coordination processes through behavioral observation. The few generic coding schemes that have been developed (e.g., Bales Interaction Process Analyses, Bales, 1950) are not specific enough for most research questions. Therefore, for most observational studies, new coding schemes must be developed, or existing schemes must be adapted to meet the specific study needs. Examples from our work are used to illustrate the development process. We code the behavior of both real surgical teams in the operating room in vivo and of medical teams performing medical tasks in patient simulators recorded on video.

Article 4 (THE PATIENT WHO FELL OUT OF BED: A SIMULATION SCENARIO COMBINING TECHNICAL AND NON-TECHNICAL SKILLS FOR MULTIDISCIPLINARY ICU TEAMS IN A NON-STANDARD EMERGENCY SITUATION**)** highlights the importance of simulation training in group-dominated work contexts such as acute care and the significance of well-designed simulation scenarios. Many simulation scenarios in medicine involve relatively simple tasks, focus on technical skills training, and, when they involve teams, provide monodisciplinary training. Therefore, they are well suited for less experienced personnel but do not adequately reflect the diversity and unpredictability of complex clinical realities (Okuda et al., 2009). We developed a high-fidelity training scenario for advanced medical professionals working in the Intensive Care Unit that reflects the complexity of clinical reality and combines task-based training with training of nontechnical or teamwork skills in interdisciplinary teams. A performance assessment checklist (Observational Assessment of Medical Technical and Teamwork Skills, MeTTS) was developed that can also be used for feedback purposes after training.

The dissertation concludes by discussing the contributions and implications of each article and identifying the limitations and possible directions for future research.

Keywords: High fidelity simulator research; Behavioral observation; Implicit coordination; Explicit coordination; Team coordination; Group processes; Team performance; Communication analysis; Grounding; Chunking; Observational coding schemes; Medical education; Team training; Simulation scenario development; Non-technical skills.

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1. Introduction and Overview

The studies included in this dissertation focus on coordination processes in acute care teams, their assessment via behavioral observation, and the development of a complex scenario for simulation-based training.

Interest in group work in the workplace has increased over the last few decades (Arrow et al., 2000). Especially high-reliability organizations (HROs) such as hospitals, and more specifically, critical care medicine, rely heavily on interprofessional teams in emergency situations and in case of complex tasks (Baker et al., 2006; Weled et al., 2015).

It is commonly acknowledged that teamwork is prone to errors and mishaps (Bergs et al., 2005), in particular under high time pressure and/or in case of emergency (Gawande et al., 2003). Situations in which team members work together for a specific purpose, but without any prior forethought, prompting or planning regarding how to work together, in so called ad-hoc teams, may increase the risk of errors and mishaps in teamwork. Research has for example shown that 44% of aviation accidents happened in the first flight of a newly composed flight crew, and 73% on the first day (Board, 1994). Ad-hoc teams are a common type of cooperation in hospitals (Dwyer & Williams, 2002; Marsch, 2005).

However, teams can be very effective. Reasons why they fail to perform well are usually related to characteristics of the work context in which they are operating and/or to organizations not providing the necessary resources, including training. Arrow et al. (2000) hit the nail on the head when they state that teamwork is not self-running; simply grouping people together and call it a team is not sufficient. The benefits associated with teamwork requires (1) an understanding of what makes a team successful and (2) ensuring that teams are equipped with the skills required for successful team performance, that is the implementation of that knowledge in terms of training.

Understanding team coordination in order to use this knowledge for the development of adequate *training* methods means making coordination *measurable* and *analyzing* it. This dissertation has three aims. First, to show how coordination processes can be measured via observation, specifically how observational coding schemes are developed. Second, to better understand a specific coordination mechanism, called implicit coordination that is considered beneficial in teams studied in this dissertation: critical care teams performing a complex task in a time-critical, high-pressure environment. And third, to show how knowledge about team processes can be used for simulation-based trainings, specifically how training scenarios are developed.

1.1 Structure of the thesis

The first part of the dissertation introduces the theoretical background to group research and is divided into three parts: Understanding, measuring, and training coordination processes (Chapter 2). The third chapter contains a summary of the thesis articles, followed by the articles and manuscripts (Chapter 4). At the end of the thesis, a general discussion with limitations, outlook and conclusion is given (chapter 5).

1.2 General overview of the thesis studies

One article is published, the other articles still need some work to be submitted, but already have an article structure for publication. Two articles are based on an interdisciplinary project between Psychology and Medicine. This research project was supported by the Swiss National Foundation (grant #149734[1]). The articles are co-authored with other members of the research team.

Article 1 is a *systematic review of the literature on implicit coordination*. Considering diverse findings from available research, relevant literature from different disciplines was systematically examined to find out whether general statements on the effects and conditions of implicit coordination can be derived from available findings and/or which aspects might need to be considered additionally to achieve greater clarity. An extended model aimed at expanding the understanding of implicitness in coordination processes is presented.

Article 2 is an *observational study on the process of implicit coordination* in acute care teams repeatedly confronted with an emergency during simulation training. The focus was on a key aspect of implicit coordination, the reduced need for verbal communication as well as the role of task requirements in this process.

Article 3 focuses on the development of *observational coding schemes* for assessing observed group communication and behavior, which are often used in team research and are also suited for simulation training (e.g., to provide feedback based on team performance measurement). The development process is described in six steps and

[1] http://p3.snf.ch/Project-149734

supports practitioners and researchers to develop coding schemes tailored to their specific needs.

Article 4 focuses on the development of *simulation scenarios* in simulation-based trainings. The scenario for training medical, teamwork and technical skills of medical professionals working in the Intensive Care Unit (ICU) is described in detail so that it can be used by practitioners.

Taken together, the four papers of this dissertation cover three essential aspects of group research, which are however closely interlinked: The *measurability* of team coordination processes, which is necessary to *study and understand* team coordination, and the application of research findings to the design of appropriate (simulation) *trainings*.

2. Theoretical Background

Disclaimer: The Umbrella was written parallel to the articles contained in this dissertation. Some sentences and formulations may be similar in both documents.

Psychologists have been doing research on small groups for over 60 years; literally thousands of studies have been published, including numerous handbooks and publications on specific group topics. The beginnings of group research can be found in social psychology, where the focus was not exclusively, but to a large extent, on interpersonal processes. The influence of the group context on individual behavior as well as on influencing factors of interpersonal processes and group behavior was investigated (McGrath, 1964). Accordingly, the first decade of group research was dominated by topics such as power and social influence, societal forces holding people together, social pressure to conform, or cooperation and competition (Zander, 1979). After its heyday in the 1950s, when new research on group processes was emerging, such as that of Bales (1950b), group research had to withstand increasingly critical evaluations in the 1960s. Concerns included limited theoretical progress, fragmented research, and lack of integration (McGrath & Kravitz, 1982). The intense early interest in group interaction processes declined for over a decade. However, Bales' main contribution (Bales & Cohen, 1979), where he presented a comprehensive theory of social interaction, a measurement system and a set of tools for analyzing and improving effectiveness in groups, revived interest in the group process. In the 1980s, groups were first referred to as "task performing systems", indicating the shift in focus of group research away from interpersonal processes to performance-relevant team processes (McGrath & Kravitz, 1982). This reorientation towards team processes was certainly also due to the major change and restructuring of work during this period from individual jobs to group work. The interest in topics such as team effectiveness / performance, influence processes, or the patterning of interaction in industrial and organizational psychology increased. In their review of group research, Levine and Moreland (1990) concluded that small group research still exists, however, somewhere else (p. 620). With this statement they referred to the fact that in contrast to social psychology, which has long been critical of group research and group work, organizational psychologists were optimistic about teamwork and regarded it as "producible/feasible", i.e., as a success factor (e.g. Ulich, 2011). However, industrial, and organizational psychologists were and still are also aware that group work is challenging. Group as well as contextual dynamics (e.g., interactions among group members or group adaptions to the context) make group work complex and a multi-layered process (Arrow et al., 2000; Tschan, 2000).

This dissertation is concerned with the team process of coordination in acute care teams, including the development of appropriate measurement methods and training. To begin, definitions of *group and small group, team,* and *action team* are presented. Theoretical models as well as methods for the analysis of coordination processes, both of which will be presented afterwards, serve to deepen the understanding of these processes. These first explanations form the basis of the Articles 1 and 2 which examine the coordination process, in particular team implicit coordination, and Article 3, which deals with the development of coding schemes as a method for analyzing coordination processes. A deep understanding of the coordination process is a prerequisite for the development of adequate *training* methods, which are presented last. One example of a training method that is used particularly in high-risk professions and is therefore also increasingly used in the health care sector is simulation training; a simulation scenario was developed in Article 4.

2.1 Definitions

Group and small group. As the term implies, groups (as opposed to small groups) can consist of many people, for example, based on a social category such as middle class, or due to spatial proximity. A group has a common identity as such, though interaction is not a mandatory requirement (Arrow et al., 2000). An example is students in a lecture hall attending a lecture together. The term small group is somewhat more tailored to the research interests of industrial and organizational psychology. A small group has a shared collective identity. Its members are interdependent and mutually interact with each other, e.g., in projects and with the help of technologies (Arrow et al., 2000). Group members are aware of their group membership. They may be formed in working and non-working contexts for many different reasons and having many different purposes, such as completing a project or providing enjoyable activities. Small groups are considered as complex, dynamic, and adaptive (Arrow et al., 2000; Ilgen et al., 2005). *Complex* because of their interdependence and the different roles and tasks, and different educational backgrounds of the group members. *Adaptive* through interaction with facets of their embedding context (e.g., other work groups, individuals in the same organization, customers, the physical environment etc.). *Dynamic* through process developments over time by which groups carry out their activities, processes of adaptation to environment in which they are embedded, and processes that are automated, or changes in group composition (e.g., when roles are replaced or new members join (Arrow et al., 2000).

Teams. Teams can be defined as distinguishable work entities consisting of two or more individuals who pursue the fulfilment of a complex and interdependent task in a dynamic environment for a certain period of time. Thus, teams are groups in a specific working context, such as surgical teams or police teams. The interdependence of the subtasks requires coordination among members who are role-specifically responsible for certain subtasks (e.g. Salas et al., 1992; Salas et al., 2007; Tschan & Cranach, 2003).

Action teams. Action teams (similar to "extreme action teams" according to Hollenbeck et al., 2012) are one specific type of teams and consist of highly trained professionals with specialized skills and clearly assigned roles and responsibilities that work together for a specific purpose. Their working environment is characterized by intensive work situations that are often unpredictable (Sundstrom et al., 1990) and characterized by high levels of stress, for example due to an acute medical situation. An example are teams of medical professionals treating an emergency (e.g., cardiac arrest). As their team composition is unstable and tasks are clearly regulated to guarantee performance, they resemble what Arrow et al. (2000) classify as a crew. Team members from different disciplines, some of whom may not know each other from previous collaboration, with different backgrounds, skills and roles must cooperate (Sundstrom et al., 1990). In contrast to crews, however, they often have no opportunity to plan their cooperation, for example through a pre-action briefing. They are formed ad hoc. Ad-hoc formed action teams are thus confronted with specific challenges in order to perform well.

The focus of this dissertation is on ad hoc formed medical teams (medical students and experienced professionals) having no prior experience in joint collaboration.

2.2 Understanding Coordination Processes

If group coordination is to be studied, it is important to understand how groups function. The purpose of this chapter is to understand teams and the coordination processes within teams. This part of the theoretical background is given the most weight because understanding coordination processes is the basis for all three parts of this thesis, the development of measurement methods, the analysis of the coordination process and the development of training methods.

First, a rather general introduction is given by presenting the "Input-Process-Output-Model" (I-P-O), which has dominated group research until today (McGrath, 1964). Then the coordination process is described in more detail and the following questions are addressed: (1) *What* is being coordinated? (2) what are *determinants* for good group coordination? (3) *how* is coordination being done? (4) and *how much* coordination is necessary?

2.2.1 I-P-O Model(s)

The I-P-O model (McGrath, 1964) assumes that the *input* factors, such as characteristics of the persons, the group, the environment, or the task, influence the group *process*. The *output* of the group depends on this process. Team characteristics include, for example, the level of experience, status, demographic variables, or personality aspects. Task characteristics include the nature of the task, for example whether it is a routine or non-routine task. The process refers to the interaction of team members during the task execution, i.e., coordination and communication. Outputs refer to the team performance, in a medical context for example, the successful treatment of the patient.

Although the I-P-O model is widely accepted, certain aspects of the model have also been repeatedly criticized. On the one hand, it is a rather static model that does not consider the time component of team activities. Teams change systematically over time; they develop (Arrow et al., 2004; Tschan & McGrath, 2008). For example, teams (including ad hoc teams) develop habitual routines (Gersick & Hackman, 1990) in repeated interactions or for aspects of the task that are repeated during a given team session (Bangerter & Clark, 2003). They develop team-specific ways to coordinate, based on their common experience, which may serve as inputs for future tasks. The criticism of the I-P-O is thus also directed against the “single-cycle linear path” of the I-P-O model (Ilgen et al., 2005; Kozlowski et al., 1999; Marks et al., 2001). There are several alternative models that adopt a “multi-cycle view”, in which outputs (e.g., team performance) can also be inputs in later team processes indicating that processes are not static but unfold over time. For example, what is specific to the input-mediator-output-input (IMOI) model developed by Ilgen et al. (2005) is the additional input (I) at the end that represents the cyclical causal feedback. The elimination of the hyphen between the letters means that the causal links may not be linear or additive. Furthermore, the process (P) is replaced with a mediator (M), indicating that the relationship between inputs and outputs can be mediated by various variables and that many of these variables are not processes.

A main focus of this dissertation is on effective team coordination processes (P) in ad hoc formed ad hoc teams. The cyclical perspective, as described for example in the IMOI model, is an important basis particularly for understanding Articles 1 and 2, which concern implicit coordination that is assumed to develop over time. Article 3 describes how coding schemes to measure team processes (P) can be developed. In Article 4 we developed a scenario focusing on effective coordination processes (P) and the output itself (O) in terms of a performance marker checklist that can also be used for feedback purposes in debriefing sessions after simulation training.

2.2.2 Coordination in task-performing groups

Team coordination is a key factor in understanding how a group of individuals work together effectively and thus an essential component of successful team performance (McGrath, 1991; Okhuysen & Bechky, 2009). In order to achieve common goals and ensure that the right actions take place at the right time, team members must manage their interdependencies by using specific strategies and behavior patterns to integrate their knowledge, actions and individual goals (Rico et al., 2008; Rico et al., 2011).

In this section, the focus it on four essential questions regarding effective coordination. The questions are (1) What is being coordinated? (2) What are the determinants of good coordination? (3) How is coordination being done? and (4) How much coordination is necessary? At the end of this section, the importance of effective coordination processes in ad hoc formed medical teams is outlined, which are investigated in this thesis.

2.2.2.1 What is being coordinated?

Groups have long been described primarily as 'information-processing' systems (Hinsz et al., 1997) because they often work on problem-solving and decision-making tasks where the decisions based on discussion and interaction are already the task solution. However, groups, especially in the working context, often also process tasks with manual parts (McGrath, 1984; Tschan & Cranach, 1996). This is why Cranach described them as ‘acting systems’ and proposed to adapt concepts of psychological theories of individual action for acting groups (Frese & Zapf, 1994; Hacker, 2014; McGrath & Tschan, 2004a; Von Cranach, 1996; Von Cranach et al., 1987). Dealing with (coordinated) work behavior therefore first requires an examination of the concept of action.

Action Regulation Theory. ART (Hacker, 2014) is a cognitive psychological theory that analyzes the way individuals achieve their goals by looking at two essential processes of human action: the action process itself and the regulatory process underlying the structure of action in a hierarchical system.

Action process. In simple terms, goals (or *goal development*) stimulate actions by motivating actors to take a certain action. Information about the situation and relevant signals are collected (*orientation*), which results in the need for action and an action plan (*plan generation*). Signals are information that indicate the need for action, they trigger actions and are the link between knowledge and behavior. Signals must be recognized and interpreted, which experts often do better because they have a good signal inventory (e.g., an experienced physician who can take appropriate measures very quickly when recognizing certain breathing sounds). The optimal use of signals (also referred to as cues by other authors, see e.g. Clark, 1996; Wachs et al., 2014; Wittenbaum, 1996) enables foresighted action, which can be of great value especially in emergency situations such as those that can occur in acute care teams. Finally, a decision is made (*decision*) to execute the action. This decision can involve an iterative process of Test-Operate-Test-Exit (TOTE) to fine-tune the process between the plan and decision. The action is *executed and monitored*, and is completed by *feedback*, which provides a basis for comparison and learning.

Regulation. A task is usually formulated as a goal (e.g., resuscitation of a patient), which can be specified and broken down into sub-goals (e.g., cardiac massage, ventilation, drug administration etc.). The goals and sub-goals of the action are *hierarchically* structured (Frese & Zapf, 1994; Hacker, 1976; Shiffrin & Schneider, 1977; Volpert, 1983; Von Cranach et al., 1986). This means that higher-level goals (e.g., saving the patient's life) are achieved by working down lower goals (e.g., cardiopulmonary resuscitation). Actions are *sequentially* structured by working through one subgoal after the other. Both the task structure (i.e., tasks as requirements) and the action behavior (i.e., the regulation of action execution) can be represented as a hierarchical structure. Action regulation can take place on different levels, which differ in the degree of consciousness of the regulation processes (conscious to automated) and concern the type of regulation (sensorimotor to intellectual). The *sensorimotor* regulation of actions concerns small, often automated (Reason, 1990) and no longer conscious actions (e.g. hand movements, Von Cranach et al., 1986). The level of *flexible action patterns* marks the retrieval of predefined schemata or rules that contain the most important and thus prototypical representations of action structures. Action schemes can be conscious or automated, they are thus capable of but do not require consciousness. The *intellectual* regulation of action involves the conscious, explicit reflection, and coordination of action (Von Cranach et al., 1986).

Psychological action theories were originally conceived for the actions of individuals. However, since they generally describe goal-oriented behavior, they are not limited to individual actors. Von Cranach et al. (1986) was the first to apply the theory of action to groups. In a group, individual actions are coordinated so that they become group actions. To carry out a task together effectively, it is necessary that group members fulfil the requirements of the task in a coordinated and task-adapted way (Tschan, 1995). Thus, they need to know the task structure and make sure that different members perform different subtasks or that they work together and in a coordinated manner on the same (sub)tasks. In contrast to individual actions, which are regulated by means of cognition, group actions are regulated and coordinated by means of *communication*. This also corresponds to the perspective of Clark (1996) who takes an "action approach to language" and regards coordination and communication as inseparable.

The coordination process via communication will be examined in more detail in Section 2.2.2.3 “How is coordination being done?” (p. 11). For now, I will return to the initial question “What is being coordinated?” and conclude that considering groups as acting systems suggests that both *actions* and *information* need to be coordinated. While individuals regulate their actions cognitively, the regulation of actions in the group takes place via *communication*.

2.2.2.2 What are the determinants of good group coordination?

In the previous section it was stated that both action and information must be coordinated. In the following, two central determinants of good coordination that are important for this thesis are presented from an action and communication-theoretical perspective.

Action regulation theories describe how people act but can also be used to predict how successful action regulation can be achieved, both at the individual and the group level (Tschan, 2000). In simplified terms, actions are performed well if the group has sufficient knowledge relevant to the action and can verify this knowledge at the right time. A good representation of the problem and the intervention possibilities, i.e., good mental models, allows the existing knowledge to be used optimally (e.g. Hacker, 2014). Mental models are the basis for action planning, strategy development, action execution, and the evaluation of actions. In order to achieve good *group* performance, it is particularly important that mental models are *shared* (Tschan & Cranach, 2003). Shared mental models include knowledge about the task (e.g., procedures, rules, strategies), the available technology, environmental conditions, roles and responsibilities, strengths and weaknesses of other team members, and coordination rules of the group (Converse et al., 1993; Klimoski & Mohammed, 1994; Tschan & Semmer, 2001). They help actors develop appropriate explanations and expectations for task performance and, based on these, coordinate their actions, including adjusting their actions to the task requirements and the behavior of other group members (Converse et al., 1993).

Common ground. From a communication theory perspective, common ground comes very close to mental models. Common ground is the sum of two people's mutual, common or joint knowledge, beliefs and suppositions (Clark, 1996). Clark (1996) assumes that coordinating and communicating is only possible when group members have a shared basis. This common basis should be constantly updated throughout the coordination process. Stated in very simplified terms, when people are aware of their own and their partner's common ground and constantly update it, it is very probably that these two people "understand each other" and can anticipate what action is expected of them in order to successfully achieve the common goal together.

2.2.2.3 How is coordination being done?

What translates group members' individual goals, meanings, and behaviors into group processes, are coordination mechanisms (Boos et al., 2011). The degree of its explicitness and implicitness is one important distinction (Entin & Serfaty, 1999; Espinosa et al., 2004; Rico et al., 2008; Wittenbaum, 1996; Wittenbaum et al., 1998; Zala-Mezo et al., 2009). First, the most prominent models of implicit (and explicit) coordination are introduced. Afterwards, coordination of information, respectively the process of coordination via communication, is presented.

Theoretical models of implicit coordination. Wittenbaum et al. (1998) present the *model of coordination mode in task-performing groups*. According to this model, group coordination varies on two dimensions: on the time when it takes place (before vs. during interaction) and its explicitness (explicit vs. implicit). Coordination is considered implicit (or tacit) when it is based on unspoken expectations and intentions, and explicit when it is based on verbal agreements or formally adopted plans for joint task completion. From these dimensions, four modes of coordination emerge: 1) *explicit pre-plans* (e.g., job descriptions, organizational rules), 2) *explicit in-process planning* during which the work roles of team members are explicitly defined, 3) *implicit pre-coordination* which involves pre-interaction hypotheses about group members and the task to be done, influencing team member's coordination intentions and making them adapt their behavior accordingly, and 4) *tacit in-process coordination* where team members make mutual strategy adjustments based on the observed behavior of others during task execution. By means of this model, the authors discuss functional (e.g., efficiency) and dysfunctional (e.g., coordination failures by over-reliance on assumptions and suppositions about how others will approach the task) consequences. Various potential moderators of the coordination modes are presented, including task factors (interdependence, task uncertainty) group factors (group size, recomposition, diversity), temporal factors (time pressure and temporal milestones), environmental factors (feedback, goal setting, interventions) and factors of the work context (natural vs. laboratory groups). Particularly relevant for this dissertation is task interdependence. High dependencies between team members, which mainly occur when tasks are very closely coupled in time and space, contribute to the complexity of synchronization, so that tacit coordination strategies tend to be ineffective. However, if there is no or low dependency (one could also speak of loosely coupled tasks here), in-process planning is likely to be inefficient because it takes too much time. Also, temporal factors play a role since teams in Article 2 are faced with an emergency situation where they must resuscitate a patient suffering a cardiac arrest, and the simulation scenario developed in Article 4 is a non-standard emergency situation where an ICU patient fell out of bed. In brief, a surplus of time may facilitate in-process planning, as members have time for such activities. Time deficits may require teams to tacitly coordinate to avoid using valuable task time to plan, and positive feedback may support tacit coordination once it has been developed by reinforcing the groups' familiar behavioral patterns and strategies.

In a former study, Wittenbaum (1996) examined the *anticipatory process of tacit coordination* in more detail, specifically, how members tacitly coordinate their activities in anticipation of small group task completion. Tacit coordination is defined in their study as the "synchronization of members' actions based on unspoken assumptions about what others in the group are likely to do" [p.129]. Three key components for anticipatory tacit coordination in groups are identified: Member's expectations before interaction, task assessment, and resource allocation. Thus, based on expectations and hypotheses about the abilities and actions of others, members infer how others are likely to e.g., approach a task. The tasks at hand are analyzed based on assumptions about successful task performance, about procedures and strategies that facilitate goal achievement, and whether the task is perceived as cooperative or competitive and thus benefits from diverse inputs or not. Depending on this task assessment and the expected actions of others, members evaluate their relevant resources in terms of effort, time, information, strength, or talent and assess their potential contribution to the task execution/completion.

Espinosa et al. (2004) present an *integrated framework of explicit and implicit coordination* and discuss the interplay between implicit and explicit coordination mechanisms and how they jointly affect team coordination and performance. In essence, the model states that task variables (e.g., mechanical task vs. problem solving task), team variables (e.g., familiarity), and context variables (e.g., organizational factors such as standard operating procedures, or culture) affect the type of dependencies in a work task. These in turn affect which coordination mechanisms are used to effectively manage these dependencies, respectively, to successfully complete the task. Coordination affects team performance to the extent that these dependencies are important for performance. In other words, the dependencies vary according to the type of task and even within a task at the level of the individual subtasks. It seems important for team performance to find the right mix of implicit and explicit coordination strategies.

Rico et al. (2008) present an integrated *theoretical framework for team implicit coordination processes*. Focusing on those processes that are directly related to implicit coordination in that model, the following propositions are made. Implicit coordination is more likely to occur in the presence of shared and accurate Team Situation Models (TSMs) and in turn results in alterations to current TMSs. It is assumed that implicit coordination mediates the relationship between TSMs and team performance. Implicit coordination is expected to facilitate team performance when task routineness is high, whereas when task routineness is low, the exclusive use of implicit coordination is assumed to have negative effects on team performance. Furthermore, the effect of implicit coordination on team performance is anticipated to be grater when teams perform highly interdependent tasks. Virtuality is introduced as a moderator of the relationship between implicit coordination and team performance.

In a more recent study, Rico et al. (2019) present a theoretical *model that focuses on the coordination processes that support team adaptation and increase team effectiveness* over time. It addresses how team members understand and manage changes in the task based on Team Mental Models (TMMs) and TSMs. TMMs are fundamental, long-term cognitive structures about the task or how the team functions (Klimoski & Mohammed, 1994). In contrast, TSMs are short-term and contextual mental representations about individual elements of the current situation (Cooke et al., 2003). Emergent task demands are an example. According to the model, certain team characteristics (e.g., team task expertise) encourage them to compare whether TMMs and TSMs match when the task suddenly changes. That is, teams compare their expectations of a particular environment or situation with what they will face in the current situation.

This comparison enables adjustments in coordination, in which teams either coordinate more explicitly or more implicitly.

Combining empirical results and theoretical considerations, Kolbe et al. (2011) propose a model that allows to systematize coordination mechanisms in healthcare action teams. The model incorporates coordination input entities (e.g., individual goals), coordination mechanisms (i.e., explicit vs. implicit, pre-process vs. in-process coordination) and coordination processes (i.e., team adaption). Similar to other studies, the authors assume that implicitness is based on anticipation and the corresponding adaptation, and explicitness is by its nature directive and verbal. Any coordination can be distinguished according to what is being coordinated (i.e., information or action) and how it is being coordinated (i.e., explicitly, or implicitly). These two dimensions are independent of each other. An example of *explicit action coordination* is giving instructions, representing an explicit act of coordination. *Explicit information coordination* includes communicative actions that explicitly aim to manage information processing in a team (e.g., requesting information). *Implicit information processing* includes actions to implicitly manage the information process (e.g., information-related talking to the room). *Implicit action coordination* involves actions that are mutually anticipated. Finally, coordination mechanisms are regulated by adaptation (i.e., when alternating between coordination styles). Based on this model, Kolbe et al. (2013) presented the Framework for Observing Coordination Behavior in Acute Care Teams (Co-ACT) in a later study.

Coordination via communication. Communication to regulate group actions can be very explicit and open (e.g., open communication of the group goal on the intellectual level of regulation) or become unnecessary, change or simplify through the formation of routines in groups (e.g. Gersick & Hackman, 1990). In this way, flexible action patterns can be established also at group level, which can be called up by signals that are capable of being communicated but not required to be communicated (Von Cranach et al., 1986) (cf. Section 2.2.2.1 “What is being coordinated”, p. 8). Not only verbal but also non-verbal communication is possible, for example on the sensorimotor regulation level, when individual movements need to be synchronized (e.g., to lift a patient).

Psycholinguistic theories offer special insights into the communication process during coordination. Particularly relevant for the purpose of this thesis are the explanations of Clark (1996). Clark’s premise is that whenever a group of people performs joint activities that require coordination, language is used. He thus promotes an 'action approach to language use' since one cannot understand one without the other (Clark, 1996). He calls the use of language during coordination ‘joint actions’, which themselves require coordination. In each joint action participants are faced with a coordination problem they need to solve: the joint construction of the language used in order to be able to infer what individual actions they can expect from each other to pursue the goal of their joint activity. The use of language is therefore a collaborative process; the communicative intention (speaker's meaning) must not only be perceived by the listener, but also correctly understood.

Since it is impossible to present Clark's comprehensive work on the use of language in its fullness here, the focus will be on two aspects relevant to this thesis. The first concerns the question of how speakers coordinate what they mean with what their addressees understand them to mean. According to Clark (1996), this is a question of *signaling systems*. The second question is how speakers adequately communicate meaning to the addressees based on their common ground? Amongst other things, this is a question of *referencing*.

Signals play a major role in Clark's explanations. Signals are devices for coordinating actions. They generally refer to the use of language itself and, specifically, include linguistic as well as non-linguistic acts (e.g., pointing, nodding, eye-gaze). Signaling, in general terms, describes an act in which one person "means something " to another person. Most signals are the result of a fusion of three methods of signaling, which employ the symbolic, indexical and iconic respectively: "describing-as" (i.e., linguistic expression), "indicating" (e.g., pointing), and "demonstrating" (e.g., manual, facial and/or vocal gestures). But what does it take for the listener to actually understand what the speaker means? This question is important because coordination is ultimately about the partners being able to identify the one course of action in which their expectations converge. The answer is that participants must reach a joint construal of the signal. In doing so, they rely on what Clark called "common ground": the shared knowledge, beliefs, and suppositions about the activity, which accumulates over the course of action. Referring to the common ground in interactions helps to form "mutual expectations" about individual actions each person will take, thus providing them with a basis for choosing the right participatory action to perform.

The second question is about how speakers adequately communicate meaning to the addressees based on their common ground. As indicated above, one of the aspects involved here is referencing. In general, referencing is about designing utterances and learning when to use which words based on common ground so that a particular listener easily understands the meaning the speaker wants to communicate (Clark & Wilkes-Gibbs, 1986). For example, a physician may provide a different amount of information (longer vs. shorter), shape sentences differently and choose different words (e.g., "heart attack" vs. "myocardial infarction") when speaking with a patient compared to when speaking with a colleague (Isaacs & Clark, 1987). Sources of common ground may be tied to specific interactions, such as shared experiences in the past (Clark & Marshall, 1981) or to the previous linguistic context, i.e., the language they have used in current or past interactions and the meaning they have mutually established. By creating a common basis, communication becomes faster and more efficient; fewer words and fewer turns are needed to reach a common understanding. This process, when communication partners shorten their communication based on common ground, i.e., when they group individual pieces of information into larger units, is also known as “chunking” (Miller, 1956). This adaption of communication based on common ground can be observed not only over different occasions of interaction, but also within one course of action over time (Clark & Wilkes-Gibbs, 1986).

By establishing such a new conventional signaling system (i.e., special expressions that only the partners who are interacting understand), communication becomes increasingly difficult to understand, e.g., for non-experts who lack part of the common ground previously established between the interacting partners. In other words, communication becomes more ambiguous for “outsiders”, and coordination problems may arise. In general, when signals (language) may be interpreted in multiple ways, respectively interpreting the speakers’ meaning requires increasingly more inference, successful coordination with such “outsiders” requires explicit agreement (i.e., common ground) to a larger degree. For example, on how to proceed by explicitly communicating intentions. Another possibility, which comes very close to what was previously referred to as cues (cf. 2.2.2.1 ”What is being coordinated”, p. 8) in this thesis, is that interacting partners rely on perceptual (joint) salience where the next step out of many possible steps is apparent due to the environment or available information (e.g., from the monitor). Or, lastly, interacting partners may refer to something in a certain way based on norms and expectations developed within the on-going experiences of the joint activity, respectively, based on previous experiences of the participants. Taken together, the construction of mutual expectations via the joint construal of signals is achieved by using cognitive (i.e., conventions) and situated coordination devices (i.e., cues) and relying on the common ground of the participants. There are similarities between shared mental models and common ground. Clark’s work is especially pertinent for this thesis because he analyzes how common ground changes the way people communicate in much more detail than typically found in the psychological literature on coordination. The process of chunking, that is, the increasing scope of information contained in successively smaller signals (cues) is of central importance for our purposes.

2.2.2.4 How much coordination is necessary?

The question of the "optimal level" of coordination is a question of the *coordination requirements* of the task. In short terms, groups perform better the more they structure, coordinate, and adapt their processes to the specific requirements of the task (Tschan, 2000; Tschan et al., 2000). However, in research on coordination processes, the task is often not the focus of interest, but is rather seen as a necessary prerequisite for the investigation of a particular hypothesis: One can only observe coordination processes if the group actually does something. However, the task has a far greater significance in the study of coordination processes: A specific behavior may be positively related to performance for one task, but detrimental in another task (Tschan, Semmer, Hunziker, et al., 2011). Thus, coordination processes do not exist independently of the specific group task (Espinosa et al., 2004; Kerr, 2010; McGrath, 1984; Tschan et al., 2000; Tschan & von Cranach, 1996), and tasks influence the group process (Hackman & Morris, 1975; McGrath, 1984).

Coordination requirements can be on a *sequential* basis, for example when information on certain parameters must first be acquired before it is clear whether or not the heart rhythm of the patient is shockable (Tschan et al., 2000). Requirements may also be *time* or *frequency* related. For example, some parameters require that they be assessed very quickly and others only once. Some requirements are *mandatory* implying absolute constraints, others offer at least limited *choice*. Parts of tasks can often be performed in different ways, but these differ in their efficiency (e.g., collecting information even though the heart rhythm has already been classified as shockable). Requirements may be very *direct*, this is when parts of the task require mutual adaption of two or more team members. For example, in non-intubated patients, chest compressions and ventilation should alternate sequentially and seamlessly (Tschan, Vetterli, et al., 2011).

In order to understand what demands a task places on the behavior of the team members, it is necessary to understand the task, i.e., its goals and subgoals (cf. Section 2.2.2.1 “What is being coordinated”, p. 8). The hierarchical task analysis (HTA) describes, respectively decomposes hierarchically nested and temporally linked tasks into their structures, goals and sub-goals including task requirements and steps to complete the task. As a result, a more detailed analysis of between team behavior and performance can be performed. (Annett, 2004; Shepherd, 2001). The important influence of task requirements in the analysis of group processes is widely recognized (Arrow et al., 2000; Cannon-Bowers et al., 1995; Hackman & Morris, 1975; Tschan & Cranach, 1996).

In the next concluding section on team coordination, which describes coordination in ad hoc formed ICU teams, a simplified version of an HTA for the resuscitation task the teams in Article 2 are confronted with, is presented as an example. Simplified, since the very detailed form of the original system is not used and some subgoals are omitted.

2.2.2.5 Coordination in ad hoc formed ICU teams

The teams in Article 2 of this thesis were given the task of resuscitating a patient and the simulation scenario presented in Article 4 is based on this task.

In a medical emergency, effective team coordination is essential for patient safety (Pierre et al., 2016). When treating a patient suffering a cardiac arrest, the teams must therefore coordinate efficiently, including very fine-grained coordination. For the cardiac arrest situation, algorithms specify very precisely what needs to be done by the resuscitation team, specifying not only the tasks, but also their sequence, including strong recommendations as to how many seconds a passage from one task to another task can take (Soar et al., 2015). Such recommendations are important; for example, a delay of more than five seconds between cardiac massage and the application of a defibrillation (an electrical shock delivered to the patient to set the heart in motion) reduces the chances of the shock being successful significantly (Soar et al., 2015). Medical professionals are therefore regularly trained in the specific guidelines, which provides them with a shared mental model (Soar et al., 2015) and opens the possibility for implicit coordination. However, one of the characteristics of a medical emergency is that it normally does not take place with an established team being present and functioning. In case of a cardiac arrest (e.g., in a hospital), the first responder sounds an alarm, and many medical professionals join the situation and form an ad-hoc team. The members of this newly assembled team may not be familiar with each other (Marsch, Muller, et al., 2004) and therefore could not establish habitual routines, although they may individually have experience with the procedural requirements. These constitute “programming mechanisms” that may guide coordination to some extent (Espinosa et al., 2004). This may explain why explicit coordination in terms of task assignment and leadership are beneficial for such teams (Fernandez Castelao et al., 2013; Tschan et al., 2006).

To pursue their goal of saving a patient’s life, teams must divide the task (resuscitating the patient) into sub-tasks; one person takes over the ventilation of the patient, another one the cardiac massage, again someone else can operate the defibrillator while someone else provides the medication, etc. These individual actions are highly interdependent, because the execution of one sub-task directly influences the execution of another sub-task. For example, it is not possible to perform ventilation and cardiac massage at the same time, but this must be done in a coordinated but sequential way; during defibrillation, no one may touch the patient, but ventilation and cardiac massage must be resumed within seconds after defibrillation, etc. (Tschan, Semmer, Vetterli, et al., 2011a). Figure 1 shows the coordination requirements in a simplified HTA. The HTA is based on the European resuscitation guidelines (Soar et al., 2015). General guidelines on advanced cardiopulmonary resuscitation for health care professionals are updated regularly upon the availability of new research.

According to the task analysis and in accordance with the general structure of goal-related actions (Frese & Zapf, 1994; Von Cranach et al., 1986; Zacher et al., 2016), a defibrillation episode can be described as a sequence of four task phases.

First, the team needs to *diagnose* whether defibrillation is appropriate, given the state of the patient (defibrillation is not appropriate for all heart rhythms). Second, the team must *prepare* the defibrillation (attaching defibrillation pads to the patient handling of the defibrillator, choosing joules, and charging). The third phase is the proper *execution* (safety command and shock delivery). This phase has one particular coordination requirement: All team members need to step back from the patient, in order to avoid receiving an electrical shock from the defibrillator. We refer to this type of coordination requirement, which demands close spatial and temporal coordination between the actions of team members and, correspondingly, that team members focus on the same subtask at the same time, as a "*tight*" *coordination requirement*. In contrast, subtasks that do not require all group members to focus on the task simultaneously are referred to as "*loose*" *coordination requirements*. Such tasks can be performed by a single team member, allowing the other team members to focus their attention on other tasks or to perform other tasks in parallel (e.g., adjusting the energy level of the defibrillator). The fourth and last phase is called *control* and contains the assessment of the effect of the defibrillation and the passing to the next step.

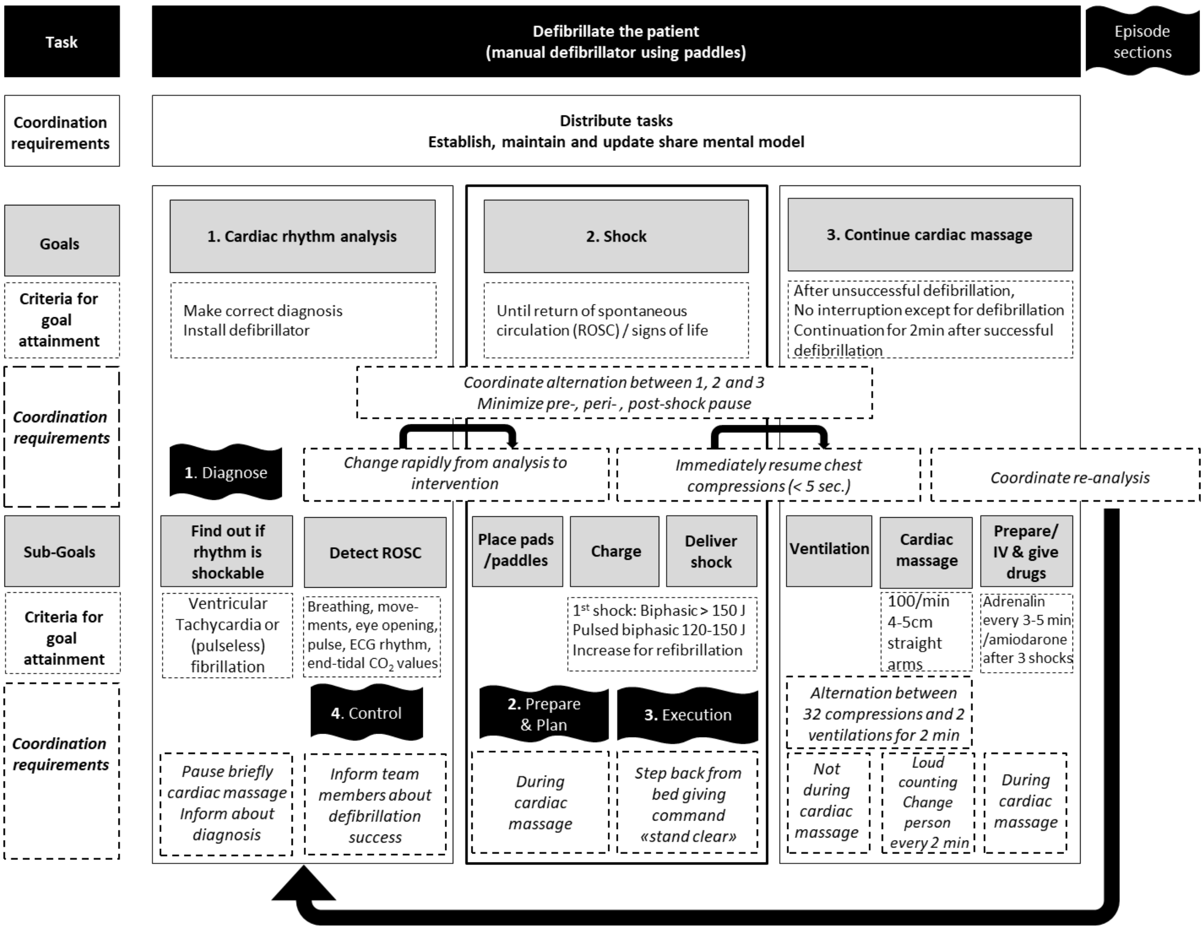

Figure 1. Simplified hierarchical task analysis for the defibrillation task, including coordination requirements.

Communication serves to coordinate and link individual action regulation; the person operating the defibrillator announces the shock with the command 'stay away from the bed', or the person doing cardiac massage indicates when to interrupt it so that ventilation can take place. The type of communication, e.g., its linguistic presentation, may change over time due to advanced SMM / experience in working together. Team members may replace sentences or explanations with a *reference word* that reminds the actors of the common ground that was established in earlier interactions. Such communication may be less intentional, becoming a more or less automatic part of task execution; even a single word may act as a signal that activates an *action pattern* that contains increasingly large “chunks” (Zacher et al., 2016). For example, a number of specific instructions during resuscitation such as “open shirt”, “start 30 chest compressions”, “ventilate 2 times”, “get defibrillator”, “attach pads”, “analyze heart rhythm”, “stop CPR”, “defibrillate”, “prepare adrenaline” may in later interactions or during the same interaction but over time be combined into one; “CPR and get ready for defibrillation!”.

At the same time, for repeated defibrillations of the same patient in the same environment and with the same equipment, some subtasks become obsolete. In particular, the subtasks "Get defibrillator," "Turn on defibrillator," "Open patient shirt," and "Apply defibrillation electrodes to patient chest" are subtasks that must be performed only once in each simulation, while the subtasks "Set defibrillation energy," "Charge defibrillator," "Ensure safe shock delivery," "Deliver shock," and "Check shock delivery" must be performed for each defibrillation.

2.3 Assessing Coordination Processes

If coordination processes are to be examined, they must be made measurable. This chapter serves to understand how coordination processes and outcomes can be measured. It is not only the basis of Article 3, in which we outlined the process of developing coding schemes, but also of Article 2, where we developed a coding scheme for capturing overall coordination and communication, and specifically, implicit coordination. First, a short introduction regarding the measurement of coordination processes via observation is given, followed by a brief summary of the process of developing coding schemes, which is described in detail in Article 3. The focus is then placed on two essential aspects of the development process that are only briefly addressed in Article 3 due to space limitations. They concern (1) sampling and recording rules, i.e., the question of which subjects to observe and when and how, respectively how the behavior is recorded, and (2) potential sources of bias during observation and how to avoid them. To close the chapter, conclusions for our own work are presented by summarizing the development process of the coding system used in Article 2 on implicit coordination. Detailed information on the coding schemes used or developed in this thesis can be found in the methods section of each paper.

Coding systems must be developed when coordination processes are studied by means of observation. Observing behavior is the gold standard to assess coordination processes because retrospective reports of group members as well as generalized observer reports are likely to be biased (Guzzo et al., 1986; Staw, 1975). Observation as a methodology provides researchers from various disciplines the opportunity to gain a realistic view of a particular phenomenon they intend to study. The aim of a structured observational coding scheme (hereinafter referred to as OCS) is to clearly define the construct to be observed and thereby enable the observer to record what is taking place in an observational setting (Boyd & DeVault, 1966). So far, a large number of different OCSs from different disciplines within the behavioral and social sciences have been developed to observe human behavior. As early as 1966, Boyd and DeVault classified 26 representative OCSs according to their application field. Ever since, the number of newly designed OCS has increased steadily. This may be because only a few OCSs are conceived as generic instruments (e.g., Bales' interaction process analyses, (Bales, 1950b)) applicable to a wide range of observational studies. The constructs of interest are often diverse and so are the respective research purposes and hypotheses. However, there is general agreement that OCSs should be applied specifically to the research question at hand. (Brett et al., 2004; McGrath & Altermatt, 2001; Weingart, 1997). Hence, for most observational studies, new OCSs must be developed, or existing OCSs need to be adapted to the specific study need.

Developing an OCS is not a straightforward issue and should therefore be approached in a systematic manner through a multistep process.

2.3.1 Developing Observational Coding Schemes

The decision whether and to what extent to develop a new coding scheme should be well considered. Not only because the development process is labor-intensive, but also because the use or adaptation of existing coding schemes allows for comparison with previous research. This makes reviews and meta-analyses much easier (Bakeman, 2000; McGrath & Altermatt, 2001; Waller & Kaplan, 2016; Weingart, 1997). However, using an existing coding scheme is only recommended if it is compatible with one's own research question and if it ensures that all relevant behaviors are captured. At first glance, this seems to be rarely the case. However, existing OCSs can be adapted or combined with one's own scheme. Regardless of whether an existing scheme is used or a new one is developed; it should be precise and tailored to the research questions and for later data analyses.

The development process, as outlined in Article 3, comprises six steps. First, the team task should be at the center and the coding scheme should be adapted to it. This is important because the type of task performed influences the group process; behavior that is positive for performance in one task may be a hindrance to good performance in another (Hackman & Morris, 1975; McGrath, 1984; Tschan, Semmer, Hunziker, et al., 2011). Helpful in adapting the coding scheme to the task is the HTA (see also Section 2.2.2.4 "How much coordination is necessary?", p. 17, and Section 2.2.2.5 "Coordination in ad hoc formed ICU teams", p. 18). The analysis of the task and its coordination requirements facilitates a decision about which behaviors should be coded and provides a basis for identifying specific task phases or turning points for example. A turning point in the resuscitation task is the moment when the team has made the correct diagnosis of a cardiac arrest. At this point the team changes from deliberation to action (Gollwitzer, 2012).

The choice of the data source, also called recording rule, is the next step to decide. This decision is important because it is the basis for the type of coding that is possible. The different options (e.g., video recording vs. in vivo encoding) and the advantages and disadvantages of each method will be discussed in more detail in Section 2.3.1.1 “Sampling and recording rules” (p. 24). A next important aspect in the coding of interactions is to decide when an observable unit begins and when it ends (McGrath & Altermatt, 2001), because it affects the coding and later analysis. For example, if communication is coded, a unit can be the identification of a sentence or speaking turns, or even longer phases. Alternatively, the process can be divided into fixed segments, e.g., 10 seconds, and then these time-based units are coded (Hirokawa, 1983; Waller, 1999; Waller & Kaplan, 2016). Each decision is associated with certain advantages and disadvantages, which are explained in detail in Article 3. Probably the most prominent part of the development process is determining the coding contents, i.e., the behaviors to be coded. Thereby, temporal aspects play a role (i.e., when something is coded), the questions of who is involved in the interaction (i.e., which persons are coded or not), which behaviors are being expressed (i.e., which behaviors are to be observed), and whether the coding includes qualifiers or not (e.g., intensity ratings vs. behavior is shown or not) are of concern. This is the most labor-intensive part of the development process and is described in detail in Article 3. The fifth step involves writing the coding manual. This very important document serves as a guideline for coding and contains clear definitions including examples and near non-examples to define the boundaries of the developed codes, and a description of the coding process. Once a first version of the OCS has been developed, it can be applied to sample observations or transcripts in order to test and refine it (Bakeman, 2000; Chorney et al., 2015a; Heyman et al., 2014). To this end, the observers are trained, and the consistency of their coding should continuously be checked. This is because interpretations of the codes can change over time. This and other sources of bias (e.g., agreement checking) can be one of several reasons for insufficient interrater reliability indicating that the (at least two) coder perspectives are in average not an accurate intersubjective measure (Weingart et al., 2006). The issue of biases during coding is addressed in Section 2.3.1.2 “Potential sources of bias” (p. 31). To conclude this section, Figure 2 gives an overview of the development process.

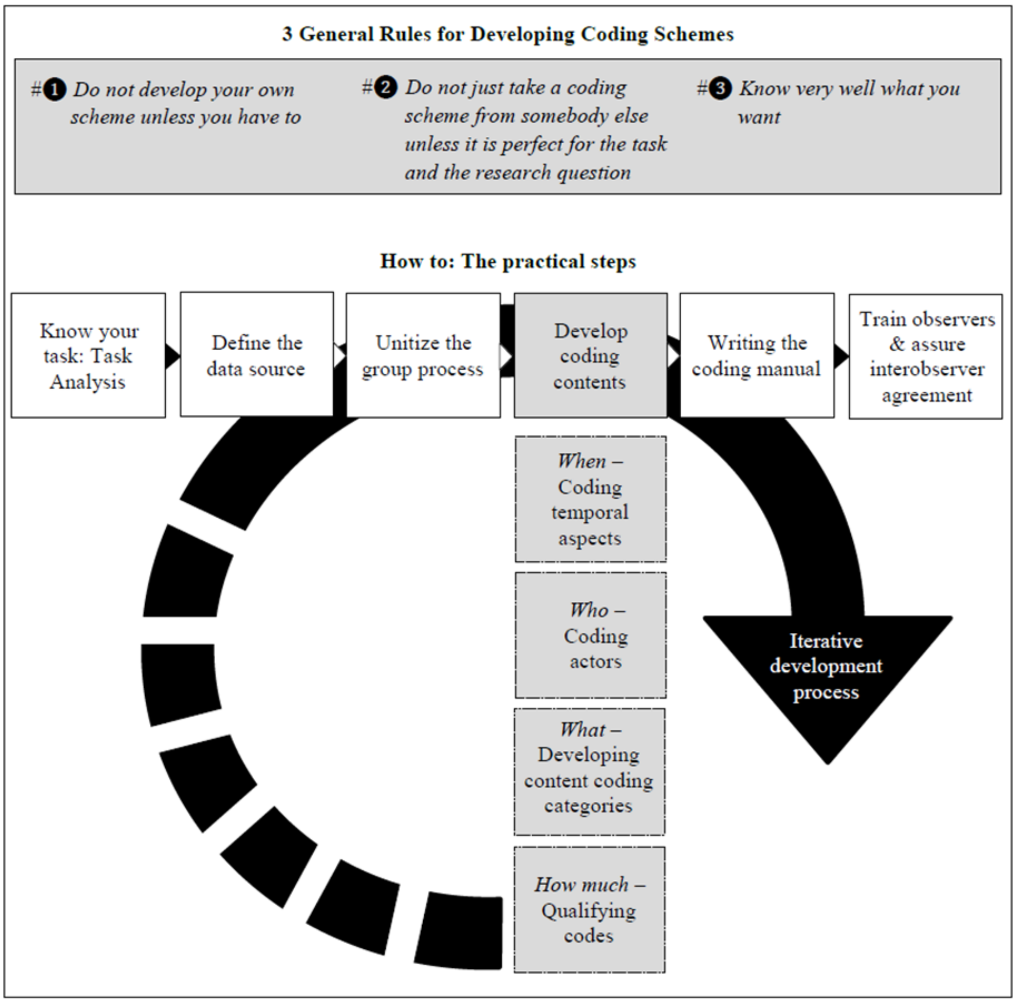

Figure 2. Overview of the coding scheme development process (Tschan et al., 2018).

In the next three sections, the focus will be put on two specific aspects of the development process: the sampling and recording rules, and potential sources of bias and possible countermeasures.

2.3.1.1 Sampling and recording rules

In this section some more attention is given to the decision of which subjects to observe and when (sampling rule) and how the behavior is recorded (recording rule). There are three main sampling rules ranging from recording all behavior without any restrictions to sampling with restrictions regarding the number of people and behaviors observed, each of which is associated with different advantages and disadvantages (see Table 1).

Table 1. Sampling rules (inspired by Hames & Paolisso, 2014; Martin et al., 1993, pp. 84-87).

Sampling rule	Definition	Pros & Cons	Application
Ad libitium	No systematic restrictions are imposed on what is recorded; *recording states and events*	C: Biased observation towards behavior patterns and individuals that are more conspicuous than others; behaviors may be missed and/or underestimated	During preliminary observations; for recording rare but important events
Focal sampling	One individual (or dyad or other unit) is observed for a determined time whilst recording all occurrences of its behavior for, usually, different behavior categories; *recording states and events*	C: Interruption of observation when the subject is out of sight; observation bias if subjects systematically do certain things whilst out of sight; rare behavior patterns tend to be missed	Most satisfying to study groups; often used in combination with continuous recording (see Table 2); if interested in a detailed characterization of behavior desirable along with instantaneous sampling (see Hames & Paolisso, 2014, Table 2)
Scan sampling	An entire group of subjects is quickly checked at regular intervals; recording the behavior of each at that instant; *recording states*	C: Restriction to record only a few simple behavior categories; biased observation towards behavior patterns and individuals which are more conspicuous than others; rare behavior patterns tend to be missed	Behavior recording by instantaneous (time) sampling (see Table 2); possible to use in addition to focal sampling during the same observation session
Behavior sampling	An entire group of subjects is observed; recording each occurrence of a certain type of behavior (e.g., aggression) along with details of which individuals were involved; *recording events*	Same source of bias as scan sampling	Recording rare but significant types of behavior where it is important to record each occurrence (e.g., fights); commonly used in conjunction with focal or scan sampling

As shown in Table 1, a distinction is made between the recording of momentary (discrete) events and behavioral states. Researchers who are interested in discrete events, deal with the question, how often and usually also in which order a certain event occurs. How long they last are not of importance. However, if they are interested in behavioral states, the duration is very important (Altmann, 1974; Bakeman, 2000). The choice of whether to record events or states affects how behavior is observed, as does the choice of data source (e.g., in vivo or via audio or video cassettes).

Table 2 provides information about a variety of different recording rules that determine how the behavior is sampled to assign a code to the observation. Note that not only do different researchers use different names when describing the same methods, but sometimes sampling rules are also mixed up with recording rules (e.g., when "scan sampling" is referred to as "instantaneous sampling"). For clarity, alternative names of the same methods are listed in Table 2.

Table 2. Recording rules

Coding Procedure	Synonym	Definition	Example	Pros (P) & Cons (C)	Application
Behavior checklist	-	The presence or absence of behavior is recorded on a pre-determined format (Taylor et al., 2006)	Presence or absence or side conversations (e.g., of anaesthetists, circulating nurses, or visitors) during surgery	P: Data is already quantified C: Behaviors and characteristics are determined when the checklist is devised (important behavior may be missed) (Jackson, 2014)	When important but infrequent behavior is observed (Taylor et al., 2006)
Global ratings	-	Numbers represent ordinal ratings (e.g., frequency, duration, intensity) of the behavior over a time period (Chorney et al., 2015a)	Intensity of side conversations during surgery (e.g., low, medium, high)	P: Potential to capture some constructs (e.g., degree of conflict resolution) more appropriately by taking the broader context of behavior into account (Hawes et al., 2013) C: May include rather far-reaching judgements, supporting bias (e.g., halo). Does not retain the sequential relations of events; therefore, provides less information on the functional dynamics of behavior (Hawes et al., 2013)	When outcome (rather than process) is central; where the degrees of behaviors are well defined, where there is a distinct difference in the behavior (Adamson et al., 2014)
Continuous recording		Like a video (Hames & Paolisso, 2014); recording any occurrence of a target behavior; Moment-by-moment recording of a stream of behavior over a short time scale (Chorney et al., 2015a)	Number of side conversations during surgery each and every time it occurs during the observational period	P: Most comprehensive representation of data (Chorney et al., 2015a) C: Time and resource intensive (Chorney et al., 2015a); making generalization across a population difficult due to small samples; intrusive; difficult to know when a behavior begins and ends (Hames & Paolisso, 2014)	Well-defined and restricted patterns of behavior are in the focus; fine-grained analysis of specific kinds of behaviors or behavior complexes (e.g., classroom behavior) (Hames & Paolisso, 2014); can be used simultaneously with time sampling (Martin et al., 1993)

Table 2 (continued). Recording rules

Coding Procedure	Synonym	Definition	Example	Pros & Cons	Application
Event recording	Event sampling; frequency recording; tally method; continuous sampling; focal sampling; actual sampling	Number of times a specific (predefined) behavior occurs during the observational period is recorded. Other types of behavior are ignored (Whitcomb & Merrell, 2013)	Number of times side conversations take place during a surgery	P: Can be used to determine antecedents and consequences of behavior and infrequent behaviors C: Not useful with behaviors that occur frequently (difficult to separate each occurrence); focus on only one or a few behaviors (Whitcomb & Merrell, 2013); may lose time information unless onsets and offsets are noted (Bakeman & Gottman, 1997)	Best to use when behaviors have a clear beginning and end (Haynes & O'Brien, 2003); have approximately the same amount of time each time it occurs and does not occur (Whitcomb & Merrell, 2013); inappropriate when it is hard to define the mutual dependence of events; may be used with frequently or infrequently occurring observations (Ostrov & Hart, 2013)
Event-sequential continuous recording	-	List of codes representing the order in which behaviors were observed; precise information on how often behavior occurred; timing and duration of behaviors are not gathered (Chorney et al., 2015a)	Number of times and when side conversations take place during surgery; no information regarding the duration of side conversations	See event sampling	
Timed-event sequential continuous coding	-	Information on frequency and order of behavior; information on timing; permits collecting start and stop times for all behaviors with significant durations (“event codes”); if a behavior does not have a meaningful duration (e.g., an utterance) data on the begin of a behavior only (“point codes”) can be captured (Chorney et al., 2015a)	Number of times and exact duration of side conversations during surgery	See event sampling P: Provides the most detailed description of behavior; highest flexibility regarding reportable metrics (Chorney et al., 2015a) C: Time- and resource-intensive (Chorney et al., 2015a)	

Table 2 (continued). Recording rules

Coding Procedure	Synonym	Definition	Example	Pros & Cons	Application
Time sampling	Interval-recording; interval method; one zero sampling	Observation is divided into intervals (e.g., every hour for 10 minutes, 1 hour per day); the occurrence of specific (predefined) behavior momentarily at interval is recorded (Whitcomb & Merrell, 2013); possible to record several different categories of behavior simultaneously (Martin et al., 1993)	Number of intervals in which side conversations (e.g., of anesthetists, circulating nurses, visitors) during surgery take place and exact point of interval	P: Only one observation per interval required (Martin et al., 1993) C: Less information is preserved (compared to continuous sampling); exact recording is not necessarily obtained (Martin et al., 1993); possibility of inadequate categorization of time units (Ostrov & Hart, 2013); may miss important low-frequency behaviors (Whitcomb & Merrell, 2013)	Can be used simultaneously with continuous recording (recording different categories of behavior) (Martin et al., 1993); less utile for rarely occurring behaviors; suitable for common occurring and/or discrete behaviors (Ostrov & Hart, 2013)
Partial-interval recording	One-zero recording	If a target behavior occurs at any moment during an interval, the behavior is coded as present (zero-one coding) (Chorney et al., 2015a)	Number of intervals in which side conversations during surgery take place at any point	P: Capturing all behavior that occurs C: Does not differentiate between behavior that starts and stops within an interval and continuing behavior; may overestimate behavior occurring for only a part of an interval; may underestimate behavior if multiple cases occur within one interval (Chorney et al., 2015a); requires complete attention of observer (Whitcomb & Merrell, 2013)	-
Whole-interval recording	-	Recording specified behaviors that occur during the entire interval (*whole interval*) (Whitcomb & Merrell, 2013)	Number of intervals in which side conversations during surgery take place during entire time	See partial-interval recording	-

Table 2 (continued). Recording rules

Coding Procedure	Synonym	Definition	Example	Pros & Cons	Application
Momentary time sampling	Instantaneous recording; point sampling; time sampling	Like a photo/snapshot (Hames & Paolisso, 2014); recording during very brief, discontinuous and real-time sequenced sampling intervals on a continuously rotating basis (O'Brien & Haynes, 1993); gather information only on behaviors present at the preselected moment; ignore behavior occurring beyond this moment; no information about timing, duration or frequency (Chorney et al., 2015a)	Number of side conversations during surgery at one minute intervals for a 2.5-hour period of time	P: Can, under certain conditions, estimate the absolute duration of the occurring behavior (Harrop et al., 1990) C: Behaviors outside the instant are ignored; risk to underestimate behavior (Chorney et al., 2015a); lacks the depth of complexity of continuous recording (Hames & Paolisso, 2014); complex (O'Brien & Haynes, 1993)	-
Real-time sampling		Combination of event, duration and interval sampling; real time is recorded at the onset and termination of target behavior (O'Brien & Haynes, 1993)		C: Complex since the recording of the onset and cessation of every occurrence of the target behavior is required (O'Brien & Haynes, 1993)	Not the method of choice if the target behavior occurs in a high frequency or has unclear beginning and end points (O'Brien & Haynes, 1993)
Duration / latency recording	-	Recording how long a particular behavior lasts (duration) or how long from the end of one behavior to the beginning of another (latency) (Whitcomb & Merrell, 2013)	How long a side conversation takes place (duration); time that elapses between side conversations taking place and a surgeon saying it should be quiet (latency)	P: Simple to do with a stopwatch or wall clock C: Difficult for behaviors without clear beginning or end (Whitcomb & Merrell, 2013)	Best used with behaviors that have a discrete beginning and end, are not extremely brief and that do not occur at a high frequency (Haynes & O'Brien, 2003; Whitcomb & Merrell, 2013)

The sampling strategies listed in Table 2 segment continuously occurring behaviors in different ways and differ in their complexity and workload (O'Brien & Haynes, 1993). Event, duration, and interval sampling are less labor-intensive, while real-time and snapshot sampling are more complex and labor-intensive. It should be noted again that interval sampling procedures are prone to measurement errors because they do not capture the frequency or duration of each event (for a detailed discussion see Wirth et al., 2014).

2.3.1.2 Potential sources of bias

This section gives a brief overview of possible biases during the coding process by one or more observers and options to minimize particular biases, especially throughout coder training (see Table 3). The interested reader is referred to Harris and Lahey (1982) who provide a detailed discussion and critical analysis of the listed factors causing inaccurate coding behavior.

Table 3. *Potential sources of bias and effective remedies* (source: Harris & Lahey, 1982)

Source of bias	Definition	Recommendations regarding coder training
Expectation bias (p. 540ff.)	Being informed of a researchers' expectation regarding target behaviors influences the coders to alter their recording to confirm those expectations	- Give feedback / approval based only on accuracy and/or interrater reliability - Compare recording of unexperienced ("new") observers who are more easily kept unaware of experimental hypotheses than more experienced observers - Let coders code taped observations in a random fashion to diminish the likelihood of coders being aware of experimental conditions - Insist on a high level of agreement calculated by conservative means
Agreement checking (p. 543f.)	Coder checking agreement with other observers or a criterion protocol during observation	- Let coders believe that interrater reliability is getting checked for (most or all) their recordings - Keep coders unaware of when exactly interrater reliability is being calculated - Consider to train coders individually to deal with possible consensual drift
Consensual drift (p. 544ff.)	Coders modifying their recordings to agree with those of another coder with whom they previously had the opportunity to compare behavioral definitions	- Limit interaction regarding behavioral definitions between coders whose recordings are going to be compared during reliability checks (e.g., by train them individually or by getting all information regarding a code form a common source (e.g., a single trainer) or standard protocols and training procedures) - If limitation is not possible, bring in (covertly whenever possible) another "calibrating" coder regularly

Table 4 (continued). *Potential sources of bias and effective remedies* (source: Harris & Lahey, 1982)

Source of bias	Definition	Recommendations regarding coder training
Coding complexity (p. 547f.)	Refers to the number of codes, codes coded on a given occasion, subjects observed, proportion of subjects observed, or a combination of the above	- Let coders observe one subject and/or track and/or one behavior at a time only (rotate to other subjects and/or behaviors during observation session) - Let coders view segments more than once and track different behaviors and/or subjects each time - Coders should be led to believe that interrater reliability will be checked for all observations
Predictability of behavior (p. 548f.)	-	- Train coders with unpredictable behavior patterns - Analyze different types of coding errors
Extraneous cues (p. 549f.)	Extraneous cues refer to cues that a target behavior has occurred	- Train coders to distinguish occurrences from non-occurrences in the presence of erroneous extraneous cues - (or) collect data in a manner in which coders never are exposed to extraneous cues
Behavior valence (p. 550)	The label assigned to a class of behaviors influences the way in which coders record the occurrence of those behaviors	- Warn coders to attend only to the behavior under study, using labels that do not contain obvious value judgements - Insist on a high level of agreement with a standard criterion
Differential coder training (p. 550)	-	- Train the coders uniformly in an investigation
Observer cheating (p. 550f.)	Refers e.g., to different coder behavior in presence of the trainer or cheating in the calculation of the interrater reliability	- Keep coders completely independent during data collection - Closely monitor observation sessions, the positioning of coders, have barriers separating them - Use tapes and have observers code them alone - When symbols are slashed (using article pencil recording) to determine occurrences, include a "no behavior" code to minimize the possibility of coders auditorily cueing on others' recordings - Do not permit coders to calculate their own interrater reliability
Individual differences (p. 552)	Differential accuracy as a function of individual differences between coders	- Insist on high levels of accuracy via precise behavior definitions - Minor modifications of training and recalibration procedures
Observational media (p. 551f.)		- Use tapes in the preparation of criterion protocols for coder training and recalibration (e.g., to train the coding of hard-to-score behaviors)

2.3.1.3 Conclusions for own research

We developed own coding schemes in Paper 2 which deals with implicit coordination, and Paper 4 to measure team performance in Simulation Based Training (SBT). The development of performance measures in simulation scenarios is discussed in the next Chapter 2.4.3 (Developing Performance Measurement Tools for SBT, p. 42). In the paper on implicit coordination in ad hoc formed medical teams two coding schemes were developed: one for measuring implicit coordination and one to capture the participants' actions and communication. The development process of the second coding scheme is described here as an example and against the background of the theoretical explanations in this chapter.

We code the coordination and communication behavior by means of *behavior sampling;* behaviors of interest are observed and recorded during a specific period of time. We chose this method because we were also interested in rare but for the coordination of the resuscitation task important tasks (e.g., safety command before shock delivery).

Step 1: Defining the Data Source

All simulations were video recorded. Enabling coders to rewind and observe the group interaction several times helped to reduce the complexity of the coding and allowed to assess more fine-grained aspects of group coordination.

Step 2: Unitizing the Group Process

The group process was unitized with a clear start and end of the recording: start of the coding was at the entrance of the participants in the simulation room, end of the coding at the interruption of the scenario by the study director after 3 minutes. To ensure the comparability of the observational units, each scenario was divided into episodes (see also "coding temporal aspects"). Only the first three episodes were included in the analysis. For coding communication, we segmented spoken language (of word-by-word transcripts) around the predicate (i.e., the main verb): The verb was identified as the center of meaning and everything that was directly related to it was coded as part of this "thought" unit. A thought unit is "a sequence of a few words containing a single thought" (Weldon et al., 1991, p. 559). Such a definition is helpful because people do not always speak in whole sentences with correct grammar and punctuation. However, if such sentences contain a meaning, they should still be considered for coding (Meyers et al., 1991).

Step 3: Developing the Coding Content

Coding temporal aspects. Each occurrence of behavior and their duration was coded. This allowed a fine-grained analysis of coordination behavior, including the analysis of the frequency of particular coordinative actions and communication. As already mentioned, we were interested in the development of group interaction over time, so we considered temporal aspects in the coding. We coded different phases of interaction: on the one hand, defibrillation episodes (1-n) and on the other hand, the episode sections within these defibrillation episodes, which refer to the diagnosing, preparing and planning of the defibrillation, executing the shock and controlling the efficay of the shock. The transcripts of the communication were written in a spread sheet, using a separate row for each thought unit. We included temporal information directly (one row per second), and transcribed the units into the rows with the corresponding onset time. This allowed us to prepare time information in advance instead of noting times manually. The many empty rows resulting from this approach are quickly deleted during data preparation. The timing with this method is not absolutely precise, however, it is precise enough for our research purposes. All in all, this kind of coding is time consuming, yet the effort was reasonable as we have rather small samples

Coding actors. We coded the individual actors because this enabled us to analyze the coordination behavior in the team in detail. The coding was facilitated by the fact that the participants wore T-shirts with numbers on the front and back and both arms, so that they could be identified at any time while moving around the room and around the patient.

Defining the categories. The decision which actions and which communication should be coded was based on the task analysis and the resuscitation guidelines (Soar et al., 2015). Only task-relevant behavior and communication were coded. Where appropriate, we also developed a communication code for each action code, in order to later link action and communication. We did not use qualifying codes but simply coded the presence of a behavior or communication. When defining the codes, we made sure that they needed little or no interpretation, especially when coding the communication.

Step 5: Writing the coding manual

The coding manual provided a comprehensive description of the developed coding categories and for each code several examples as well as non-examples were given. The manual was adapted several times during test coding: Unclear definitions were made more precise, further examples were added to the individual codes. The coding process was described in detail. Since we coded the actions of several persons individually, coding was done in six rounds per video: The episodes and episode sections were coded first, followed by the actions of the three simulation participants, including the study nurse. This was done in four separete rounds. Finally, the communication was coded.

Step 6: Train observers

All coders received an introduction to the environment of the intensive care unit, including visits to the simulation center. In particular, guidelines for cardiopulmonary resuscitation, defibrillation, the necessary technology and the critical medical terminology, including frequently used abbreviations and insider terms were explained. Coder were trained until sufficient interrater reliability was achieved at the level of the individual codes. Disagreements between the coders were discussed after each double-encoded transcript to minimize ambiguity.

To prevent some of the biases listed in Table 4, the second coder was individually trained (agreement checking). Furthermore, the inter-rater reliability was calculated only by the first author of the study (observer cheating). Double codings were done individually (consensual drift) and the same source of information was made available to all coders (the coding manual). Furthermore, we provided examples and non-examples for the definition of the individual codes, in order to be able to easily distinguish the occurrence from the non-occurrence of a certain behavior or communication.

The next and last chapter of the theoretical background now deals more intensively with simulation-based training in healthcare, specifically with the development of simulation scenarios as the basis of Article 4, where we developed a scenario for experienced, ad hoc formed teams of the ICU.

2.4 Training Coordination Processes

Research-based findings on coordination processes should be used to design adequate trainings. The aim of this chapter is to understand what constitutes effective team training and how training interventions and performance measurement tools can be developed. It is the basis for Article 4, in which we developed a simulation scenario to train experienced ICU physicians and nurses in task-related and teamwork skills and a performance marker checklist for providing immediate and reliable feedback after simulation training. Furthermore, Article 2 is based on data obtained during such simulation trainings.

Teamwork skills can and need to be trained (Salas & Cannon-Bowers, 2001), wherefore team training is often recommended, in particular to prepare medical professionals for managing emergencies (Donaldson et al., 2000; Soar et al., 2010). In fact, research has found important performance shortcomings even in experienced ICU staff who are regularly trained in cardiopulmonary resuscitation (Abella et al., 2005; Ravakhah et al., 1998). Quite often there are problems with coordination and cooperation involved (Marsch, Muller, et al., 2004; Marsch, Hunziker, et al., 2004). Crafting good training methods for such teams seems therefore important.

One of the best-known sets of team trainings are Crew Resource Management (CRM) based interventions. They were originally implemented for improving safety in aviation, but were adopted in other HROs, and now are also popular in medicine (Dunn et al., 2007; Wiener et al., 2010). Many CRM trainings use high-fidelity simulators, because SBT allow teams to experience realistic tasks in a realistic environment (DeVita et al., 2005; France et al., 2005; Gaba et al., 2001).

First, simulation as a training method in health care is shortly introduced. Then the process of simulation scenario development is described.

2.4.1 Simulation Based Training in Healthcare

SBT is important in healthcare because it is often difficult or even impossible to train medical emergencies realistically. Simulations offer various advantages, for example and relevant for this thesis, that also unplanned, non-routine medical events and emergencies can be trained and thus be made accessible for research-based examinations. Coordination processes can be studied in detail, especially when training sessions are video recorded. They enable learning processes for team members based on mistakes made during training. For example, if the patient is not adequately cared for, there is no need to intervene, as no patient can be harmed (Hunziker et al., 2009; Moorthy et al., 2005; Riley, 2008).

For SBT to be effective, it should reflect the complexity and reality of the environment in which the teams operate. Since most work systems today are socio-technical systems, where people interact with technology to achieve goals, training interventions should combine the training of technical skills with the training of teamwork (non-technical) skills (Alinier, 2007; Beaubien & Baker, 2004; Okuda et al., 2009; Rudolph et al., 2007). *Technical skill*s can be defined as abilities and knowledge individuals need to perform for a specific task, such as handling a manual defibrillator. *Non-technical skills*, on the other hand, are critical to system safety despite not being directly linked to technical expertise (Reader et al., 2006). According to Gordon et al. (2012), non-technical skills refer to a person's cognitive as well as interpersonal skills that enable them to provide effective and safe care. The main non-technical skills categories are *task management* (i.e., resource and task management for goal achievement), *teamwork* (i.e., skills to work in a group for ensuring joint task completion), *situation awareness* (i.e., building and maintaining a global awareness of the ongoing situation through perception and understanding of environmental elements), and *decision making* (i.e., making decisions e.g., to reach a situational diagnosis, or select a course of action). Reader et al. (2006) identified non-technical skill contributory factors in ICU critical incident studies and related them to the core categories of non-technical skills. Examples are inexperience with equipment (task management), poor communication (teamwork), error of recognition or anticipation, wrong diagnosis (situation awareness), or wrong technique chosen (decision making). They conclude that overall, 50% of the identified contributory factors of critical incidents are associated with non-technical skill deficits of some kind. Non-technical skills, although proved to be important for delivering safe care, are often not explicitly addressed in the medical or academic curriculum (Flin & Maran, 2008; St.Pierre et al., 2011). Complementing the training of technical skills with training of non-technical skills seems therefore to be very important for effective team training interventions.

2.4.2 Developing Simulation Scenarios

Well-designed simulation scenarios are critical in SBT. The aim of a clinical simulation scenario is that participants (e.g., physicians and/or nurses) achieve specific learning outcomes (e.g., teamwork skills such as communication or leadership) by interacting with simulated patients in a safe and controlled learning environment (Alinier, 2010). In recent years, the design of clinical simulation scenarios has evolved and training providers can purchase prewritten scenarios (Waxman, 2010). However, they may not always fit the needs and training requirements of the participants, wherefore customized scenarios must be developed. A brief summary of the steps involved in the scenario development process is given in the following.

One possibility when developing a simulation scenario is to follow the development guidelines provided by several authors; some of them describing the process in great detail (e.g. Alinier, 2010; Benishek et al., 2015; Cannon-Bowers, 2008; Eppich et al., 2011; Fowlkes et al., 1998; Lazzara et al., 2010; Rosen, Salas, Wu, et al., 2008; Waxman, 2010; Weaver et al., 2010). In general, many authors (e.g. Eppich et al., 2011; Fernandez et al., 2008) recommend the Event-Based Approach to Training (EBAT, Fowlkes et al., 1998) for scenario design. Using EBAT means that designers identify and incorporate specific scenario conditions (called critical events or triggers) that create a requirement to act within the training exercises. This allows for observing the behaviors of interest, also called targeted responses. The critical events and targeted responses represent the learning objectives (Fowlkes et al., 1998). Learning objectives can range from human factors (e.g., summon help in an emergency situation or interacting with a difficult patient) to more specific medical or clinical topics such as “diagnosing and managing a patient with bradycardia” (Alinier, 2010; Leonard et al., 2004). To define the learning objectives one can for example use real-life cases and translate the lessons learned in clinical practice into learning outcomes, and based on that, formulate learning objectives (Alinier, 2010).

The critical events and targeted responses are linked and based on explicitly defined knowledge, skills, and attitudes necessary for team performance (Fowlkes et al., 1998; Rosen, Salas, Wu, et al., 2008). Examples for such an event-based approach are TARGET (Targeted Acceptable Responses to Generated Events or Tasks (Fowlkes et al., 1994) and SMARTER (Simulation Assessment of Resident Targeted Event Responses (Rosen, Salas, Silvestri, et al., 2008). Both originate from the desire to provide trainee feedback and evaluate performance (Waxman, 2010). SMARTER as well as TARGET allow for the design and development of simulation scenarios and accompanying measurement tools to capture complex performance during SBT, specifically in clinical contexts. In fact, the success of SBT is not only facilitated by the thoughtful development of simulation scenarios, but also by the development of appropriate assessment tools, which are best used to guide specific and poignant feedback to participants (Benishek et al., 2015; Fernandez et al., 2008). The individual steps in creating an EBAT-based simulation scenario, including the development of performance measurement tools are presented in Table 5. Performance measurement in SBT is discussed in greater detail in the next Chapter 2.4.3 “Developing Performance Measurement Tools for SBT” (p. 42).

Table 5. Steps in developing simulation scenarios

Step		-	Leading questions	References
Step 1:	**Requirement / needs analysis**	- -	Who needs to be trained (person analysis)? Which organizational factors (e.g., resources, climate) might affect training effectiveness or the transfer of trained knowledge, skills, and attitudes (KSAs) (organizational analysis)?	(Lazzara et al., 2010) (Fernandez et al., 2008)
Step 2:	Select **teamwork competencies** to be trained	-	What are focal competencies (e.g., medical knowledge) within the complex overall performance in the targeted clinical area (e.g., emergency medicine)?	(Lazzara et al., 2010) (Rosen, Salas, Silvestri, et al., 2008; Salas, DiazGranados, et al., 2008)
Step 3:	Define clear, concise, relevant, observable, and measurable **learning objectives** rooted in a chosen subset of teamwork competencies	- - -	What should residents learn in the simulation? What does the scenario intend to instruct? Can the learning objectives effectively be trained and measured?	(Alinier, 2010; Waxman, 2010)_ENREF_20 (Lazzara et al., 2010) (Eppich et al., 2011) (Cannon-Bowers, 2008) (Rosen, Salas, Silvestri, et al., 2008; Salas, DiazGranados, et al., 2008)
Step4:	Choose a **clinical context** to frame the scenario	-	Which clinical scenario, resp. which task can be used to assess the learning objectives?	
Step 5:	**Task analysis**	- -	Which behavioral steps are necessary to fulfil the particular task? Which behaviors are observed during task execution?	(Cannon-Bowers, 2008) (Tschan, Semmer, Vetterli, et al., 2011a)
Step 6:	Define a **targeted set of knowledge, skills and/or attitudes** to capture the predefined objectives and competencies	-	What must a participant know / be able to do to be able to meet the defined learning objectives?	(Eppich et al., 2011) (Rosen, Salas, Silvestri, et al., 2008)

Step		-	Leading questions	References
Step 7:	Define the **critical events/ triggers** and targeted responses to capture the targeted knowledge, skills and/or attitudes	- -	What are triggers / critical events (learning opportunities) that allow to learn / carry out the targeted KSA's? What elicits performance that requires the participant to display the targeted KSA's?	(Eppich et al., 2011) (Rosen, Salas, Silvestri, et al., 2008) (Cannon-Bowers, 2008) (Lazzara et al., 2010)
Step 8:	Define a set of **targeted responses** for each of the critical events	- -	Which directly observable behaviors / responses are expected to be exhibited by participants in response to the inserted triggers / critical events? What are indicators of the presence or absence of the targeted KSA's?	(Rosen, Salas, Silvestri, et al., 2008) (Eppich et al., 2011) (Lazzara et al., 2010)
Step 9:	Develop diagnostic **measurement tools** in form of an event-based checklist	- -	What means "performance" in behavioral terms? Are the targeted responses for each critical event observed / performed correctly, omitted/failed, or was there no opportunity to perform the targeted response, resp. was it not required?	(Lazzara et al., 2010) (Rosen, Salas, Silvestri, et al., 2008; Salas, DiazGranados, et al., 2008)
Step 10:	Develop the **scenario script**	-	What is the plan for the scenario, how will the scenario unfold? Consider the following questions: - How is the patient's initial physical condition (i.e., vital signs, physical appearance, and context)? - How is the patient's health or mental status likely to evolve (e.g., in response to a provoked event, or another medical condition or the patient's medical history)? - What are key physiological parameters and the patient's levels of consciousness for critical stages of the scenario? - What are the time limits for a patient to remain in a certain health status before it deteriorates further or improves again after appropriate treatment? - What restrictions exist for encouraging participants to consider alternative actions (e.g., by providing medications or certain medical devices)?	(Alinier, 2010) (Lazzara et al., 2010) (Eppich et al., 2011) (Rosen, Salas, Silvestri, et al., 2008)

Step		-	Leading questions	References
			- How should the mannequin appear, e.g., in terms of its position (does it sit on the floor, or sitting in bed, etc.), its clothing (does it wear torn pants, a patient's gown, etc.), or certain requisites that must be in place before the scenario begins (does it wear a hearing aid, glasses, or a helmet, etc.)? - What are potential approaches / different pathways participants could take and which are not primarily intended (i.e., eventualities)? This enables you to decide where you would like to end the scenario.	
Step 11	**Pilot** the scenario	-	What do participants of the trial scenario feed back to refine the scenario? Consider asking the participants the following questions: - Were the objectives of the simulation clear? - How appropriate was the simulated clinical case? - What are strengths/weaknesses of the scenario? - Was all the equipment needed available? - Did the scenario permit to develop the intended skills? - Are any changes needed to be made?	(Alinier, 2010) (Furman et al., 2010)
Step 12	Develop a **debriefing and feedback protocol**	-	What, specifically, was good, bad, why in the simulation etc.?	(Lazzara et al., 2010)

Another effective assistance in designing simulation scenarios are scenario templates. Benishek and colleagues (Benishek et al., 2015) provide a helpful overview of six different scenario templates; (1) their self-developed *Template of Events for Applied and Critical Healthcare Simulation* (TEACH Sim) which they describe in detail, (2) the *California Simulation Alliance Scenario Template* (CSASST, Alliance), (3) the Human Patient Simulation Scenario Development Patient Case Template (HPSSDPCT, Pharmacy, 2010), (4) the *Simulation Design Template* (SDT, Jeffries, 2007), (5) the *Special Interest Group Simulation Scenario Template* (SIGSST, Rev, 2009), and (6) *Template for Simulation Patient Design* (TSPD, Taekman, 2003). For details see Benishek et al. (2015). One final well-known tool for designing simulation scenarios is TEAM MEDSS (*Teamwork Education and Assessment Map for Medical Educators Designing Simulation Scenarios*) described in detail in Lazzara et al. (2010). The templates listed here may differ in terms of the individual steps presented; however, what they hold in common is that they help the parties involved to organize their thoughts and avoid oversights during the development and implementation process of a high-fidelity simulation scenario (Benishek et al., 2015).

2.4.3 Developing Performance Measurement Tools for SBT

Immediately after simulation trainings, teams usually come together for a debriefing session, where team performance is discussed (Kolbe et al., 2015; Runnacles et al., 2014; Salas, Wilson, et al., 2008; Vashdi et al., 2007). Team performance, in contrast to individual performance, requires the interaction of individuals, is thus dynamic and generally more complex due to the involved coordinated action of the team members (Salas, Rosen, Held, et al., 2009). An objective assessment of team performance allows for an appropriate feedback to participants and is one of the bases for discussing limitations and knowledge gaps. It is thus important to develop performance measures that allow for an evidence-based assessment of performance. The description of the development steps in the following, are based on publications describing this process in greater detail (Baker et al., 2005; Rosen, Salas, Wilson, et al., 2008; Rosen et al., 2010; Salas, Rosen, Held, et al., 2009; Salas, Rosen, Weaver, et al., 2009; Schmutz et al., 2014). There are several possibilities to measure and evaluate team performance; team self-assessment, observational rating scales, checklists, and EBAT (Rosen et al., 2010).

Self-assessment measures offer the possibility of assessing unobservable, implicit components of teamwork (e.g. team cognition, Rosen et al., 2010), task work knowledge and moderators of performance (e.g., team cohesion, collective orientation). However, where the objective is to capture the dynamic interactions of team members, other assessment methods may be better suited (Rosen, Salas, Wilson, et al., 2008).

Observational ratings of either specific behavioral aspects, overall performance or both are based on trained observers who record and rate the observable behaviors according to standardized measurement protocols, e.g., using global Likert-scale ratings(Baker & Salas, 1996; Black, 1996). Examples from the healthcare setting in general are the *Mayo High Performance Teamwork Scale* (Malec et al., 2007) and BARS (Wright et al., 2009); for teamwork and nontechnical skills in surgery, examples include the *Observational Teamwork Assessment of Surgery* (OTAS, Undre et al., 2007), *Nontechnical Skills for Surgeons* (NOTSS, Yule & Paterson-Brown, 2012), or *Communication and Teamwork Skills Assessment* (CATS, Frankel et al., 2007). The latter three tools focus on team and non-technical skills aspects, but do not assess medical or technical performance. Further weaknesses of rating scales in general are that rated behaviors are not explicitly linked to scenario events, often require summative evaluations over time and therefore are susceptible to rater bias and drift (Rosen, Salas, Wilson, et al., 2008). The limited number of behavioral dimensions an observer is capable to rate validly is another drawback of rating scales (Thornton III et al., 2003; Thornton III & Rupp, 2006).

In contrast to rating scales, which primarily capture the overall quality of behaviors, observational checklists identify the presence or absence of behaviors and activities the participants should show (or should not show) during the simulation, or steps that define a complex competency (Baker et al., 2005). Checklists in general should be based, not primarily on the written case, but on predefined critical events, and targeted responses. Such event-based checklist are beneficial for reliability and reduce workload for raters (Rosen, Salas, Wilson, et al., 2008). Event-based assessment techniques (EBAT), as discussed above, are best suited to handle the complexity of evaluating team performance over the course of complex simulation scenarios (Fowlkes et al., 1998; Fowlkes et al., 1994; Rosen, Salas, Wu, et al., 2008).

Irrespective of the measurement method used, it is recommended to ground performance measures in team theory and focus on both, individual as well as team level performance. It is furthermore essential to not only capture performance outcomes (successful task completion) but also process variables (e.g., coordination, communication) (Baker et al., 2005). Campbell (1990) argued that “performance is not the consequence or result of action; it is the action itself” (p. 174). When performing cardiopulmonary resuscitation for example, only measuring performance as the outcome “patient survival” would be erroneous because a patient may also deteriorate when team performance was good, or a patient might survive even when team performance was mediocre or poor. In other words, there are many other factors than group performance that play a role in survival of a cardiac arrest (Tschan, Semmer, Vetterli, et al., 2011a).

Table 6 provides an overview of best practices in team performance measurement for SBT for healthcare and some leading questions for the development process. For a more detailed description of the measurement development process see Salas, Rosen, Held, et al. (2009), who provide a review and best practices related to assessing team performance in healthcare and Rosen et al. (2010), who give an overview of tools for evaluating team performance in SBT.

Table 6. Best practices in team performance measurement for SBT for healthcare, description, and leading questions (adapted from Rosen et al., 2010, p. 356)

Best practice		Tips for implementation	Leading questions
#1	Base the content of the measurement tool in **theoretically and empirically grounded teamwork competencies**	Conduct a literature research regarding team performance science and develop the competency model based on the best evidence available	- Are there any established teamwork models in the clinical area under study? If no, look for more general teamwork models (e.g., Salas et al., 2005)
#2	Link the measures to specific **learning objectives**	Explicate what is being trained in practice activities and you know so you know what should be measured	- What is being trained? - Do the instrument's contents cover the competencies specified in the learning objectives?
#3	Capture **multiple levels** of team performance	Create opportunities for teams to show teamwork behaviors that are not linked to team members' level of clinical knowledge – include them in your measurement tool (e.g., communication, coordination, leadership). Both, technical as well as teamwork skills are part of the overall team performance – measure both but make sure to clearly separate them in the measurement tool	- What kind of teamwork behaviors do participants need to perform in order to reach good team performance? - What kind of technical skills do the participants need to perform for a good team performance?
#4	Use **scenario events** to anchor measurement opportunities	Scenario events represent opportunities to perform a specific teamwork behavior; by focusing on these pre-defined points in the scenario where a targeted teamwork competency should be practiced, observers can focus their attention on critical aspects of the scenario	- Is there a temporal flow to which the scenario can be matched to in order to help structure the observations?

Table 5. Best practices in team performance measurement for SBT for healthcare, description, and leading questions (adapted from Rosen et al., 2010)

#5	Focus measurement on **observable team behaviors**, and the **processes** of performance, not just the **outcomes**	Knowing the outcome of a team's performance is insufficient for guiding improvement; knowledge about *how* the team reached that outcome (i.e., the processes of performance) is necessary	- Is the measurement kept on a fine enough level of granularity in order to allow feedback of specific behaviors participants showed during the scenario? - Did you make sure there are no performance measures based on summative ratings over time or team members (e.g., the quality of leadership throughout the entire scenario)? They are poorly suited for specific feedback. - Are there multiple opportunities for participants to perform a targeted behavior? - Are possible responses to a specific scenario event and different behavioral paths considered, mapped out and possible interventions defined?
#6	Focus on "**diagnosing**" **performance**	In a practice-based learning activity, capturing what happened is important, but understanding why a team performed the way it did is necessary to guide feedback; understanding the underlying causes of performance is important for learning	
#7	**Train** and **monitor** observers	The reliability and validity of a measurement tool is not a property of the tool itself, but how that tool is used; observers need to be trained so that they are "on the same" page in terms of expectations for performance	- Is there a coding manual with definitions, operationalization and examples of all behaviors measured? - Are observers trained and reliability assessed (regularly), e.g., using previously videotaped simulation session?
#8	Use measurement to support **post-session debriefs** and remediation	The real value of measurement is in driving learning and change in a systematic way; to do this, it needs to support the process of facilitated debriefs	- What happened during the scenario? - What went well, what needs improvement?

2.4.4 Conclusion for own research

Our goal was to develop a challenging scenario, that corresponds to the needs and requirements of experienced ad hoc formed ICU teams. This scenario is special in that it is designed for *experienced* and *multidisciplinary* ICU teams. The decision to develop such a scenario was mainly based on the fact that many existing scenarios are designed for novices, with relatively simple tasks, often focusing on technical skills. And if they include teams, these teams are monodisciplinary. This makes them well suited for less experienced personnel but do not necessarily reflect the complexity and unpredictability of the complex ICU environment (Okuda et al., 2009).

We designed a scenario based on a *non-standard* but yet realistic emergency situation that the participants might actually encounter in their work. We thus paid particular attention to ensuring that the psychological fidelity of the scenario is high (e.g. Salas, DiazGranados, et al., 2008). In developing the scenario, this meant getting to know the trainees' tasks, including the typical mistakes made in the daily routine. The scenario developed is described in detail in Article 4. The procedure for developing the scenario was guided the EBAT approach (cf. Table 5). In the following some selected main aspects of the development process are briefly discussed.

Selecting teamwork competencies to be trained. The goal of the scenario was to train both taskwork (i.e., technical skills) and teamwork (i.e., how teams work together effectively). Although there is evidence that training methods that combine task and teamwork do not make the training incrementally more beneficial (Salas, DiazGranados, et al., 2008), both approaches have been shown to be effective. Moreover, the combination of these two approaches corresponds to the clinical reality in ICU: ICU staff work with technical equipment they have to master and effective team communication and coordination play an essential role in patient care, especially in an emergency.

Defining learning objectives. The overall learning objectives were based on the core competencies formulated by the Accreditation Council for Graduate Medical Education (ACGME, Swing, 2007). Relevant for this scenario were Patient Care, Medical Knowledge, Practice-based Learning and Improvement, and Interpersonal and Communication Skills. The learning objectives for these competencies were formulated specifically for different phases of the scenario. The scenario was divided into six phases and for each phase desired actions and associated learning objectives were formulated. Desired actions in phase 2 "Systematic first assessment of the patient" were for example: check responsiveness, pulse, saturation, call for help, and recognize disconnected pulse oximeter. The learning objectives regarding Patient Care were: To demonstrate the ability to perform a targeted amnesia and emergency medical examination, and to provide initial medical assessment of the patient in an uncommon medical situation (i.e., patient lying on the floor with one leg angled up at the bed). We also formulated phase-non-specific learning objectives concerning Systems-Based Practice and Professionalism. The latter included, for example, participation in interdisciplinary care in an unusual medical situation and the ability to interact effectively with team members of an interdisciplinary team. A detailed overview of the learning objectives and the exact structure of the scenario is presented in Article 4.

Task analysis. To determine the steps necessary to complete the task, a task analysis was carried out. By identifying these steps, the scenario was divided into the above mentioned six phases and the desired learner actions and learning objectives were formulated for each of these phases.

Defining a targeted set of knowledge skills. The Scenario is specially designed for training ad hoc formed and experienced ICU nurses and physician. Thus, the main medical knowledge that is required to achieve the desired learning actions and objective are, for example: Knowledge regarding the performance of a systematic medical assessment, the diagnosis of bradycardia, the difference and importance of external and internal pacemakers, as well as the technical know-how regarding external pacing.

Critical events, targeted responses, and action triggers. The definition of critical events and targeted responses (i.e., desired learning actions) was based on the task analysis. Good team performance in phase 6 of the scenario, which is the "safe transfer of the patient to the bedside", required, for example, that the team a) applies a cervical collar because the patient may have injured himself when he fell, b) to use the scoop stretcher for the transfer, c) to lift the patient onto the stretcher in a coordinated manner without disconnecting the external pacer, and d) to lift the patient safely back to bed. A trigger to perform these actions is the scoop stretcher, which was placed visibly in the simulation room.

Develop a measurement tool. We developed an event-based, observational performance marker checklist for the evaluation of team performance, respectively the technical and non-technical aspects of the scenario. The development of the checklist was based on medical literature, the task analysis, and the analysis of the coordination requirements of the medical and technical tasks to be carried out during the scenario. As the name suggests, we did not use summative assessments, but instead either checked whether certain behaviors were shown or not. In some cases, we noted the time of a particular behavior each time it occurred because there were several occasions to show that behavior (e.g., patient (re-)assessment). Thus, the checklist is based on observable team behaviors, and the process of performance rather than (only) performance outcomes (such as patient survival) are measured.

Such event-based checklists are advantageous for the assessment of complex scenarios by reducing the workload for raters. Furthermore, behaviors are directly linked to scenario events. The complexity for raters was also minimized by the fact that there were certain timepoints in the scenario where certain team behaviors were expected. For example, after the external pacing, a physician joins the team. At that point, the team was expected to provide a handover to the incoming physician.

The performance marker checklist can be used for providing feedback after simulation training and based on it, discuss limitations and knowledge gaps of the participants (Fernandez et al., 2008; Fowlkes et al., 1998).

3. Summary of Thesis Studies

3.1 Understanding coordination processes

3.1.1 Article 1: Implicit coordination: A Systematic Review and a New Approach

Article 1 is a systematic literature review summarizing articles that investigated implicit coordination among a variety of teams performing a common task. Research on coordination mechanisms such as implicit and explicit coordination have a long tradition, but empirical findings are not always unequivocal. The aim of the review was to identify potential reason for discrepancies in results and to present and extended model of implicit coordination aimed at clarifying and expanding the understanding of implicitness in coordination processes.

A literature search in four major databases was conducted in November 2018. No restrictions were set in terms of year of publication, but only articles published in English were considered. Inclusion criteria were: Any accessible original research study investigating action-oriented (e.g., not dialogue-related) *implicit* or *tacit* coordination during *face to face* or *computer mediated* but *direct* (i.e., not asynchronous) *interaction* between *more than two* (i.e., in small groups) *human* individuals (i.e., not primates) for *immediate task completion* (e.g., anesthesia induction). Studies aimed at developing measurement tools were excluded but were made available / listed in the annex of the article when they presented a new tool for measuring implicit coordination, independent of methodology.

Thirty-one studies were included in the review. Empirical findings regarding whether, how and under what circumstances groups benefit from implicit as compared to explicit coordination are mixed. We identified several conceptual issues that may contribute to a better understanding of the functioning of implicit versus explicit coordination resulting in four implications for further research: (1) Coordination-related communication is associated with action, i.e., less explicit communication indicates implicit coordination only if it is not due to a reduced need for action. (2) A reduction in explicitness may go beyond a reduction in verbal communication. In addition, implicitness may be indicated by shorter communication, i.e., fewer words per unit of communication. (3) Verbal communication is not exclusively explicit and nonverbal communication implicit; verbal utterances may also be more implicit, while nonverbal behavior may be more explicit. And (4) the more implicit communication becomes, the more its meaning is ambiguous to non-experts, as it can only be inferred based on SMM. Based on these implications, we presented a model for conceptualizing and measuring implicit coordination by putting stronger focus on action-triggering cues and considering the ambiguity of verbal and nonverbal cues as a more direct criterion.

To the extent that our model is viable, it will be important for future research into new ways of operationalizing implicitness and for teaching teams to carefully analyze the necessity and usefulness of implicit coordination and the many ways to achieve it.

3.1.2 Article 2: Moving from Explicit to Implicit Coordination in Acute Care Teams: The Role of Verbal Communication and Coordination Requirements

In Article 2, we conducted a detailed analysis of the assumption that verbal communication decreases in groups that repeatedly coordinate the same task while evaluating different communication indicators. This process from explicit to implicit coordination was analyzed in 35 groups of three fourth-year medical students performing cardiopulmonary resuscitation of two consecutive patients suffering a cardiac arrest in a simulator setting. The task studied was defibrillation because it is a recurring task within resuscitation. Executions of defibrillation within the same task are referred to as defibrillation episodes.

We hypothesized that communication quantity in terms of the *number of words*, *number of communication units*, *number of words per communication unit*, across repeated task executions within and across context decreases (H1a, H1e, and H1g), respectively, the percentage of *tasks coordinated without any verbal communication* increases (H1c). We furthermore postulated a “carry over effect” of implicitness in terms of all four indices, meaning that performing defibrillation for the first time in a new context (i.e., Task 2) is associated with a lower amount of communication or an increase in subtasks coordinated without verbal communication compared with the first defibrillation in Task 1 (H1b, H1d, H1f, H1h). Hypothesis 2 postulated that the decrease of words as a general indicator of more implicit coordination can be explained by two processes a) a decrease in the amount of information communicated (*communication units*, H2a), b) grounding or chunking processes, i.e., a decrease of *words per communication unit* (H2b). In Hypothesis 3a we stated that more implicit coordination is characterized by increasing *communication ambiguity*, a qualitative indicator of the grounding mechanism, involving groups changing their mode of communication such that they chunk (i.e., break down) information into smaller units and thus use fewer words per unit of information exchanged (Bangerter & Clark, 2003; Clark & Brennan, 1991). And in Hypothesis 3b we assumed again that this effect would "carry over" from Task 1 to Task 2. Finally, in Hypothesis 4 we distinguished subtasks with *tight* (team members need to be focused in parallel on the same subtask) vs. *loose* (subtasks can be done in parallel to other subtasks) coordination requirements and postulated that subtasks with tight coordination requirements are coordinated more explicitly than subtask with loose coordination requirements.

The results showed complete support for all hypotheses except hypothesis 1g, which was only partially confirmed. This was because there was no significant decrease in the number of words per unit of communication (chunking/grounding) between defibrillation episodes during the second task performance. In summary, the results support a) the contention that groups use less verbal communication when coordinating the same task repeatedly, b) that they establish a shared understanding relatively quickly, c) that fully implicit coordination without any verbal communication is possible and not uncommon, d) that qualitative changes (i.e., ambiguity of communication) in communication must be considered in addition to quantitative changes, and e) that greater implicit coordination depends not only on prior experience that enables anticipation but also on task demands.

While the results of this study were largely to be expected and are generally very consistent with the basic claims of explicit and implicit team coordination theories, it is important to provide empirical support for the generally plausible claims in detail.

3.2 Assessing coordination processes

3.2.1 Article 3: Rules for Coding Scheme Development

Assuming that valid coordination process measures are essential to the study of coordination processes, Article 3 focuses on the process of developing coding schemes for evaluating coordination processes via behavioral observation. The aim of an observational coding scheme is to define the construct(s) to be observed and to enable the observer to record what is taking place in a particular setting (Boyd & DeVault, 1966). The few generic schemes developed (e.g. Bale's interaction process analyses, Bales, 1950b) are not sufficiently specific for most research questions. Therefore, for most observational studies, new coding schemes need to be developed or existing schemes need to be adapted to the specific study need.

To illustrate the development process, we use examples from our work. We code both the behavior of real surgical teams in the operating room in vivo and the behavior of medical teams performing medical tasks (e.g., cardiopulmonary resuscitation) in patient simulators that have been recorded on video. Three general rules are introduced helping researchers to decide, whether, and to what extent a coding scheme should be developed: (1) Don't do it unless you have to, (2) Do not just take a coding scheme from somebody else, unless it is perfect for the task and the research question, and (3) Know very well what you want. The development process is described in six practical steps: (1) Know your task – task analysis, (2) Define the data source, (3) Unitize the group process, (4) Develop coding contents, (5) Writing the coding manual, and (6) Train observers and assure interobserver agreement.

The process of developing a new observational coding schemes corresponding to high methodological standards is a labor-intensive, time-consuming, and a non-trivial multistep process. We therefore recall our first rule: Don't do it unless you have to. However, when creating a coding scheme from scratch, attention to the details outlined in the article can help to avoid excessive work and regrets when starting data analysis. The approach presented in this article provided for a valid and reliable assessment of the coordination processes in Articles 2 and 4.

3.3 Training Coordination Processes

3.3.1 Article 4: The patient who fell out of bed: A simulation scenario combining technical and non-technical skills for multidisciplinary ICU teams in a non-standard emergency situation

Effective coordination and communication in healthcare teams is crucial; the quality of teamwork affects the quality of care and thus patient safety. Teamwork skills can and need to be trained (Salas & Cannon-Bowers, 2001), wherefore team training is often recommended (Donaldson et al., 2000; Soar et al., 2010). High-fidelity simulations have a long tradition in other domains, such as aviation, but are now also common in medicine (Dunn et al., 2007).

Well-designed simulation scenarios are critical in SBT. However, many simulation scenarios in medicine entail relatively simple tasks, concentrate on the training of technical skills, and, if they include teams, provide monodisciplinary training. They are thus well suited for less experienced personnel, but do not adequately reflect the variety and unpredictability of complex clinical realities (Okuda et al., 2009).

Article 4 focuses on the development of an effective high-fidelity training scenario for advanced medical professionals working in the ICU. We present a simulation scenario that reflects the complexity of clinical reality and combines task-related training with the training of non-technical or teamwork skills in interdisciplinary composed teams. A performance marker checklist (Observational Assessment of Medical Technical and Teamwork Skills, MeTTS) is developed. Results regarding 44 teams (132 participants) reveal variability in performance; inter-observer reliability of performance ratings based on 8 teams are good to excellent. Reliable in-vivo assessment of team performance is challenging and requires reliable observational checklists. Existing instruments to assess non-technical skills neglect task-related performance and the technical aspects, which are important for training. The performance assessment checklist developed allows providing immediate and reliable feedback to the teams and is a good basis for debriefing discussions.

4. Thesis Articles and Manuscripts

The four papers of the dissertation are presented as separate articles or manuscripts with their own references. The language, formatting, and citation style conform to the requirements of the journals in which the articles were published or will be submitted. The thesis references are listed at the very end of the thesis.

4.1 Article 1: Implicit coordination: A Systematic Review and a New Approach

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This manuscript will be submitted to Small Group Research.

Title: Implicit coordination: A Systematic Review and a New Approach

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Introduction

Team coordination is a key factor in understanding how a group of individuals work together effectively[1 2]. In order to achieve common goals, team members must manage their interdependencies by using specific strategies and behavior patterns to integrate their knowledge, actions and individual goals[3 4]. Team coordination can be achieved in different ways; one important distinction refers to explicit versus implicit coordination [4].

Explicit coordination, sometimes called directive coordination[5-8], means that teams plan and coordinate by explicit, (typically verbal) communication and with a high degree of intentionality: The problem at stake is expressly stated, team members share and seek task-relevant information and ideas, plans are discussed and spelled out; when coordinating actions, one asks for information, reacts on specific commands, etc.[5 7 9-11]. Explicit coordination behavior is related to intentional communicating acts used for coordination purposes[8 9 12-14]. Implicit coordination, on the other hand, builds on pre-existing, and shared, knowledge about the task and/or the team and prior experience in working together[15-24]. Once a shared representation is formed, team coordination becomes implicit to some degree, because team members can now anticipate the intentions, needs and actions of each other[4 5 8 25-29]. In the course of these developments, team processes change, and one characteristic of implicit coordination is the lower need for communication. Some researchers contend that no explicit communication is necessary: cooperation is achieved even "... without having to communicate directly with each other or plan the activity"[7, p.164].

Research and theorizing on whether, how and under what circumstances groups profit from implicit as compared to explicit coordination has a long tradition. In general, explicit coordination is seen as time- and resource-consuming, whereas implicit coordination is seen as fast and efficient, and thus as an advantage for team performance. However, empirical findings are mixed. On the one hand, teams may benefit from implicit coordination [23 30-35]. On the other hand, explicit coordination has been found to be related to higher team performance as well: A recent meta-analysis showed that in general, more communication was related to higher team performance across a wide variety of teams [36]; a lack of explicit communication can lead to coordination breakdowns [37] and better teams engage in more explicit coordination during non-routine events [38 39].

Considering the diverse results, we conducted a systematic review of implicit coordination. The aim of the review was to find out whether general statements on the effects and conditions of implicit coordination can be derived from the available findings and/or which aspects might need to be considered additionally in order to achieve greater clarity. We further present an extended model of implicit coordination aimed at expanding the understanding of implicitness in coordination processes. Quantitative and qualitative empirical studies conducted with a variety of groups performing a common task were examined, focusing on both the effects and conditions of implicit coordination.

Methods

The literature search and the way the results are reported were based on the PRISMA guidelines[40]. The first aim of the literature search was to identify studies investigating implicit coordination either empirically or at a conceptual level in different disciplines. These studies can provide a comprehensive understanding of the theoretical foundations of implicit coordination and the empirical findings regarding its effects (e.g. on performance). The second aim of the review was to identify potential sources of diverging research results, including gaps in the measurement of implicit coordination. Finally, we develop an extended theoretical model of implicit coordination.

Eligibility criteria

We included all accessible original publications, conference papers, conference reports, book chapters, and books from social sciences, medicine, nursing (health care), engineering and environmental sciences focusing on implicit coordination in joint task completion. We set no restrictions in terms of year of publication but considered only papers published in English.

Data sources and search strategy

We systematically searched for articles in four databases: Scopus, MEDLINE, ScienceDirect and PsychINFO in November 2018. We included any original research study investigating *action-oriented* (e.g. not dialogue-related) *implicit* or *tacit* coordination during *face to face* or *computer mediated* but *direct* (i.e. not asynchronous) *interaction* between *more than two* (i.e. in small groups) *human* individuals (i.e. not primates) for *immediate task completion* (e.g. anesthesia induction). One study, published in 2019, was identified by a subject alert in the databases and was included in the review in May 2020 for eligibility assessment.

Studies aimed at developing measurement tools were not further processed. An overview of studies that presented a new tool for measuring implicit coordination is given, however, in Appendix 1.

Table 1. *Inclusion and exclusion criteria for study selection*

Inclusion criteria	
	Human coordination
	Group coordination
	Action coordination
	Direct interaction
	Face to face interaction
	Computer mediated direct interaction
	Immediate task completion
Exclusion criteria	
	Non-human
	Non-group
	Non-behavioral
	Asynchronous communication
	No (direct) communication/interaction (e.g. studies on tacit collusion between firms)
	Overarching tasks (e.g. patient care)

The SCOPUS data base search strategy is included in the Additional Material (Appendix 2). Additional potentially eligible articles were identified by manual literature searches, by examining article reference lists, and by contacting experts in the field.

Study records: data management and selection process

Publication records were transferred from the databases to Excel. Duplicate articles were excluded. In a first step, the lead author reviewed all titles and abstracts for eligibility. All studies potentially providing empirical results on implicit coordination or studies that potentially elaborated implicit coordination on at a conceptual level were selected for full text screening. Studies whose inclusion or exclusion could not be unambiguously decided on the basis of the inclusion and exclusion criteria were reviewed with the fourth author. The total number of studies selected was 31 (see Figure 1).

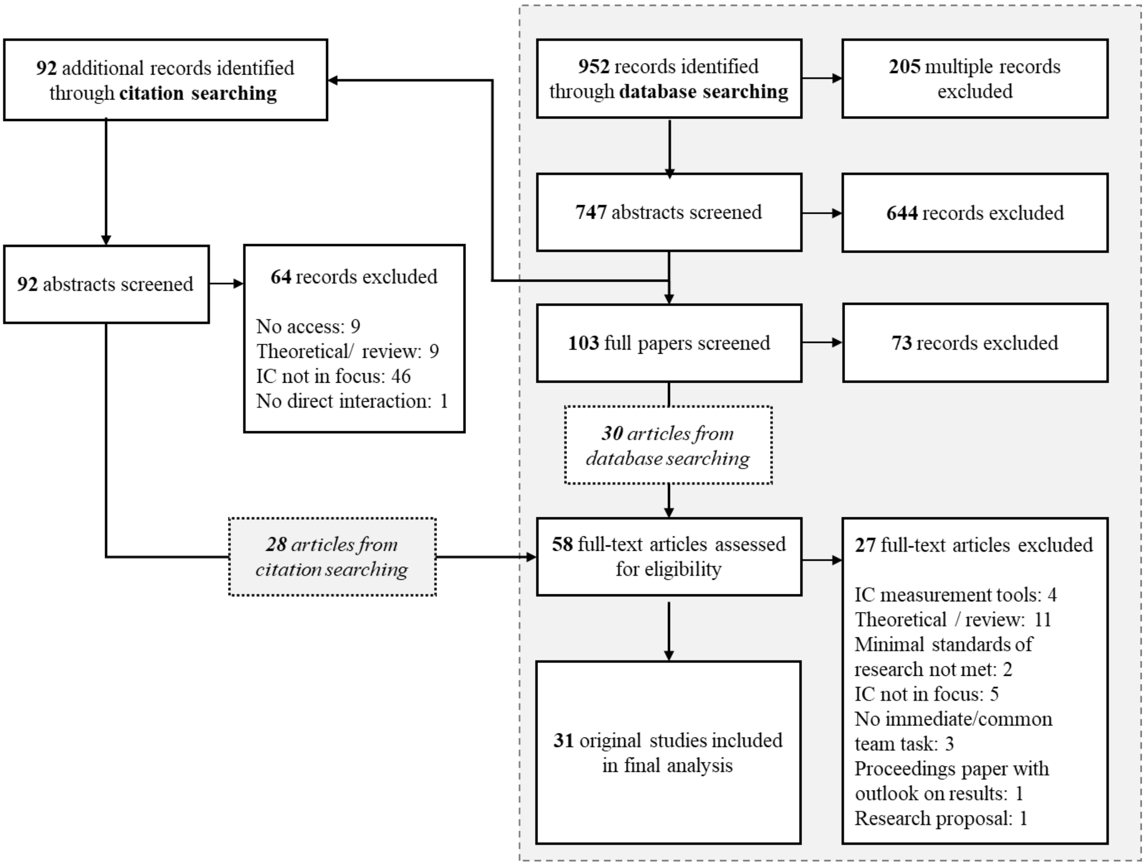

Figure 1. Flow diagram of the selection process of included studies

All articles in the abstract and paper screening that did not meet the inclusion criteria listed in Table 1 were excluded. Nine abstracts identified as potentially eligible via citation searching were not accessible, even after contacting the authors. Full-text articles that were excluded because implicit coordination was not in the focus included articles that either examined related concepts (e.g. team adaptation, shared mental models, shared cognition, habitual routines) or in which implicit coordination was only mentioned briefly, and/or not explicitly examined.

Synthesis and Analysis

The main goal of the review was to identify studies investigating implicit coordination either empirically or at a methodological level in order to identify the different conceptualizations and operationalizations of implicit coordination. In addition, we aimed to identify conditions for a differential impact of implicit coordination on different outcomes.

Results

The original research studies included in this review are presented in Table 2. In the following we present the descriptive results of the studies included, followed by a discussion of the study contents.

Study Characteristics

Time frame. Studies that fulfilled the inclusion criteria were published between 1990 and 2019 (see Figure 2). There were considerable fluctuations in the number of published studies, with a short-term continuous increase from 2007 to 2010 and a peak of 5 published studies over the years.

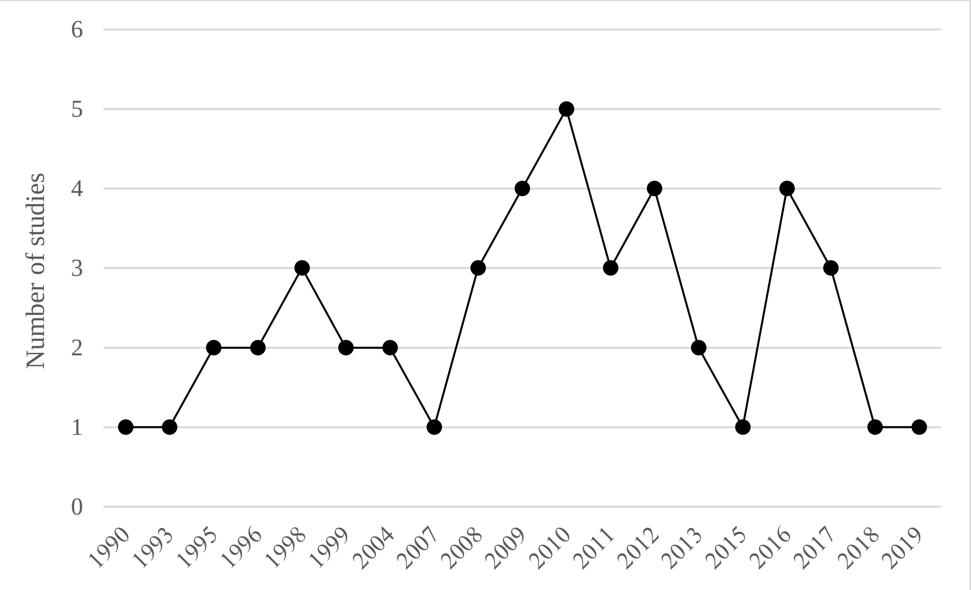

Figure 2. Publication years of the studies included

Methodology of the studies included. Thirty-one original research studies were included in the review, 24 of which studies include quantitative analyses only. Three studies include qualitative analyses only, and 5 a combination of quantitative and qualitative methods (see Table 2). Twenty-two of the quantitative, resp. mixed studies, and thus the majority, used *behavioral observations* to investigate implicit coordination. Six studies used a cross-sectional research design with *questionnaires,* and seven studies used *interview* techniques.

Disciplines, type of teams and tasks. Implicit coordination is investigated in a variety of disciplines and for a variety of groups, but it is interesting to note that many of the teams in the studies are action teams. There are studies with *medical teams* including anesthesia [37 41-47], surgery [48] or emergency medical /trauma resuscitation teams [37]. Studies with *rapid response teams* include firefighters [49] and police teams [50]. Studies within *armed forces* were conducted with naval officers [51-53] and military officers [54]. Furthermore, implicit coordination is studied in *cockpit crews* [33 41], *nuclear power plant control room crews* [55], and *tennis double teams* [56]. Studies with *student teams* include military tasks [23 57 58], laparoscopic surgery [59], developing a coordinated business strategy as a top management team [60], and performing a complex research report over several weeks [61]. De Jong and Fodor [62] also investigated student teams, but by means of a questionnaire and without a specific task. Both students and professionals carrying out a collaborative search-and-deliver task were investigated by Butchibabu, et al. [32]. There are three studies investigating implicit coordination in *inter-disciplinary teams* in industry [63-65]. A rather specific type of team, namely client-provider dyadic teams, was investigated by Wang, et al. [66], again involving a questionnaire and no specific task. Two studies [31 67] did not specify which type of teams were investigated. However, Quintal [67] specified the task as producing tangram figures under time pressure. The majority of the original research studies included in this review are from the field of *Human Factors* and/or *psychology* (21 studies, which sometimes included medical tasks performed by medical teams but also by nonmedical student teams), or *medicine* (4 studies). The other studies listed in Table 2 come from *Human factors/engineering* (2 studies), the *Business/project management* (2 studies), *Education* (1 study), *and Human factors* (1 study).

Table 2. Original research studies included (N = 31)

Authors	Discipline	Study design	Methods	Type of team	Participants	Cooperation experience	Task	Experience level	Definition of IC
Serfaty, et al. [51]	Psychology	Computer-based experimental simulation	Behavioral observation	Naval teams	20 officers in 5 teams enrolled in an operations research course in the Command, Control, and Communications curriculum at the Naval Postgraduate School	Not reported	Coordinating complex and ambiguous information to make identifications on air targets in a naval Combat Information Center. The team's objective is to infer correctly the identity (i.e., hostile or neutral) of an incoming contact in a timely fashion.	Not reported	No reference
Leedom and Simon [68]	Psychology	Simulation study	Behavioral observation; post-experiment interviews	Cockpit crews	24 AH-64 aviators paired under two different conditions; based on the battle-rostered crew pairings already established within the unit. For the remaining two evaluation missions, we randomly paired the 24 subjects from within each of the three companies in the aviation battalion. Battle rostered crew and mixed-crew missions were counterbalanced	Not reported	Set of flight tasks typical of the studies 1 and 2 (1: standard cargo/utility mission, 2: standard attack mission) after having completed the U.S Army's field program of team coordination training 4 months earlier. 4 different scenarios	Ø 621 hours of flight experience	No formal definition
Urban, et al. [58]	Psychology	Computer-based experimental simulation study (2x2 factorial design)	Behavioral observation	Student teams	24 teams of 5 undergraduate students from the University of Central Florida	Not reported	Resource Management Task (REMAN) incorporated in the team performance assessment battery (TPAB). Goal: Manage collective "resources" and coordinate actions in order to	Not reported	No formal definition

Authors	Discipline	Study design	Methods	Type of team	Participants	Cooperation experience	Task	Experience level	Definition of IC
							destroy incoming enemy targets		
Volpe, et al. [57]	Human Factors / Psychology	Computer-based experimental simulation study	Behavioral observation	Student teams	80 male undergraduate psychology students in 40 teams from a southeastern U.S. university taking introductory psychology courses	Not reported	Fly a F-16 aircraft simulation called Falcon 2.0 (Louie [69]) and "shoot down" enemy aircraft	No experience	Referring to Kleinman and Serfaty [18]
Cannon-Bowers, et al. [52]	Human Factors/ Psychology	Computer-based experimental simulation study	Behavioral observation	Naval teams	120 male U.S. navy recruits and trainees from a southeastern training center in 40 teams	Not reported	Radar task using Tactical Naval Decision Making System (TANDEM; Dwyer, et al. [70])	Ranks from E1 to E3 (from basic training to advanced training)	Referring to Volpe, et al. [57]
Serfaty, et al. [54]	Human Factors/ Psychology	Experimental simulation Study	Behavioral observation	Military officers	60 active-duty military officers from two training sites in 12 CIC anti-air warfare (AAW) teams of 5 individuals	Not reported	CIC anti-air warfare (watch station) / CIC aboard an AEGIS platform	Not reported	No reference
Entin and Serfaty [53]	Human Factors/ Psychology	Experimental simulation study (Decision-Making Evaluation Facility for Tactical Teams (DEFTT) simulation)	Behavioral observation Post-experiment interviews	Naval teams	30 naval officers attending Department Head School at the Surface Warfare Officers School (SWOS) in Newport, Rhode Island, and 29 officers + 1 civilian enrolled in courses at the Naval Postgraduate School (NPS) in Monterey, California in 6 ad hoc formed teams	Not reported	Situation assessment and deconfliction (the process of discriminating friend or foe) within team adaptation and coordination training (TACT) procedure.	Not reported	No formal definition
Stout, et al. [23]	Human Factors / Psychology	Low-fidelity simulation study	Behavioral observation	Student teams	40 male undergraduate students from a southeastern U.S. university in teams of 4	Not reported	Perform a surveillance/defense mission using Gunship, a commercially available low-fidelity helicopter simulation	Not reported	No formal definition

Authors	Discipline	Study design	Methods	Type of team	Participants	Cooperation experience	Task	Experience level	Definition of IC
Xiao [37]	Human Factors / Medicine	Field study	Behavioral observation	Medical teams (trauma resuscitation and anesthesia)	120 trauma resuscitation and anesthesia cases. Study 1: 17 cases Study 2: 40 cases (76 uncertain items)	Not reported	Trauma patient resuscitation and anesthesia in admitting areas and operating rooms	Not reported	No formal definition
Grote, et al. [41]	Psychology	Simulation study (aviation) / Field study (medicine)	Behavioral observation Interviews	Cockpit crews & anesthesia teams	42 aviation in teams of 2 23 anesthesia teams (team size not reported)	Not reported	Cockpit crews: Simulated approach and landing without flaps and slats (clean approach) Anesthesia teams: Live inductions in emergency department	Not reported	Referring to Serfaty, et al. [54]
Toups and Kerne [49]	Human factors	Ethnographic field study	Semi-structured Interviews Behavioral observation	Firefighting teams	Interviews: 6 Fire Emergency Responders (FER) Observation: 38 students (team size not reported)	Not reported	Three mock burns (three-story prop)	Interviews: highly experienced (11-31 years) FER professionals Observation: students in education at the fire school	Referring to MacMillan, et al. [26] Serfaty, et al. [51]
Kolbe and Boos [65]	Psychology	Field study	Focused interviews	Interdisciplinary team	8 experts from different occupational fields (team size not reported)	Different experiences with work groups	Not applicable	Many years of experience with facilitating small group processes	Wittenbaum [71]
Zala-Mezo, et al. [43]	Psychology / Medicine	Field study	Behavioral observation	Medical teams (anesthesia teams)	69 participants (including residents, staff anesthetist, nurse anesthetist, nurse in training, medical students) in 23 anesthesia teams. Team size: 2 to 4 (Ø 3)	Not reported	Anesthesia induction	Not reported	
Stachowski, et al. [55]	Psychology	Simulation study	Behavioral observation	Nuclear power plant control room crews	61 licensed nuclear power plant control room operators in 14 crews in the northeastern United States	Tenure with one's crew: Ø 2.36 years (SD = 0.77)	Manage a simulated crisis event	Average tenure as an operator 8.83 years (SD = 3.47)	No formal definition

Authors	Discipline	Study design	Methods	Type of team	Participants	Cooperation experience	Task	Experience level	Definition of IC
Chen, et al. [64]	Business	Field study	Question-naire	Interdiscipli-nary teams (manufactory)	Team size: 3 to 6 (Ø 4,36) 355 individuals in 64 work teams and their su-pervisors from manufac-tory industry (sales, op-erators, administrative officers, and research personnel)	Team tenure Ø 3.97	Not applicable	Not reported	Referring to Rico, et al. [4] , Bandura [72]
Shah and Breazeal [31]	Human Factors / Engineering	Laboratory / experimental study	Experiment/ Behavioral observation	Not reported	Team size: Ø 2,25 30 teams (60 individuals) from the Massachusetts Institute of Technology and Greater Boston	Not reported	Building predefined structures using an off-the-shelf building block set	Not reported	Referring to Entin and Serfaty [53] Serfaty, et al. [73], Entin, et al. [74], Orasanu [75], Volpe, et al. [57]
Grote, et al. [33]	Human Factors / Psychology	Quasi-experi-mental high-fi-delity simula-tion study	Behavioral observation	Cockpit crews	42 civil aviation (Airbus A320) cockpit crews in teams of 2	Not reported	Execution of a clean approach during the annual flight simulator training	1 captain (Ø 3.4 years in current posi-tion, 5000-10'000h flight experience) and 1 fist officer (Ø 2.3 years in cur-rent position, up to 5000 h flight experi-ence) per crew	Referring to Stout, et al. [23] Wittenbaum, et al. [27] Entin and Serfaty [53] Mathieu, et al. [76]
Blickensder fer, et al. [56]	Psychology	Field study	Behavioral observation	Tennis double teams	71 American tennis double teams (142 adult females)	yes (years not reported)	Tennis double game (30 ratable points)	61 teams with tennis skill level of 3.0 and 3.5 and 10 teams with tennis skill level of 2.5 according to the National Tennis Ratings Program (1 = never played be-fore, 7 = competitive on the world profes-sional tour)	Referring to Kleinman and Serfaty [18]l, Espinosa, et al. [77] Rico, et al. [4], Cannon-Bowers and Bowers [15], Eccles and Tenenbaum [17], Poizat, et al. [19]

Authors	Discipline	Study design	Methods	Type of team	Participants	Cooperation experience	Task	Experience level	Definition of IC
Badke-Schaub, et al. [63]	Psychology	Case study	Behavioral observation	Interdisciplinary team	7 members from a technology development company in two meetings	"Team shared a common history through previous meetings"	Develop a print head mounting for a thermal printing pen	Not reported	No formal definition
Riethmuller, et al. [78]	Psychology / Medicine	High fidelity simulation study	Behavioral observation	Medical teams (anesthesia teams)	24 final year medical students in practical training participating in the medical anesthesia training assigned to 9 teams Team size: 2 to 3	not reported	Administering of a simulated anesthesia (with a routine phase and confrontation of an unexpected medical complication), 4 scenarios per team	Inexperienced	Referring to Wittenbaum, et al. [27] Rico, et al. [4] Espinosa, et al. [77]
Fisher, et al. [60]	Psychology	Business simulation	Business simulation Questionnaire	Students (management teams)	186 participants in 32 teams enrolled in a capstone business course at a large midwestern university Team size: 2 to 8 (Ø 5.8)	Not reported	Developing a coordinated business strategy across all functional areas of their respective fictitious organizations	Undergraduate- and graduate-level students	Referring to Rico, et al. [4]
Marques-Quinteiro, et al. [50]	Psychology	Field study	Behavioral observation	Police teams	200 male individuals in 42 tactical teams from the Portuguese police special unit Team size: 2 to 11 (Ø 6.87)	Ø 5.8 years	A wide range of tasks related to the police special unit (e.g. hostage rescue and counterterrorism operations, high risk arrests and search warrants)	Not reported	Referring to Rico, et al. [4]
St Pierre, et al. [47]	Medicine	Experimental simulation study	Behavioral observation	Medical teams (anesthesia)	19 residents and 19 nurses from anesthesiologic clinic Team size: 2	not reported	Urgent anesthesia induction for an infant	Physicians: Briefing 4.0 ± 2.2; No briefing 4,9 ± 1,5 years Anesthesia nurses: Briefing 11,5 ± 7,4; no briefing 9,6 ± 9 years	Referring to Rico, et al. [4 41]
Butchibabu, et al. [32]	Human Factors / Engineering	Experimental Simulation Study	Behavioral observation	Student and working professional teams	52 participants in 13 teams from the Massachusetts Institute of Technology (MIT) and the Greater Boston area	Teams trained together on the task	Collaborative search-and-deliver tasks within a synthetic task environment (STE)	Not reported	Referring to Entin and Serfaty [53]

Authors	Discipline	Study design	Methods	Type of team	Participants	Cooperation experience	Task	Experience level	Definition of IC
					including undergraduate students and working professionals Team size: 4	(prior to the experiment)			
Zhang, et al. [61]	Education	Field study	2 Question-naires (week 4 and 8)	Student teams	135 participants in 40 teams of graduate stu-dents from an eight-week business analytics course Team size: 3 to 4 (Ø 3.34)	not reported	Performing a complex research report over eight weeks using Slack (processional tool for team communication and collaboration) and including data extraction and analyses, case study, report writing, and presentation in the form of team collaboration	Not reported	Rico, et al. [4] Espinosa, et al. [77]
Quintal [67]	Psychology / Business	Laboratory study	Question-naire	Not reported	243 participants in 51 teams (23 from companies, 28 from laboratory study) Team size: Ø 4.9	not reported	Getting tangram figures under time pressure (20min.)	Not reported	Referring to Rico, et al. [4]
Gjeraa, et al. [48]	Medicine	Field study	explorative, semi-struc-tured inter-view-based study	Medical teams (surgery)	21 participants from all four thoracic surgery centers in Denmark that perform VATS lobectomy Team size: not reported	experience in working together	Operating (Video-as-sisted thoracic Surgery VATS Lobectomy)	Not reported	Referring to Kolbe, et al. [79]
Zheng, et al. [59]	Medicine	Experimental	Behavioral observation	Student teams	16 university students in teams of 2 and a group of 8 bi-manual single-operators	None (do not know each other)	Laparoscopic cutting tasks (reaching, £ grasping, and cutting a piece of thread using a laparoscopic grasper and scissor)	Completely naive to laparoscopic techniques	No formal definition
De Jong and Fodor [62]	Psychology	Quasi-experi-mental study design	Question-naire	Student teams	Study 1: 35 student-teams enrolled in a course at a large Romanian university	Team familiarity at T2	Not reported	Not reported	Referring to Rico, et al. [4]

Authors	Discipline	Study design	Methods	Type of team	Participants	Cooperation experience	Task	Experience level	Definition of IC
					Study 2: - 66 work teams Team size: Ø4.06				
Wang, et al. [66]	Project Management	Field study	Question-naire	Client-provider dyadic team	235 Questionnaires on projects accomplished by 133 service providers / companies Team size: dyadic	Not reported * all analyses controlled for coopera-tion experi-ence	no task	Not reported	Referring to Rico, et al. [4]
Manser, et al. [45]	Human Factors / Psychology / Medicine	Prospective field study	Literature review Interviews Field notes	Medical teams (cardiac anesthesia)	24 cardiac surgery procedures (team size not applicable)	Not applicable	Cardiac surgery procedure	Not applicable	Referring to Wittenbaum, et al. [80] Wehner, et al. [81] Serfaty, et al. [51] Serfaty, et al. [54] Xiao [37] MacMillan, et al. [26] Rico, et al. [4]

Note. Discipline refers to the disciplinary character of the research subject and the authors' affiliation to their research discipline

Study design and methods. The majority of the studies (15) investigated implicit coordination via *simulation*. Of these 15 studies, eight studies had an experimental design [32 47 53 54], of which four were computer-based [51 52 57 58]. Two studies used high fidelity simulators [78], one of them with a quasi-experimental design [33]. One study used low-fidelity simulation[23] and three studies did not specify the type of simulation involved [41 55 68]. All simulation studies used behavioral observations to investigate implicit coordination. *Field studies* were second in frequency (12 studies). Three of these studies measured implicit coordination exclusively based on behavioral observations [37 43 56], four studies based on questionnaires [50 61 64 66], and two studies exclusively via interviews [48 65]. A combination of different methods (i.e. observations, interviews, review, field notes) was used in three studies [41 45 49]. In addition, there were four *(quasi) experimental (laboratory) studies* using behavioral observation [31 59] or questionnaires [62 67], and one *case study* using behavioral observation [63]. Fisher, et al. [60] conducted a *business simulation* with a questionnaire. In sum, simulation studies, followed by field studies, were conducted most frequently, and behavioral observations (22 studies in total) were the most commonly used method when investigating implicit coordination.

Cooperation experience and experience level. It is interesting to note that while researchers agree that implicit coordination is based on pre-existing knowledge about the task and/or team and previous experience of working together [e.g. 15-18 23], the amount of prior experience is rarely reported in empirical studies. In particular, only four studies reported both, task experience and the experience of working together [55 56 59 65]. Thirteen out of 32 studies reported neither the task experience nor the experience of working together [23 31 37 41 43 51 53 54 58 61 66 67]. Eight studies reported only task experience [33 47 49 52 57 60 68 78] and six studies only the experience of working together [32 48 50 62 63 66]. However, Wang [66] controlled for cooperation experience (i.e. number of projects completed for a client at the time of the study) and Volpe and colleagues[57] included team familiarity as a covariate in their analyses. In studies reporting team members' task experience (11 in total), experience ranged from “completely naïve” to “very experienced” (see Table 1). The studies that provided data on team cooperation experience differ greatly in their level of detail, ranging from “experience in working together” [48] to e.g. the precise indication of team tenure [50 55 64]. In one study, considering task experience and experience in working together was not applicable due to the study design [45].

Definition and operationalization of implicit coordination

Implicit coordination is most frequently defined based on the early studies of Entin, Serfaty and colleagues (e.g. [51 53 54 57 82 83]) (15 studies), Rico's theoretical framework on the development of team situation models and implicit coordination behaviors[4] (14 studies), the studies of Wittenbaum and Strasser [71 80] (6 studies), and Espinosa and colleagues[77] (5 studies) (see Figure 3). Studies without a formal definition of implicit coordination[23 55 59 68] either mention the term exclusively in the methods section when describing the measurement method, and/or describe individual aspects that are often discussed/examined as manifestations of implicit coordination (e.g. providing information in advance, anticipation). The authors of the two studies with formal definitions but without a reference [51 54] are among the initiators of implicit coordination as a research topic. Table 3 shows the most frequently cited definitions (see Figure 3) of implicit coordination. These definitions also show who these frequently cited authors themselves cite for their definition of implicit coordination.

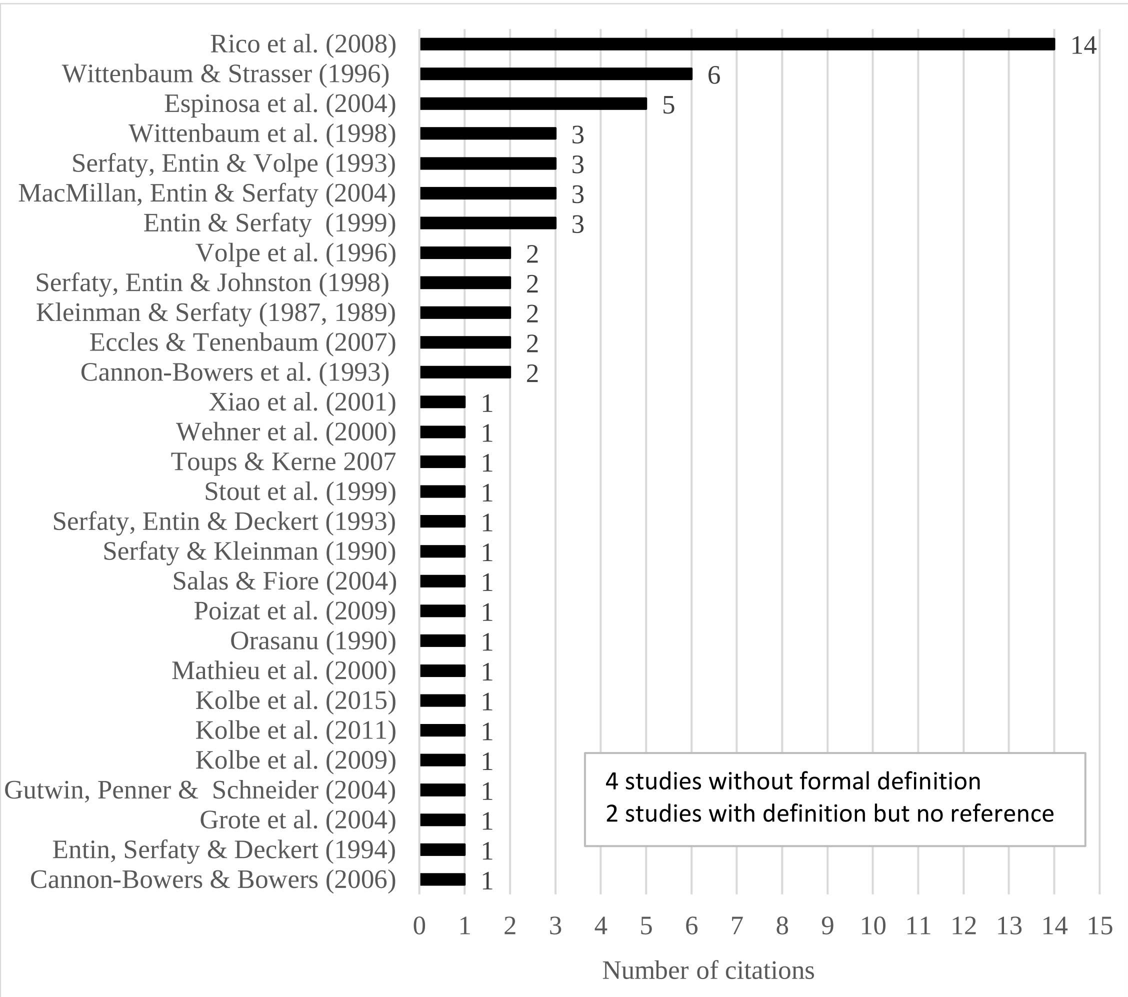

Figure 3. Sources used to define implicit coordination of the studies included in the review

Table 3. *Frequently cited definitions of implicit coordination*

Authors	Definition
Rico, et al. [4] p.164	"Implicit coordination takes place when team members *anticipate* the actions and needs of their colleagues and task demands and *dynamically adjust* their own behavior accordingly, *without having to communicate directly* with each other *or plan* the activity (Cannon-Bowers, Salas & Converse, 1993; Espinosa et al., 2004; Wittenbaum, Strasser & Merry, 1996)."
Wittenbaum [71] p. 129 f.	"(…) Such coordination is often tacit in that members *do not explicitly discuss* strategies for performing the task (Hackman & Morris, 1975). Stasser and Wittenbaum (1995) identified this phenomenon as tacit coordination, defined as the synchronization of members actions *based on unspoken assumptions* about what others in the group are likely to do. (…) If members correctly *anticipated* others' attention to information, then the group has coordinated itself tacitly *without explicit discussion* of who should remember what."
Espinosa, et al. [77] p. 2, 10	"(…) teams can also coordinate "implicitly" (i.e., *without consciously trying* to coordinate) through *team cognition*, which is based on *shared knowledge* team members have about the task and about each other. This shared knowledge helps team members understand what is going on with the task, and also helps them *anticipate* what is going to happen next, and which actions team members are likely to take, thus helping them become more coordinated. (…) has been referred to as the "synchronization of member actions *based on unspoken assumptions* about what others in the group are likely to do" (Wittenbaum & Stasser 1996). (…) we define implicit coordination mechanisms as those mechanisms that are available to team members from *shared cognition*, which enable them to explain and *anticipate task states and member actions*, thus helping them manage task dependencies. We refer to these mechanisms as implicit because they are available to the team in the form of shared cognition and as such they are *not consciously employed* for the purpose of coordinating."
Wittenbaum, et al. [80] p. 178	"(…) Coordination may be tacit, based on *unspoken expectations and intentions*, or it may be explicit, based on *verbal agreements or formally adopted plans* that fully and clearly designate who is to do what and when they are to do it.
Serfaty, et al. [51] p. 1229 f.	"Implicit Coordination relies on *anticipation of the information and resource needs* of the other team members as obtained through the exercise of *mental models* of the other decision-makers, or via the exercise of a *common mental image of the situation*. (...) It should be noted that implicit coordination does *not necessarily implies (sic) only a reduction of intra-team communications*. It rather involves a *re-allocation of communication resources* (network discipline), a higher proportion of *unsolicited information transfers* (anticipation), and - depending on the context - different mix of information granularity (raw data processed information). In short, implicit coordination is observed not only through a reduction and redirection of communication traffic, but also through a different mix and context of messages."
MacMillan, et al. [26] p.63	"*Explicit* coordination requires that team members *communicate to articulate* their plans, actions, and responsibilities, whereas *implicit* coordination describes the ability of team members to act in concert *without the need for overt communication*. For implicit coordination to be successful, team members must have a *shared understanding* of the situation and an accurate *understanding of each*

	other's tasks and responsibilities. The term shared mental model is often used to describe this shared team awareness (Cannon-Bowers, Salas, &Converse, 1993; Fiore, Salas, &Cannon-Bowers, 2001; McIntyre & Salas, 1995; Orasanu, 1990)."
Entin and Serfaty [53] p. 312 f.	"(…) switch from explicit to implicit coordination, a special mode of coordination (Kleinman & Serfaty, 1989; Orasanu, 1990; Wang, Luh, Serfaty, & Kleinman, 1991). Cannon-Bowers and Salas (1990), Orasanu (1990), and others have effectively argued that implicit coordination involves the use of *shared or mutual mental models* among team members. It is hypothesized that shared mental models are made up of two principal components: a common or consistent model of the tactical *situation* among team members and a set of mutual mental models about the other *team-member functions*. It is the mutual mental models that team members have of one another that allow one team member to *preempt the actions and needs of another* so that actions can be coordinated, and needs met in the *absence of explicit communication*. In this way implicit coordination *reduces communication* and coordination overhead."
Volpe, et al. [57] p. 89	"Specifically, Kleinman and Serfaty (1987) argued that the reason some teams were able to maintain a high level of performance under heavy workload conditions (i.e., restricted communication) was that successful teams were able to compensate for their inability to communicate via the exercise of a *common understanding of the situation*. The investigators contended that this knowledge permitted the team members to use an "implicit coordination strategy" in which the *need for overt communication is minimized*. This strategy is one in which team members *anticipate the actions and resource demands* of environmental stimuli on other team members, thus *reducing the need for explicit communications*."
Serfaty, Entin & Johnston Serfaty, et al. [54] p. 225	"The concept of a *shared mental model* has proved to be a powerful mechanism for understanding the relationship between team coordination behaviors and team performance. (…) that a shared mental model was developed when the captains in the high-performance crews shared their plans, allowing the first officers in those crews to *provide information relevant to the plan (i.e., implicitly coordinate)* under high-workload conditions. The coordination mechanisms that support adaptation may be *explicit, based on specific communications*, or *implicit, based on a shared mental model*. *Both explicit and implicit coordination modes will generate observable communication patterns*; *the presence and the absence of communication may be important*. (…) alternative channels of implicit and explicit team coordination to support the shared mental model concept. For example, *communications that provide information to a team member in the absence of requests for that information indicate an implicit coordination mechanism* at work. Measures must be sensitive to changes in the team's coordination and communication patterns as they *adapt their behavior to the demands of the task and the environment*. Teams generally alternate between team communication modes dominated by explicit coordination and those dominated by implicit coordination."
Kleinman and Serfaty [83] [84]	*No access*

Note. Italics added.

Although definitions of implicit coordination from different authors differ in detail, they share a common core.

Prerequisites. Implicit coordination is typically described as acting in a coordinated manner by *anticipating* the actions and needs of colleagues and task demands as well as the *dynamic adjustment* of one's own behavior. Anticipation in turn requires that team members have shared, compatible, and accurate *team-level knowledge structures* (such as mental models, team situation models, mutual understanding, shared cognition or common knowledge) about roles and responsibilities, and/or the task itself. The general assumption is that if teams can foresee/anticipate what happens next and what information or support is needed from other team members, then they can also act in a coordinated manner and successfully complete their task without (or only with minimal) verbal communication, which is considered costly in terms of time and cognition with only few resources remaining available to cope with the task at hand, especially in situations with high workload[31 53 80 85]. Team-level knowledge structures can for example be built through (common) experiences (e.g. with the task) or through an explicit exchange of information prior to task execution[86-89].

Manifestations. Implicit coordination shows itself at two levels, the communicative/verbal and the non-verbal behavioral level. When teams coordinate implicitly, it is assumed that they reduce verbal communication, share information with their team members in a less obvious, direct or overt way and pass on more unsolicited information to other team members. In terms of behaviors, team members act more often unsolicited (e.g. offer help/support). Implicit coordination processes of successful teams, both via communication and coordinative actions, are assumed to take place consciously or automatically (e.g. depending on the team-level knowledge structure or task experience) and are characterized by their flexible adaptation to the environmental conditions (e.g. changes in coordination mechanism in routine vs. non-routine situation).

In sum, as compared to explicit coordination, implicit coordination is frequently defined by a *reduced* verbal communication. This reduction often is due to information given without being solicited; implying that the communication consists of two elements (request and answer) in the explicit, and of only one element (“answer”) in the implicit case. The reduction may also be due to unsolicited actions, implying that no verbal communication is exchanged. It is interesting to note that only a few studies [e.g. 31 65 80] mention a non-verbal component of implicit coordination in that teams coordinate their actions through non-verbal signals (e.g.

eye contact, finger point, head nods). Furthermore, gestures, when investigated, are assumed to be only implicit in nature [65] (for an exception see Shah and Breazeal [31]).

Operationalization of implicit coordination. The operationalizations used to measure implicit coordination in the studies included in this review can be classified along two dimensions: the degree of verbalization and their specificity (see Figure 4; allocation of the operationalizations by study and author can be found in Appendix 3 Table 5). The level of abstraction among the operationalizations of implicit coordination varies considerably and ranges from specific (e.g. providing unsolicited assistance) to rather general coordination behaviors (e.g. monitoring). Typically, implicit coordination is operationalized through decreased verbal communication (e.g. silence, decreased communication frequency in general), and unsolicited verbal or non-verbal communicative acts, indicating anticipation of others' actions and needs (e.g. providing unsolicited information or actions, talking to the room). Non-verbal behaviors, or more generally speaking, signals indicating a need for action, such as gestures (e.g. finger point, thumbs up) or signals from the environment (e.g. alarm on vital signs monitor) have only rarely been investigated. Furthermore, it is noticeable that all studies that operationalized implicit coordination by counting verbal utterances or using rather abstract observational categories investigated implicit coordination independently of a specific task that was performed.

Implicit coordination was measured by a) questionnaire items, b) by behavioral observations, or c) by interviews. Questionnaires tend to be more general (e.g. "Members of my teams provide task-related information to other members without being asked"[60], or "we anticipate what each member of the team is going to do/need in each certain moment"[67]), whereas behavioral observations often use specific behavioral markers for coding actions such as unsolicited assistance, or via interviews. In interviews, which again tend to me more general, either the coordination style was subjectively rated by the interviewed person (e.g. from 1 = implicit to 7 = explicit[68]) or a deductive content analysis was carried out classifying the text into a particular taxonomy containing categories of explicit and implicit coordination behaviors (e.g. Co-ACT[79]) [48 65]. In addition to the individual analysis of behavioral categories, some authors calculated the anticipation ratio based on team members' information transfers and requests, capturing the degree to which the members of a team anticipate the needs of colleagues (e. g. information, help)[53-55 82].

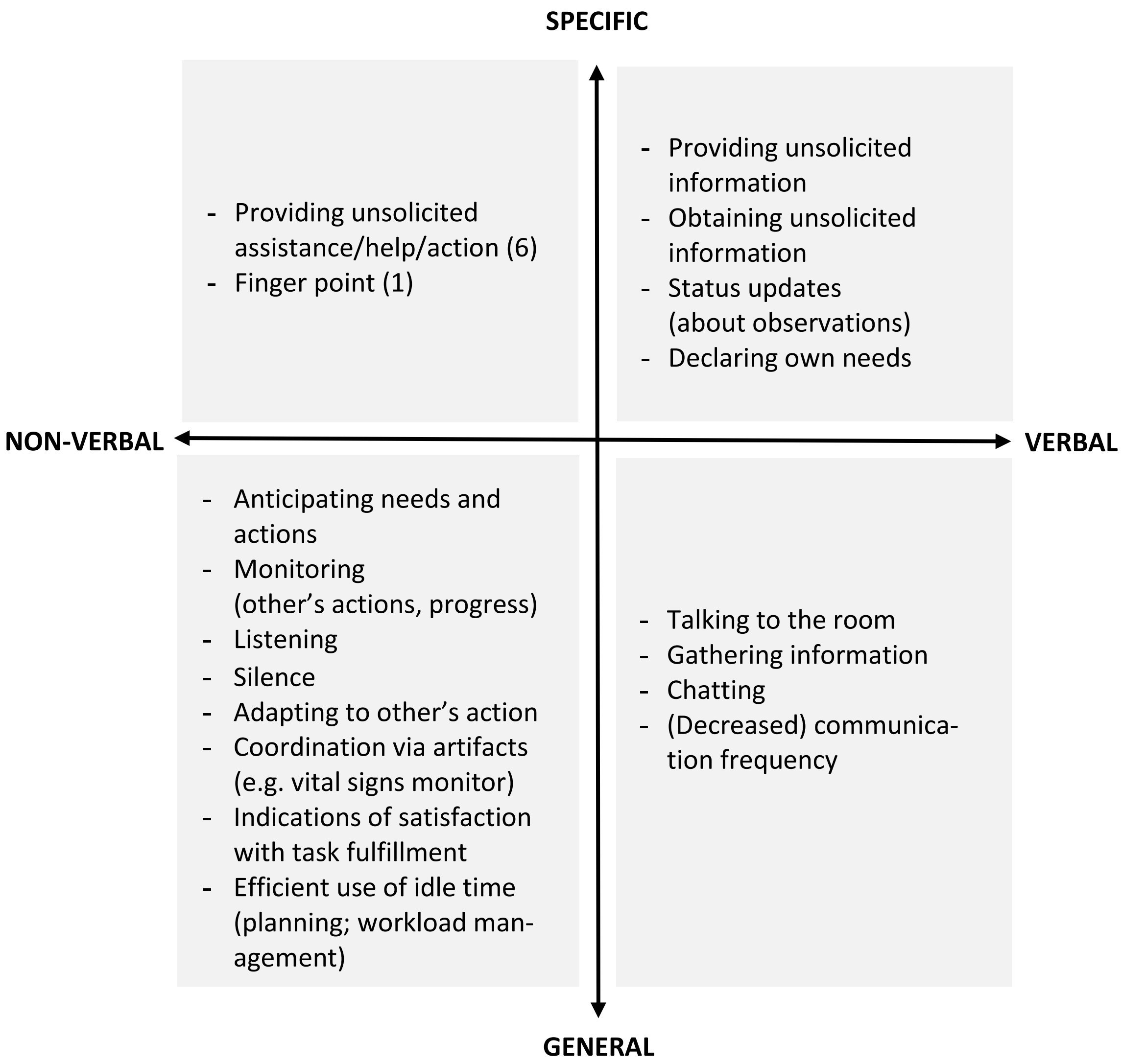

Figure 4. Operationalizations of implicit coordination. *Note.* Detailed information on questionnaire items and observational categories with allocation of the operationalizations by study and author can be found in Appendix 3 Table 5.

Major findings

All hypotheses and findings of the studies included in this review are listed in Table 5 (Appendix 3). The main findings are grouped according to studies that investigated conditions of implicit coordination (30 studies), studies examining effects of implicit coordination on performance (17 studies), and studies examining effects of implicit coordination on other variables than performance (2 studies).

Prerequisites for implicit coordination

Most often implicit coordination was investigated in connection with group factors such as *team or task familiarity, team level knowledge structures* (e.g. shared mental models, SMM), partly in the context of specific training interventions. Such factors are typically regarded as crucial for the development of implicit coordination.

Team and task familiarity. Blickensderfer, et al. [56] studied tennis doubles teams and were able to show that previous experience (coaching received and familiarity with the team) was positively related to implicit coordination, operationalized as "relative position", that is, "the degree to which the teammates adjust an adapt their positioning with respect to each other's positioning during team performance and maintain positioning half court apart" [p. 492] without openly strategizing. They also showed that shared expectations (operationalized as the agreement between team members in the evaluation of various scenarios presented during interviews) were a significant predictor of implicit coordination, accounting for the effects of previous experience. In the study of Leedom and Simon [68], teams that were paired over time (battle-rostered crews) and therefore were expected to have a higher level of team familiarity, showed more implicit coordination. Riethmuller, et al. [78] examined the choice of the coordination mechanism with regard to the teams' experience in working together and to task characteristics, such as routine and complication phases. They found that implicit coordination increased, and explicit coordination decreased over time (i.e., with increasing common experience) in routine phases; however, the complementary process of increasing explicit, and decreasing implicit, coordination in complication phases did not occur, as both forms of coordination did not change significantly over time in phases with high complexity. In addition, however, the difference between routine versus complication phases decreased for explicit coordination (i.e., increasingly less time was devoted to explicit coordination in routine as compared to complication phases), whereas the difference between routine and complication phases increased for implicit coordination (i.e., the clearly lower employment of implicit coordination in routine (as compared to complication) phases, changed to a slight prevalence of implicit coordination in routine phases over time. The authors interpret this latter result as a sign of adaptability.

Manser, et al. [45] studied cardiac anesthesia teams and found that attending anesthesiologists who had a supervisory function within the team and therefore substantial experience, showed more implicit coordination behaviors than anesthesia residents. In the study of Zheng, et al. [59], practice in terms of accumulated trials had no effect on anticipatory movements in a laparoscopic thread-cutting task. Also, Stachowski, et al. [55] did not find a relationship between the anticipation ratio (ratio of information transfers over requests for information) and average crew tenure or average tenure among nuclear power plant control room operators. Badke-Schaub, et al. [63] showed a significant decrease in the number of process utterances from a first to a second team meeting, which was interpreted as an increase in implicit coordination.

In sum, although two studies found no effect, familiarity with the task and/or the team seems to facilitate implicit coordination.

Team knowledge structures. The general assumption of studies investigating implicit coordination in the context of team level knowledge structures is that teams with shared knowledge about the team and/or the task are more likely to coordinate implicitly. The effect of familiarity is mostly interpreted in terms of the development of such shared knowledge structures. Some studies, however, directly focus on such knowledge structures, either by measuring them or by an intervention aiming at their improvement.

Thus, Fisher, et al. [60] found a positive relationship between team mental model (TMM) similarity and implicit coordination, which was operationalized by questionnaire items based on Rico, et al. [4]. Stout, et al. [23] investigated implicit coordination based on the assumption that implicit coordination in the form of efficient communication is most needed during periods of high workload. Teams were given the opportunity to plan their surveillance/defense mission in a low-fidelity helicopter simulation, assuming that planning quality positively contributes to the development of SMM**.** Results showed that better planning teams developed greater SMM of each other's informational requirements and teams that demonstrated overall higher quality in planning behaviors provided more information in advance during high workload periods. Perplexingly, teams with greater SMM of other's informational needs did not demonstrate more efficient communication when their workload increased. St Pierre, et al. [47] also did not find a difference in the frequency of implicit versus explicit coordination pattern in groups that received a briefing compared to the control group without briefing before being confronted with an urgent induction of anesthesia in an infant due to unanticipated airway problems. In both groups, overall coordination was less implicit than explicit. Volpe, et al. [57] and Cannon-Bowers, et al. [52] examined the influence of cross-training of team members' knowledge of one another's tasks (interpersonal knowledge) on implicit coordination in a computer-based air-craft, respectively navy based simulation task. Both studies found that cross-trained teams tend to volunteer more information before being asked. However, there was no effect of interpersonal knowledge on fewer requests for information, nor did cross-trained teams communicate more appropriately under high workload (i. e. exhibit more volunteering and less requesting of information). Instead, all communication frequencies decreased under high workload conditions[57].

In the studies by Serfaty, et al. [54] and Entin and Serfaty [53] team members were taught how to anticipate one another's need for information in the team adaption and coordination training (TACT). In TACT+, they were instructed to provide periodic situation updates so that their team would develop a shared understanding. In both studies, TACT as well as TACT+ produced higher rates of anticipatory behavior than the practice only control groups. Serfaty, et al. [54] did not find any differences in anticipatory behavior between low and high stress conditions. Interestingly, Entin and Serfaty [53] assumed that the overall communication does not necessarily decrease as a result of a shift from explicit to implicit coordination. In fact, the communication rate did decrease after training, but only in the low-stress scenarios. In the high-stress scenarios the communication rate was similar across pre- and post-intervention. This suggests that while teams communicate more efficiently in low-stress scenarios, increasing demands in high-stress scenarios require a higher communication rate between team members. However, TACT and TACT+ intervention resulted in different communication patterns in high-stress conditions. Specifically, the anticipation ratios based on all transfers and requests made in a team and the anticipation ratios by communication partners (specifically between the tactical action officer and subordinates and vice versa) were confirmed to be higher after training, suggesting that TACT facilitates the development of better mutual mental models and thus implicit coordination. However, TACT+ additionally increased lateral communication rates.

Finally, Toups and Kerne [49] conducted an ethnographic field study and described various aids to implicit coordination in fire-fighting teams. These include "overhearing" radio communications to hear what other team members are doing and to get an overview of the situation without explicit coordination. Through "ambient monitoring", fire emergency responders (FERs) maintain a mental model of the incident by listening to background sounds in the environment and on the radio, in addition to local sensory perceptions. Team members reported that they have strong SMM building through cross-training and situational awareness skills. Also, a high anticipation rate was reported, trained in emergent practices. After all, in an explorative interview-based study Gjeraa, et al. [90] examined which non-technical skills of team members in video-assisted thoracoscopic surgery are considered important with regard to patient safety. Various non-technical skills such as planning and preparation, situation awareness, problem solving, leadership, risk assessment, and teamwork were reported to enable the team members to build SMMs and thus better anticipate potential problems and next steps.

In sum, one must distinguish the effects of planning or interpersonal knowledge (cross-training) or trained anticipation (TACT training interventions) from effects of stress. Training seems to result in more anticipatory behaviors and more information sharing without request. At the same time, however, the need for communication seems to be rising under stress, which implies that demands for information and / or communication rates do not necessarily decrease under high stress.

Workload. Workload can be considered a form of stress[91], but it is listed here separately because a number of studies specifically refer to workload. Some of the studies discussed in the context of team knowledge structures, respectively specific training interventions above also referred to possible differences due to workload / stress (see Cannon-Bowers, et al. [52], Entin and Serfaty [53], Serfaty, et al. [54] Volpe, et al. [57]). Studies that focus specifically on workload are rare, and results are mixed. In the study of Shah and Breazeal [31], teams building predefined structures using an off-the-shelf building block set showed more implicit coordination in terms of anticipatory offering of information when time pressure increased. Investigating teams dealing with complex and ambiguous information to identify air targets in a naval Combat Information Center, Serfaty, et al. [51] showed that coordination strategies evolved from explicit coordination under low workload conditions to implicit coordination with increasing workload (in terms of subordinates' information transfers to leaders' information requests). Cockpit crews in the study of Grote, et al. [33] showed more implicit coordination in work phases with high as compared to low task load phases during execution of a clean approach. However, analyses carried out based on the relative frequencies of the coordination mechanism in the different work phases per crew showed no effect. Manser, et al. [45] found that monitoring of team members' activities was the prevalent coordination mechanism in critical episodes that pose high coordination demands during cardiac anesthesia. However, there was also a slight increase in explicit coordination mechanisms during such episodes such as situation assessment, planning and decision making. Also, implicit coordination was mostly employed during periods that require increased coordination such as the actual coronary artery bypass grafting.

On the other hand, Zala-Mezo, et al. [43] did not find more implicit coordination under high task load situations. Also, Urban, et al. [58] did not find a main effect of workload across the communication categories they analyzed (questions, answer forming requests, requests, responses, statements).

Standardization. Standardization is considered to enhance the shared understanding of the task and therefore to support implicit coordination. Consistent with this assumption, highly standardized work phases were associated with more implicit coordination in anesthesia, respectively cockpit crews in the studies by Zala-Mezo, et al. [43] and Grote, et al. [33]. Interestingly, significantly more of all coordinative actions were rated as explicit. However, the opposite tendency became apparent when looking at the duration of these coordinative actions: Implicit coordination assessed as percentage of time was higher. In an earlier study, Grote, et al. [41] examined implicit and explicit communication units in aviation and anesthesia teams in different and combined phases with high versus low task load (TL) and standardization (S). Cockpit crews consistently showed less implicit communication units in the take-off phase (S high, TL low), problem solving (S low, TL low) and approach and landing (S high, TL high). However, compared over the three phases, more implicit coordination was found in the last phase with high task load. Implicit communication units in anesthesia teams were lower in comparison to explicit communication units during preparation (S high, TL low), pre-intubation (S moderate, TL moderate), tracheal intubation (S high, S moderate, additional preparations (S low, TL high), and the patient transport (no S, TL low). There was no support for the assumption that the lower level of standardization in medicine would be associated with less implicit coordination by comparing the field of aviation and medicine. Overall, more implicit coordination was observed in the anesthesia team.

In sum, studies investigating implicit coordination and workload and/or standardization commonly assume that implicit coordination is a way out of the paradox that cognitive resources are not available exactly when they are needed most, namely in complex/high workload situations. However, results from the studies included in this review suggest that this may not always be true.

Other. Zheng, et al. [59] found more anticipatory movements in dyads as compared to a single operator working bimanually, in a laparoscopic threat-cutting task. The anticipatory movements were interpreted as indicators of implicit coordination; they resulted in shorter time until completion. Urban, et al. [58] examined non-specialized teams, which share common information and capabilities (non-hierarchical teams), and teams with members that perform similar functions, but within different domains or on different products (product teams). There was a main effect of team structure indicating that product teams asked more questions, provided more answers that implied a request, made more requests, provided more responses to requests, made fewer statements, and engaged in more overall asking and more overall responding behaviors.

Variables that are relatively less frequently studied but have been found to be positively related to implicit coordination are trust and leadership[67], and information processing and social connection[61]. Studying trauma resuscitation and anesthesia teams, Xiao [37] found that explicit verbal communications were mainly used when the team had reached a decisive point and the situation had to be (re-)assessed. Otherwise they were relatively rare. He identified four types of coordination without the use of explicit, verbal, or gesture-based communication that facilitate smooth performance: coordination by following protocols, coordination through monitoring the leader and e.g. providing material without explicit solicitation, coordination through anticipation in terms of providing unsolicited assistance, and coordination through activity monitoring and inferring what needs to be done.

Effects of implicit coordination on performance.

Twelve studies[23 31 33 37 41 50 55 58 60-62 66] examined effects of implicit coordination on performance, three studies (additionally) mediating[50 60 64], and three studies [58 59 66] moderating effects with performance as the dependent variable. With the exception of three studies[33 37 41], all studies report a positive effect of implicit coordination on performance. The studies of Grote, in contrast, showed a positive relationship between explicit coordination and performance[41], respectively a negative relationship between implicit coordination and performance[33], in cockpit crews. Xiao [37] studied implicit coordination in two studies with trauma resuscitation and anesthesia teams and found that coordination breakdowns occurred when teams inadequately verbalized problems, i.e. when explicit communication was lacking. Urban, et al. [58] found a main effect of performance level on communication. Specifically, better performing teams asked fewer questions, provided fewer answers that implied requests, and provided fewer responses to request. Stachowski, et al. [55] used the anticipation ratio (unsolicited over solicited information) as performance criterion; they validated it, however, by showing that it corresponded well with supervisors' performance ratings.

Team knowledge structures. Implicit coordination was confirmed as a *mediating variable* between the TMM similarity and performance in the study by Fisher, et al. [60]. Marques-Quinteiro, et al. [50] showed that adaptive behaviors regarding creative problem solving (e.g.

finding innovative ways to deal with unexpected events), dealing with uncertain and unpredictable situations (e.g. shifting focus), and handling work stress (e.g. remaining calm under pressure) mediate the relationship between implicit coordination and performance. This indirect effect of implicit coordination in predicting team performance via adaptive behaviors was stronger for teams with a well-developed TMM.

Workload, standardization, and complexity. Interestingly, only four studies have explicitly investigated the influence of implicit coordination on performance under high workload, respectively complexity. In the study of Stout, et al. [23], teams that communicated more efficiently by giving more information in advance during high-workload periods performed better during these periods. Urban, et al. [58] found an interaction effect of workload and performance. Specifically, under low workload, the better and poorer performing teams uttered approximately similar amounts of these behaviors. Under high workload, however, better performing teams exhibited less responding behavior than did poorer performing teams. Wang, et al. [66] identified project modularity and project complexity as moderators of the relationship between implicit coordination and project performance. Specifically, when project modularity increased, the increase in complexity decreased the positive impact of implicit coordination on project performance. Grote, et al. [33] found no relationship between crew performance and single coordination mechanisms in different work phases with varying degrees of task load and standardization.

Overall, implicit coordination tends to be beneficial for performance, however, not under all circumstances. The results on implicit coordination and performance thus suggest that explicit coordination also seems to have its advantages, for example, when a team reaches a decision point or experiences coordination problems[37].

Other. Urban, et al. [58] found an interaction effect of team structure (non-hierarchical teams sharing common information and capabilities vs. product structure teams performing similar functions, but within different domains of on different products) and performance regarding communication behaviors (i.e. questions, answers, request, response to request, answer forming request, acknowledgement, statements, other). In the non-hierarchical structure, the better and poorer performing teams did not exhibit different amounts of these behaviors. However, in the product structure, the better performing uttered fewer answers that formed request than did poorer performing teams. Zheng, et al. [59] also found that group structure (dyad teams vs. single operator teams) positively influences performance in terms of total task time and grasp time because of anticipatory movements in a laparoscopic threat-cutting task.

Dyad teams performed significantly more anticipatory movements compared to single operator group.

Implicit coordination was confirmed as a mediating variable between empowering leadership and performance in the study of Chen, et al. [64]. Implicit coordination in terms of Transactive Memory System (TMS) was found to be positively related to personal success of collaborative learning in a study conducted by Zhang, et al. [61].

Discussion

This review reports the current state of research on implicit coordination. The aim of the review was to see if general statements on the effects and conditions of implicit coordination can be derived from available findings and to lay the ground for an extended model of implicit coordination to clarify and expand the understanding of implicitness in coordination processes. We examined empirical studies among a variety of groups performing a common task.

A first interesting observation is that implicit coordination has been studied mainly in action teams, i.e. in teams with specialized skills that coordinate their actions in intensive, unpredictable situations[92], some of which are interdisciplinary (e.g. medical teams). This is probably due to the general assumption that implicit coordination entails an advantage especially in fast-paced, non-routine situations of high complexity and/or workload. In such situations, teams generally require more resources in terms of time and cognition to complete the task [14 31 53 85]. In this respect it is interesting that the repeatedly assumed positive effect of implicit coordination on performance under heavy workload has only rarely been investigated and could actually only be confirmed in two studies[23 58]. However, overall, implicit coordination appears to be positive for performance as shown by the majority of the studies, although there is also some evidence of the benefit of explicit coordination in high performing groups[33 37 41]. Findings regarding implicit coordination under high workload indicate that more implicit coordination occurs under high task /workload [31 33 45 51], although two studies could not confirm such an effect [43 58]. Thus, it may not always be true that implicit coordination is a way out of the paradox that cognitive resources are not available exactly when they are needed most, namely in complex/high workload situations. Grote, et al. [33] mentioned in this respect that complex situations with high workload are anything but optimal to support implicit coordination. This is because, for example, standards and common assumptions may not fit, and the need to make decisions on the spot and possibly deviate from existing routines may be recognized too late or not at all. In sum, the results regarding implicit coordination and team performance included in the review are quite mixed.

With this in mind, it is worth considering that both, implicit coordination, and performance were operationalized in very different ways. Regarding performance, for example, the majority of the studies used subjective evaluations, either self-ratings[61 62 64 66] or expert ratings[33 41 50 53 54]. Team performance was measured in terms of team effectiveness/efficacy (e.g. [50 64]), project performance[66] (e.g. "this project is completed within budget"), task performance (e.g.[61]), different team performance dimensions (e.g. planning and allocation, interpersonal skills[62]), or various teamwork dimensions [53] (e.g. team orientation, communication behavior, monitoring, feedback). Eight studies[23 31 52 55 57-60] used objective indicators to measure performance, for example in terms of mission errors[23] or task time[31 52 57 59].

Implicit coordination is typically defined as anticipating the actions and needs of colleagues and work demands and team members dynamically adapting their behavior without the need to communicate or plan directly. Typical operationalizations involve offering information or help without request and reducing verbal communication, both of which indicate that team members anticipate the actions of others based on team level knowledge structures such as SMM. Taking a closer look at the definitions and operationalizations of implicit coordination, several things stand out.

First, the review has shown that there is a strong emphasis on the presence or absence of verbal behavior. Nonverbal behavior, such as gestures, has been studied very little and when, it typically was assumed to be only implicit in nature[31]. This is interesting in two ways. On the one hand, non-verbal signals represent symbolic language that may sometimes communicate intentions or the necessity of actions quite explicitly [31]. Wittenbaum, et al. [80] used the example of body posture, arm raising or head nods in jazz groups that, if they have a mutually agreed meaning among the group members, announce the ending or beginning of a solo during performance. This non-verbal but explicit way of communication can also be applied to action teams, e.g. when a team member during resuscitation of a patient with cardiac arrest looks at another team member while pointing to the defibrillator. Directed at a specific person, this non-verbal behavior may be equally clear as the utterance “Please get the defibrillator”. On the other hand, signals or codes that represent the verbal system, when recognized and correctly interpreted, allow for anticipatory action by team members, which is discussed in literature as one of the main manifestations of implicit coordination.

With regard to verbal communication, it is particularly noteworthy that, apart from communicating less during the process from explicit to implicit coordination, communication itself may be changed. Serfaty, et al. [51] pointed out early on such changes in the way teams communicate, referring to the tendency of team members to pass on more information unsolicited, which suggest more efficient verbal communication by anticipating other's task intentions. As a result, the anticipation ratio was introduced. Little consideration has been given, however, to the fact that also the way in which something is communicated (i.e. the linguistic presentation of the communication content) changes, based on experiences from interaction and more advanced SMM. Psycholinguistic research showed for example that actors who repeatedly interact changed the way they communicate by replacing sentences or explanations with a reference word that reminds the actors of the common ground that was established in earlier interactions[93 94]. Such communication may be less intentional, becoming a more or less automatic part of task execution; even a single word may act as a signal that activates an action pattern that contains increasingly large groups of information, corresponding to the "chunks"[95] already mentioned above. Thus, communication efficiency that indicates implicitness may not only be represented by less verbal communication or the timing of communication that changes throughout the coordination process (i.e. unsolicited information sharing), but also by how information is presented to others, i.e. by shorter communications with fewer words per communication units due to chunking. For example, a number of specific instructions such as "open shirt", "start 30 chest compressions", "ventilate 2 times", "get defibrillator", "attach pads", "analyze heart rhythm", "stop CPR", "defibrillate", "prepare adrenaline" may be combined into one; "CPR and get ready for defibrillation!".

Second, studies included in this review ignore task characteristics to a remarkable degree in their analyses. This is interesting to note, because researchers agree on the importance of task characteristics, and their implications for coordination requirements have been stressed repeatedly in the study of coordination processes (e.g., [65 96 97-100]). Wittenbaum, et al. [80] and Espinosa, et al. [77] for example assume that joint task completion is associated with varying degrees of dependency among team members. While tasks with low dependencies, i.e. tasks that are only loosely coupled in terms of time and space, can be performed independently by individual members, other tasks, which are somewhat more tightly coupled, create a high degree of dependency and thus increase the need and the complexity of coordination. An example for such a tightly coupled task is lifting a patient who is in danger of hurting his or her neck if not lifted in a precisely coordinated manner. Implicit coordination strategies tend to be ineffective in such situations. For tasks that require a high degree of coordination between team members for task completion, teams are therefore recommended to use explicit coordination strategies, especially during interaction. Taken together, dependencies among team members arise from different coordination requirements the task and may differ between (sub-)tasks. Specific behaviors may be positive for one task but detrimental for another task[101]. In practical terms, neglecting the task when measuring coordination processes or implicit coordination may lead to biased conclusions in several ways. One bias concerns the general assumption that explicit coordination decreases over time (e.g. because a team gained experience with the task and/or in working together); hist may only apply to those tasks that do not require close and precise synchronization. In other words, even in familiar teams, tasks that are very tightly coupled in terms of time and space may be less easily coordinated in an implicit way or require high expertise to allow for implicit coordination (as can be assumed for the study by Manser, et al. [45]). Another bias refers to verbal communication, which may decline, because the (sub-)tasks it refers need no longer be executed (e.g., once the defibrillator has been obtained, the task of obtaining it no longer applies), and it is not a sign of implicitness if there is no further communication about it. Thus, even if the tasks remaining are coordinated explicitly, there is a decline in verbal communication that may suggest that coordination has become more implicit. The last bias concerns rather general (abstract) categories such as “monitoring”, which are mute regarding the tasks they refer to. Monitoring utterances or behaviors during resuscitation for example may relate to the initial assessment of the patient (pulse, heart rate), the check whether the shock was effective, but also to insecurities of a team member who keeps looking at the monitor while thinking about the way to proceed[102]. In such cases it is not evident which task (if any) was implicitly coordinated.

Finally, although the conceptualization of implicit coordination as outlined above is well established and has formed the basis of many studies, one important question remains open: how does implicit coordination behavior specifically look like beyond offering help/information without request (i.e. anticipation) and reduced verbal communication? This is a fundamental question and requires a closer look at what has been considered as the core of implicit coordination: Anticipation. Anticipating requires some form of feedback on what appropriate actions are being performed by the other team members and to what extent. Thus, constant monitoring and information gathering throughout the coordination process is essential[79]. This is not new. What deserves a closer look, however, is the fact that monitoring is a question of cues indicating the need for action, based on (1) the development of the situation, (2) the actions and communication of others, and (3) coordination requirements. For example, in medical teams, a ventricular fibrillation is a cue for starting Cardiopulmonary Resuscitation (CPR), and an unsuccessful defibrillation is a cue for another one.

These cues may be more or less “condensed”, based on the team members task experience or in working together (i.e. team level knowledge structures such as SMM). Little experience with the task or the team probably requires more elaborate and specific cues (e.g. “attach the pads”, “stop CPR”), whereas with more training and experience, the steps required to successfully resuscitate a patient are contained in more comprehensive mental models (scripts) and may be triggered by shorter and more global cues (e.g. “let’s defibrillate”).

This process of chunking leads to a category that may be especially important for defining implicit coordination but that is seldom mentioned explicitly but rather is implicitly contained in the conceptual considerations offered by many authors. There is wide agreement that implicit coordination requires shared mental models (e.g. [23 26 49 51 53 54 57 60]) or “common ground”(e.g. [93 94]). The reason this is important is because shared mental models enable team members to interpret cues, including verbal utterances, in a similar way because they know their meaning. As an example, only if all team members know what a ventricular defibrillation means and that it implies the necessity to defibrillate, can they derive a script containing the steps necessary for performing a defibrillation. For medical lay persons, or medical students very early in their training, someone saying “we have a ventricular defibrillation” does not entail these specific consequences. In other words, the meaning of the respective cues has to be inferred on the basis of (shared) knowledge; if one does not possess that knowledge, the cues remain ambiguous and need to be replaced by unambiguous instructions (see [71 103 104]). From this perspective, implicit and explicit coordination may be conceived as reflecting differences in ambiguity. To the extent that the meaning of a cue, be that others’ task-related, expressive, or verbal behavior or cues emanating from the process itself, is unambiguous, it is considered explicit. To the extent that it can be deciphered only on the basis of shared knowledge about the problem and the task at hand – in other words, to the extent that the regularly mentioned precondition of a shared understanding is fulfilled – the cues can be considered implicit. This approach implies that verbal behavior may well be implicit, as when someone triggers a series of coordinated behaviors such as those involved in defibrillation by uttering a single word, such as “ventricular fibrillation”. Conversely, nonverbal behavior may well be explicit, as when a nurse physically demonstrates how to hold a hook during surgery.

Conclusions

Research and theorizing on whether, how and under what circumstances groups profit from implicit as compared to explicit coordination has a long tradition, but empirical findings are contradictory. The reasons for this are certainly manifold, but the conceptual issues identified in this review may contribute to a better understanding of the functioning and effectiveness of implicit versus explicit coordination.

We discussed the importance of taking task characteristics into account in the study of coordination processes. This task-focus when studying coordination processes may seem obvious. However, studies included in this review that count verbal utterances or use rather abstract categories to measure implicit coordination often do not take it into account. For example, the fact that communication regarding the defibrillator in the course of coordination is reduced to zero can only be interpreted properly if one is familiar with the task and knows the role of the defibrillator in performing cardiopulmonary resuscitation. Therefore, we claim that tasks as the object of coordination and the point of reference require more attention.

In addressing the role of communication, we pointed out that only few studies have used gestures to measure implicit coordination and discussed the question of how tasks can be referenced by verbal and non-verbal communication and whether this is equivalent to explicit and implicit coordination. We conclude that verbal utterances can also be rather implicit, whereas non-verbal behavior may be rather explicit. Looking at communication efficiency as an indicator of implicitness we noted that the focus so far has been mainly on the timing of communication (i.e. unsolicited information sharing) rather than on how information is "packaged" and how this can change throughout the coordination process. We conclude that implicitness may also be indicated by a shortening of communication (i.e. fewer words by communication unit).

At last, we turned our attention to the conceptualization of implicit coordination and discussed the question of how implicit coordination looks like beyond offering help/information without request (i.e. anticipation) and reduced verbal communication. We conclude that in order to understand anticipation in the context of implicit coordination, it is necessary to look at the process through which anticipation takes place; by capturing cues via observing others doing something (e.g., performing cardiac massage) or saying something (e.g., not enough saturation) and the ongoing process (e.g., the patient gaining / losing consciousness) and interpreting them on the basis of SMM and situational assessments. Specifically, implicitness is based on the perceived ambiguity of these (verbal or non-verbal) cues, which depends on how much experience a team member has with the task and/or team cooperation. The more expertise tea members have has, the more they can condense longer and more complex information into more digestible / global information units, thus increasing the amount of inference needed to interpret it and thereby making it more difficult for non-experts to understand it correctly. Conversely, they can “decipher” highly chunked information to derive action requirements for themselves. The degree of implicitness may therefore be regarded as the degree to which an external observer, who is not a task expert, is able to "decipher" a verbal or non-verbal communication.

Research implications

Based on the findings of this review, we identify four important implications for research on implicit coordination.

First, coordination-related communication is related to actions, i.e. less explicit communication indicates implicit coordination only if not due to reduced need for action. Second, a reduction in explicitness may go beyond a reduction in verbal communication. Rather, implicitness may be indicated by shorter communications, i.e. fewer word per communication unit (e.g. “Please get the defi” may become “defi”). Third, verbal communication is not exclusively of explicit, and non-verbal communication of implicit nature; verbal expressions can also be rather implicit, while non-verbal behavior can be rather explicit. And fourth, as communication becomes more implicit, its meaning is increasingly ambiguous for non-experts as it can only be inferred based on SMM.

Based on the implications above, we suggest putting a stronger focus on action-triggering cues and to consider ambiguity of verbal and non-verbal cues as a more a direct criterion in the study of implicit coordination.

An Interpretability Model of Implicit / Explicit Coordination

Based on the conclusions of our review, we present a model for conceptualizing and measuring implicit coordination via behavioural observation that attempts to address the nature of implicitness in terms of the criteria discussed above.

A key finding of this review is that research has focused heavily on unsolicited behaviour (e.g., unsolicited transmission of information or unsolicited assistance) to operationalize implicit coordination. However, this does not exclude the possibility that the coordination behaviour was triggered by prior verbal or non-verbal communication. However, such triggers may originate not only from communication and behaviours of others but also from cues arising from the process itself (e.g. beeping of monitors, patients gaining consciousness, corresponding to what Manser, et al. [45] refer to as "coordination via environment"). In our model therefore, task triggering cues is the analytical basis of implicit coordination (see Figure 5). Accordingly, the decision whether a task has been implicitly or explicitly coordinated is made via the behaviour-triggering communication.

We distinguish between verbal and non-verbal triggering communication. Examining verbal communication has so far been one of the main approaches in research on implicit coordination. But as we have concluded earlier, also non-verbal behaviour conveys meaning. And although this is nothing completely new (e.g. [31 80]), gestures have actually only been investigated in one of the studies included in this review[31].

Such task-triggering verbal or non-verbal communication may be explicit or implicit in nature. In contrast to explicit communication, which can be understood even with minimal prior knowledge, implicit communication requires interpretation by means of shared knowledge. *Explicit verbal* communication consists of clear, specific statements such as clear instructions or specific questions (e.g., order to get the defibrillator). *Explicit non-verbal* communication (e.g. a gesture or communicative action[31 105]) is consciously performed to achieve a communicative goal, and these types of gestures are typically regarded as clearly defined codes. The conceptualization of implicit communication in our model is based on the finding that implicitness is not only indicated by a decreasing communication in general, but also by the shortening of communication. Implicit communication is therefore rather ambiguous for non-task experts; it requires interpretation and shared knowledge to understand its inherent message. Thus, *Implicit verbal* communication may either by a condensed code (e.g. "defi") or an indirect message such as "we have a ventricular fibrillation", indicating the need to get the defibrillator. *Implicit non-verbal* communication is represented by a gesture that requires interpretation, such as pointing to the monitor displaying an information about the patient that requires actions. Thus, we assume that not only verbal communication but also gestures develop over time. For example, a hand indicating "stop" may be re-placed by a raised eyebrow over time. Or a hand movement towards important information on the vital signs monitor is replaced by extensively looking at it.

There may be situations in which no task-triggering communication is observed. This is when task execution is based on implicit *behavioral cues* contained in the action process or in behaviours of others. In contrast to task-triggering explicit or implicit communication, such cues do not represent intentional communication. Nevertheless, they are perceptible and can act as triggers for unsolicited reactive or anticipatory behavior. For example, a team member wants to prepare the medication during resuscitation and appears stressed. Another team member notices this and offers help or helps directly with the medication.

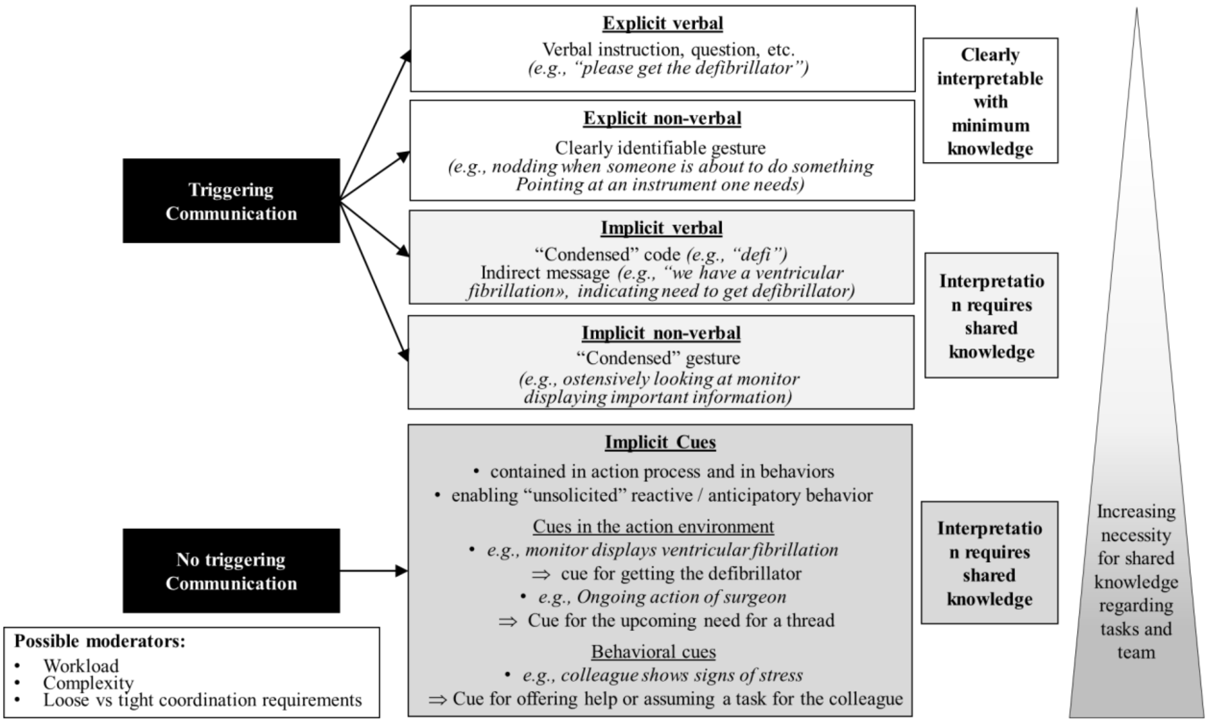

Figure 5. An Interpretability Model of Implicit / Explicit Coordination

Although its importance has been stressed repeatedly ([65 96-100]), the review has shown that the task and its coordination requirements have so far received little attention when measuring implicit coordination (see Manser, et al. [45] for an exception). Our model emphasizes that coordination requirements originate in the task(s) that need to be performed; and distinguishes between loose and tight coordination requirements. We speak of "loose" coordination if no precise synchronization is required, for example, when one person prepares the defibrillator, another prepares adrenaline. However, when several people lift a patient into the bed, they need to act simultaneously with all their movements perfectly aligned; this temporal synchronization is "tight" coordination. We propose that tight coordination requires more explicit coordination or, alternatively, especially high expertise, and thus mental models to base implicit coordination on (according to Manser, et al. [45], visibility of each other's action may be a prerequisite for implicit coordination in that case). Based on the findings in this review, we further suggest considering workload and task complexity as possible moderators of implicit coordination.

Research implications

In summary, we propose to study implicitness through the observation of verbal and non-verbal communication, as well as behavioral cues and cues contained in the coordination process itself. Relevant questions include: Which communications trigger the actions of others? How easy are they understood by non-experts? How do they develop over time? In addition to shortened verbal communication over time, gestures may also develop over time and should therefore be considered too. A promising way of assessment could be to confront actors with videos and ask them what triggered their actions and which of their own verbal and non-verbal communication they expected to trigger which actions by others.

Practical implications

We consider it important to teach cues identified as potential triggers in terms of "if-then" rules, which have shown to be effective in implementing intentions[106]. Idiosyncratic cues that are likely to remain ambiguous even for experts should be identified and possibly replaced. This may be important for experts familiar with the task but not with the team. With the Adaption and Coordination Training (TACT), Serfaty, et al. [54] recognized the potential of this type of training early on; TACT trains team members to adapt their coordination strategies to take account of changes in workload and stress. Finally, we think it is important to prevent "over-implicitness", which may occur because scripts triggered by minimal cues tend to be highly routinized. While such routines have the advantage of efficiency, there is a risk of failing to adapt these routines once they are triggered.

To conclude, we suggest to carefully analyze and teach the need and usefulness of explicit versus implicit coordination and the many – verbal and non-verbal – ways to accomplish it.

APPENDIX 1: Studies aimed at developing measurement instruments

Four of the studies identified in the literature search on implicit coordination aimed at the development of *measurement instruments*, of which two studies entailed scale development and two developed coding schemes. (see Table 4).

Kolbe, et al. [107] developed a taxonomy with i.a. observational categories for explicit and implicit team coordination specifically found in anesthesia teams. The taxonomy contains observational categories for explicit and implicit coordination of information exchange and explicit and implicit coordination of action. In a later study, Kolbe, et al. [79] presented the Framework for Observing Coordination Behavior in Acute Care Teams (Co-ACT). It consists of four quadrants organized in two dimensions (explicit vs. implicit; action vs. information coordination). Each quadrant contains three observational categories. Since Co-ACT is the result of the integration of existing taxonomies, the observational system is very similar to the taxonomy from the former study by Kolbe, et al. [107]. Two studies developed a questionnaire to measure implicit coordination. Chiocchio, et al. [108] operationalized implicit coordination in terms of anticipating needs without expressing them, the instinctive reorganization of tasks and the implicit understanding of the assigned work tasks. Chang, et al. [109] developed a multidimensional team coordination scale consisting with i.a. four subscales that measure explicit and implicit accountability, and explicit and implicit predictability. It is based on the perspective on team coordination from Okhuysen and Bechky [2]. Based on a review of the coordination literature, these authors suggest that coordination mechanisms such as routines, meetings, plans influence the organization of work by creating three integrative conditions for coordinative activity: Common understanding, predictability and accountability. Common understanding supports coordination by giving a shared perspective on the overall task and how the individual tasks fit into the big picture. The aspect of predictability enables interdependent groups to anticipate task relevant activities by knowing the elements of the task and when they will happen. Accountability delimits who is responsible for specific elements of the task.

Table 4. Studies aiming at the development of measurement methods (N = 4)

Authors	Definition of IC	Method	Categories / Items
Kolbe, et al. [107]	Referring to MacMillan, et al. [88], Rico, et al. [4], Toups and Kerne [49], Wittenbaum, et al. [27]	Observational coding scheme	**Taxonomy of explicit and implicit team coordination and heedful interrelating behavior** Explicit coordination of information exchange - Request information - Provide information upon request - Verifying information - Acknowledgement - Summary - Questioning information - Note making Implicit coordination of information - Provide unsolicited task-relevant information - Obtaining unsolicited task-relevant information - Listening Explicit coordination of action - Assistance requests - Giving orders - Assigning tasks - Making plans - Initiating actions - In-process decisions - Providing action upon request - Questioning decision - Verifying questions - Planning and procedural questions - Approval Implicit coordination of action - Providing unsolicited task-relevant action - Offers of assistance - Indications of satisfaction with fulfilment of task - Monitoring - Declaring own needs
Kolbe, et al. [79]	Referring to Wittenbaum, et al. [80], Arrow, et al. [110], Boos, et al. [111], Kolbe, et al. [112]	Observational coding scheme	**Co-ACT framework for observing coordination behavior in acute care teams** Explicit action coordination - Instructions - Speaking up - Planning Implicit action coordination - Monitoring - Talking to the room - Provide assistance Explicit information coordination - Information request - Information evaluation - Information upon request Explicit information coordination - Gather information - Talking to the room (info-related) - Information without request
Chiocchio, et al. [108]	Referring to Salas and Fiore [113]	Questionnaire	**Questionnaire with (i.a.) two subscales measuring explicit and implicit coordination** Explicit coordination - My teammates and I make progress reports - My teammates and I exchange information on 'who does what' - My teammates and I discuss work deadlines with each other Implicit coordination

Authors	Definition of IC	Method	Categories / Items
			- My teammates and I can foresee each other's needs without having to express them - My teammates and I instinctively reorganize our tasks when changes are required - My teammates and I have an implicit understanding of the assigned tasks
Chang, et al. [109]	Referring to Rico, et al. [4]	Question-naire	**Multidimensional team coordination scale** Explicit accountability (EA) - I constantly have to record work-related content to inform my supervisor and other colleagues. - I constantly need to perform task or shift handovers with other team members. - I am responsible for giving feedback. - Teamwork tasks and content are clearly defined. Explicit predictability (EP) - Equipment and resources are arranged in advance, enabling everyone to be clear about resource deployment. - The working environment is orderly, providing workers with a sense of control on work progress. - When the work progress of a worker is unsatisfactory, other team members or the supervisor inform or remind the worker. - Team members work according to their assigned tasks. - Team members can accomplish their tasks according to previously developed work plans and - processes. Implicit accountability (IA) - Taking full responsibility of my behavior at work is essential. - In my team, every member knows that he or she needs to work efficiently. - I clearly acknowledge the expectations of my supervisor and colleagues of my work. - If I did not revise or improve my behavior according to feedback opinions, bad results are generated. Implicit predictability (IP) - When thinking what I can do for the team, I consider first doing tasks that other team members do not like to do. - When a team member encounters a considerable workload, other team members voluntarily assist this member in completing some of the tasks without being requested. - Team members voluntarily provide feedback that is useful for improving task performance to other team members without being requested. - Team members voluntarily transfer task-related information to other team members without being requested. - Everyone is willing to accept problem-solving projects proposed by other team members without being asked. - I work more efficiently for the team when anticipating the performance of other team members. - I constantly observe the workload of other team members to see whether or not they need help. - When performing teamwork, team members indicate problems according to their experience without being requested.

APPENDIX 2: SCOPUS data base search strategy

TITLE-ABS-KEY (implicit OR tacit AND coordination) AND (EXCLUDE (SUBJAREA , "COMP") OR EXCLUDE (SUBJAREA , "ENGI") OR EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "MATH") OR EXCLUDE (SUBJAREA , "BIOC")) AND (EXCLUDE (SUBJAREA , "CHEM") OR EXCLUDE (SUBJAREA , "PHYS")) AND (EXCLUDE (SUBJAREA , "AGRI")) AND (EXCLUDE (SUBJAREA , "ENVI")) AND (EXCLUDE (LANGUAGE , "Spanish") OR EXCLUDE (LANGUAGE , "Chinese") OR EXCLUDE (LANGUAGE , "Portuguese") OR EXCLUDE (LANGUAGE , "Slovenian") OR EXCLUDE (LANGUAGE , "Croatian") OR EXCLUDE (LANGUAGE , "Czech") OR EXCLUDE (LANGUAGE , "Italian")) AND (EXCLUDE (LANGUAGE , "Japanese") OR EXCLUDE (LANGUAGE , "Russian") OR EXCLUDE (LANGUAGE , "Serbian")) AND (EXCLUDE (SUBJAREA , "CENG") OR EXCLUDE (SUBJAREA , "ENER") OR EXCLUDE (SUBJAREA , "MATE")) AND (EXCLUDE (SUBJAREA , "EART") OR EXCLUDE (SUBJAREA , "PHAR")) AND (EXCLUDE (DOCTYPE , "cr") OR EXCLUDE (DOCTYPE , "ed") OR EXCLUDE (DOCTYPE , "er"))

APPENDIX 3:

Table 5. Measures of implicit coordination and main findings of the original research studies included (N = 31)

Authors	Study design	Measures				Manipulation	Hypotheses & Findings Confirmed (✓) Rejected (X)
		Implicit coordination	Explicit coordination	Performance	Others		
Methodology: Questionnaires							
Chen, et al. [64]	F	3 Items; sample item*:* - *Team members pass on task-relevant information to other members without being asked*	-	Team efficacy; 5 items, self-developed; Sample item - *We are confident of achieving the occupancy goal of our team*		-	**H1**: Implicit coordination mediates the effect of empowering leadership on team efficacy in team ✓ (partial mediation, R^2 = .65)
Fisher, et al. [60]	S	4 items, based on Rico, et al. [4]: - *Members of my team provide task-related information to other members without being asked,* - *My team proactively helps individual members when they need assistance,* - *My team monitors the progress of all members' performance* - *Members of my team effectively adapt their behavior to the actions of other members*	-	Index of team performance (α = .93) based on simulation-generated indices of stock price, return on assets, and return on sales from the final week of the simulation.		-	**H1**: Team-focused TMM similarity is positively related to the team process of implicit coordination ✓ (β =.34, *p* < .05). **H2a**: The team process of implicit coordination will be positively related to team performance ✓ (β =.40, *p* < .05). **H2b**: The team process of implicit coordination mediates the relationship between team-focused Team Mental Model similarity and team performance. ✓ (indirect effect for TMM similarity, 95% CI [0.09, 14.51])
Marques-Quinteiro, et al. [50]	F	6 items developed based on descriptions of anticipatory behaviors and dynamic adjustment behaviors described by Rico, et al. [4]: Anticipatory behaviors - *Team members articulate information regarding their situation, needs and objectives, only as much as necessary (and no more than that)* - *Team members share relevant information efficiently and in the right moments*	-	Team performance; Supervisors rating quality of their teams' current performance - *"How would you rate your team's overall performance, so far?" (1 = totally ineffective, 4 = totally effective)*		-	**H1a:** Team implicit coordination is positively related to team performance ✓ (*r* = .32, *p* < .01) **H1b:** The relationship between team implicit coordination and team performance is mediated by adaptive behaviors ✓ (B = .18, 95% CI [.06 to .38]) **H2:** The conditional indirect effects of team implicit coordination in predicting team performance via adaptive behaviors will be stronger for those teams with a well-developed Transactive Memory Systems (TMS).

Authors	Study design	Measures				Manipulation	Hypotheses & Findings Confirmed (✓) Rejected (✗)
		Implicit coordination	**Explicit coordination**	**Performance**	**Others**		
		- *Team members synchronize their work during task performance, reducing communication to the bare minimum* *Dynamic adjustment:* - *Team member sequence their work in order to reduce time wasted between the performance of interdependent tasks* - *Team members anticipate what other team members are going to do in precise moments* - *Team members adjust their behavior in anticipation of the actions of other team members*					✓ (two-way interaction between TMS and implicit coordination, B = .30, p = .04; conditional indirect effect, B = .28, 95% CI [.03 to .68])
Zhang, et al. [61]	F	3 items measuring implicit coordination in terms of Transactive Memory System (TMS) [114]: - *I understand what skills my team members have and domains they are knowledgeable in* - *My team members have expertise in areas that are important in the kind of work I do* - *Overall, I am able to access other team members' thinking and knowledge*	4 items measuring explicit coordination in terms of communication [115] - *There was frequent communication within the team* - *The team members often communicated spontaneously* - *The team members communicated mostly directly and personally with each other* - *Teamwork-related information was shared openly by all team members*	Task performance; 5 items [116] - *My team achieves its goals* - *My team accomplishes its objectives* - *My team meets the requirements set for it* - *My team fulfills its mission* - *My team serves the purposes it is intended to serve*	Personal success [115] - *Team members have gained from the teamwork* - *The team members would like to do this type of teamwork again* - *After this teamwork, the team members could draw a positive balance for themselves overall* - *We were able to acquire important know how through this teamwork* - *We see this project as a success* - *Our team learned important lessons from this teamwork* - *Teamwork promotes one personally* Social media activities [117]:	-	**H1a:** Information processing is positively related to the level of TMS s in collaborative learning ✓ (β = .28*, t = 2.17) **H1b**: Social connection is positively related to the level of TMS s in collaborative learning ✓ (β = .39**, t = 2.72) **H2a:** TMS s is positively related to task perfrmance of collaborative learning ✓ (β = .36*, t = 2.55) **H2b:** TMS s is positively related to personal success of collaborative learning ✓ (β = .36*, t = 1.97) **H3:** Communication can facilitate the development of TMS s in collaborative learning ✓ (β = .27**, t = 2.9)

Authors	Study design	Measures				Manipulation	Hypotheses & Findings Confirmed (✓) Rejected (✗)
		Implicit coordination	Explicit coordination	Performance	Others		
					Information processing - *To learn about unknown things* - *It's a good way to do research* - *To learn about useful things* Social connection - *I wonder what other people said* - *To express myself freely* - *To meet people with my Interests*		
Quintal [67]	L	4 items based on Rico, et al. [4]; sample item: - *We anticipate what each member of the team is going to do/need in each certain moment*	-	-	Leadership [118] - *Leadership transition phase functions (e.g. communicates what is expected of the team")* - *Leadership action phase functions (e.g. monitors team and team member performance")* - *Leadership social climate support functions (e.g. "looks out for the personal wellbeing of team members")* Trust [119] - *Propensity to trust (e.g. "In this team most people speak out for what they believe in")* - *Perceived trustworthiness (e.g. "In this team people can rely on each other"),* - *Cooperative behaviors (e.g. "Most people in this*	-	**H1:** Leadership positively influences the implicit coordination of a team ✓ (β = .55., *p* < .01, R^2 = 0.31, *p* < .01) **H1a:** Leadership transition phase functions positively influence the implicit coordination of a team ✓ (β = .50., *p* < .01, R^2 = 0.25, *p* < .01) **H1b:** Leadership action phase functions positively influence the implicit coordination of a team ✓ (β = .56., *p* < .01, R^2 = 0.31, *p* < .01) **H1c:** Leadership social climate support functions positively influence the implicit coordination of a team ✓ (β = .37., *p* < .01, R^2 = 0.14, *p* < .01) **H3:** Trust positively influences implicit coordination ✓ (β = .37., *p* < .01, R^2 = 0.14, *p* < .01) **H4**: Leadership positively influences trust, which in turn positively influences the implicit coordination of a team ✓ (indirect effect β = .07, *p* < .05, 95% CI [.02 to .14])

Authors	Study design	Measures				Manipulation	Hypotheses & Findings Confirmed (✓) Rejected (✗)
		Implicit coordination	Explicit coordination	Performance	Others		
					team are open to advice and help from others") - *Monitoring behaviors (e.g. "In this team people watch each other very closely")*		**H4a**: Leadership transition phase functions positively influence trust, which in turn positively influences the implicit coordination of a team ✓ (indirect effect β = .08, $p < .05$, 95% CI [.02 to .17]) **H4b**: Leadership action phase functions positively influence trust, which in turn positively influences the implicit coordination of a team ✓ (indirect effect β = .06, $p < .05$, 95% CI [.00 to .08]) **H4c**: Leadership social climate support functions positively influence trust, which in turn positively influences the implicit coordination of a team ✓ (indirect effect β = .09, $p < .05$, 95% CI [.03 to .18])
De Jong and Fodor [62]	F/L	Measured in terms of "implicit coordination concepts" Team familiarity [120]: - *Transactive calculating the total sum of years of experience with each other of all pairs of two individual team members and then dividing this number by (n(n-1))/2, where n is the size of the team.* Transactive Memory System [121]; 15 items; sample items: - *I know which team members have expertise in specific areas* - *Our team had very few misunderstandings about what to do* Friendship network density [122] - *Dividing the total number of friendship ties within the team by the total number of possible ties within the team*	-	Team performance; 7 items [123] judged by the team members at T3; dimensions: - *Knowledge of tasks* - *Quality of work* - *Quantity of work* - *Initiative* - *Interpersonal skills* - *Planning and allocation,* - *Commitment to the team* - *Overall evaluation of team performance*	Cross Attuning (i.e. the extent to which members are accurately mindful about another member's work routines); Self-developed matrix measuring interpersonal relationships (Huber & Lewis, 2010) within teams based on social network analysis (Scott, 2012); 4 items (1 = yes, 2 = no): - *Understands my way of working (my habits, work-method, routines* - *Recognizes any differences between us considering habits, work-methods, and routines* - *Takes into account my way of working*	-	**H1:** Above and beyond team familiarity, transactive memory and friendship network density, Cross Attuning will have a positive impact on team performance ✓ (B = 6.33(1.61), p < .01; Rsq change = .23, F change = 24.07, p < .01)

Authors	Study design	Measures				Manipulation	Hypotheses & Findings Confirmed (✓) Rejected (✗)
		Implicit coordination	Explicit coordination	Performance	Others		
					- *Adapts his/her way of working to my way of working*		
Wang, et al. [66]	F	5 items based on Rico, et al. [4] and Kang, et al. [124]: - *Our staffs have received special training dedicated to this client.* - *We have spent a lot of time with the client on building relationships with its staff.* - *We have spent a lot of time learning our client's operational routines.* - *We have made significant adjustments in internal operational processes to adapt to this client's unusual needs and technical specifications.* - *We have spent a lot of time and effort coordinating the operational processes to adopt this client's unusual needs and technical specifications.*	-	Project performance [125]: - *This project is completed within budget.* - *This project is delivered in time.* - *This project achieves all features and functions that the client requires.* - *This project achieves critical objectives and client's business needs.* - *Overall, this project is successful.*	Project complexity; 4 items adapted from Narayanan, et al. [126]: - *The sequence of steps to be carried out to complete these activities successfully is hard to identify* - *A well-defined body of knowledge on which to base the execution of this project does not exist* - *When executing this project, problems that cannot be immediately resolved arise frequently* - *The consequences of these project-related activities are hard to predict.* Project modularity; 3 items adapted from Tiwana [125]: - *Changing this outsourced activity does not affect the client's other business processes* - *This outsourced activity can be easily detached from the client's other business processes* - *It is very easy to combine or recombine this outsourced activity with the client's other business processes*		**H1:** Implicit coordination positively affects project performance ✓ (β = .12., $p < .05$) **H2:** Project modularity positively moderates the relationship between implicit coordination and project performance ✗ (β = .02., $p \geq .1$) **H3:** Project complexity negatively moderates the relationship between implicit coordination and project performance ✓ (β = -.09., $p < .01$) **H4:** When project modularity increases, the increase in project complexity decreases the positive impact of implicit coordination on project performance ✓ (β = -.14., $p < .01$)

Methodology: Behavioral observation							
Entin and Serfaty [53]	S/L	Anticipation ratio *Dividing the number of transfers to individual X by the number of requests made by X. Anticipation ratio greater than 1.0 indicates that X's needs are being anticipated, and X receives what is needed without having to request it every time. Anticipation ratios greater than 1.0 can also be interpreted as a shifting away from explicit communication and toward implicit communication.*	-	12 behaviorally anchored items assessing overall Anti-air warfare (AAW) team performance and 15 items assessing six dimensions of teamwork (i.e. team orientation, communication behavior, monitoring, feedback, back-up, coordination) from Team Anti-air warfare performance scale; *Performance items* are based on AAW Team Performance Index and Behavior Observation Booklet [127 128]. *Teamwork items* are adapted from teamwork assessment instruments used by Serfaty, et al. [73] and Entin, et al. [82] which are in turn based on the AAW team Observation Measure (ATOM) developed by Naval Air Warfare Center Training Systems Division and a model of team evolution and maturation by Glickman and Zimmer [129] and Glickman, et al. [130]		TACT Training (teaching team strategies) *(TACT, TACT+, control)* Workload-induced stress *(high, low)*	**H1a:** The overall communication rate does not necessarily decline as a result of the shift from explicit to implicit coordination. ✓ Decline of communication rate after training intervention only for low-stress scenarios, F(2, 9) = 11.41, $p < .009$. In the high-stress scenarios communication rates stayed about the same pre- and postintervention. However, as we explain in the next set of results, the TACT and TACT+ interventions induced different communication patterns in a high-stress condition. **1b***:* Our theory predicts that TACT intervention will induce teams to shift away from explicit communication to more implicit communication. ✓ TACT and TACT+ interventions produced significantly higher global anticipation behavior (23% increase from 1.46 pre- to 1.79 post-intervention) than did the control condition, F(1, 9) = 34.59, $p < .001$. ✓ The anticipation ratio based on subordinate-to-TAO transfers contrasted with the TAO-to-subordinate requests showed a significant increase with training; shift from 1.80 in the pre- to 2.26 post-intervention condition, F(1, 9) = 17.49, $p < .003$. ✓ The anticipation ratio based on team members' information *transfers* to the TAO compared with TAO information *requests* from team members (1.58 pre- vs. 2.31 postintervention), and TAO information *transfers* to team members compared with team members' information *requests* from the TAO (4.14 pre- vs. 6.36 postintervention), show the same pattern of results: The anticipation ratio is greater after intervention than before, F(1, 9) = 15.70, $p < .004$, and F(1, 9) = 8.95, $p < .02$, respectively.

							✓ Across experimental conditions, the ratio of the TAO information *transfer* to team members compared with team members' information *requests* from TAO was greater for teams receiving the training (TACT+ and TACT conditions) than in the control condition (6.69 and 3.26, respectively), t(9) = 1.99, $p < .05$, one-tail)
Toups and Kerne [49]	F *	*(ethnographic) Not systematically measured	-	-	-	-	No explicitly hypotheses stated. Aids for implicit coordination capabilities: *Overhearing*: FERs overhear the radio communications at the fireground, which reveals to them what other members of their company and other companies are doing, granting a peek into the global situation and revealing opportunities to assist without explicit coordination [P6] [T1]. This ability is developed over time though experience [P5] and is similar to the coordination of workers in emergency call centers, where small groups of co-located call operators can tap into each other's phone calls in order to better assist one another [1]: coordination is almost automatic. *Ambient monitoring:* FERs maintain a mental model of the incident by listening to the background sounds in their environment and those coming through the radio from other FERs, in addition to immediate, local sensory perception [P1, P5, P6]. Interviewees indicated that they have a strong understanding of what their teammates are doing during firefighting operations, as well as the objectives of the team and individuals, indicating strong shared mental model building and situational awareness skills. They also subjectively described themselves as having a high anticipation ratio. Emergent practices develop this capability. These practices allow FERs to quickly determine what actions are needed, based on situational awareness and shared mental models,

							without the need for explicit communication [6]. FERs extensively use shared mental models in the field. Cross training establishes the groundwork for shared mental model formation. Each emergency responder knows how to perform different roles, which supports her/him in understanding the concurrent experiences and needs of other team members. Further, because they live and work together for as much as a third of their lives [P1], they are able to build strong personal understandings of one another. These understandings lead to an ability to model one another's thinking processes in the field, strengthening their ability to implicitly coordinate [P1].
Grote, et al. [41]	S/L	Self-developed observational categories based on Serfaty, et al. [54] - *Provide unsolicited information* - *Offer assistance* - *Silence* - *Chatting* *in case of silence or chatting > check situation if it indicates IC or not*	Self-developed observational categories - *Provide information* - *Request information* - *Provide information upon request* - *Information containing a summary of a stat of affairs or a process* - *Reassurance (e.g. feedback about comprehension of a communication)* - *Giving order* - *Asking for help* - *Communication with Air Traffic Control (specific for aviation)* - *Discussion* - *Standard communication (specific for aviation*	<u>Aviation</u>*:* Performance Index (1 to 10) consisting of: *Performance rating (1-6)* *Rating (1 to 4) of the performance of all compulsory tasks and compliance with all rules relevant to the situation.* <u>Anesthesia</u>*:* Team performance based on expert rating (1 to 10)	Leadership *e.g. make plans assign tasks* Heedful interrelating *e.g. Consider others question decisions*	Task load (TL) *(high, low)* Standardization (S) *(high, low)* Different work phases and combinations of S and TL distinguished in both settings	<u>Aviation</u> *General assumptions:* 1. If a process is well known and/or highly standardized, mostly implicit co-ordination and only few leadership behaviors are expected *(aviation H1?)* 2. In unexpected complex situations, teams need to establish a common understanding of the task. Explicit co-ordination helps teams to form a shared mental model and good leadership enables smooth and rapid co-ordination. *(aviation H2?)* 3. Task load results in a limited capacity to process information. The consequence is a possible switch to more efficient forms in the information exchange process, like implicit co-ordination *(aviation H3?)* *Phase 1 (take-off): S high and TL low* 840 CU (communication units) overall 66% CU explicit 34% CU implicit *Phase 2 (problem solving): S low, TL low* 3514 CU overall 81% CU explicit 19% CU implicit

							Phase 3 (approach and landing): S high, TL high 1429 CU overall 60% CU explicit 40% CU implicit *Performance* Positive relationship between the overall amount of explicit co-ordination and performance (r=.37, $p \leq .05$). Anesthesia *Phase 1 (Preparation): S high, TL low* 59% CU explicit 41% CU implicit *Phase 2 (Pre-intubation): S moderate, TL moderate* 68% CU explicit 32% CU implicit *Phase 3 (Tracheal intubation): S high, TL moderate* 71% CU explicit 29% CU implicit *Phase 4 (Add. Preparation): S low, TL high* 74% CU explicit 26% CU implicit *Phase 5 (Transport): No S, TL low* 70% CU explicit 30% CU implicit
Serfaty, et al. [51]	S/L	(Upward) Anticipation ratio - *Ratio of subordinates' information transfers to leader's information requests.*	Transfer of information and resources in response to requests, and the use of communication messages to coordinate actions	Error rate (miss / false alarms)	-	Uncertainty *Percentage of sensor messages that were garbled; (low/high)* Time-pressure *(high, moderate, low)* Ambiguity *Choice of target's attributes for each scenario*	**H1:** Team coordination strategies evolve from explicit coordination under low workload conditions to implicit coordination as workload increases. ✓ (no statistics reported, $p < .02$)

Leedom and Simon [68]	F	Self-rating; perceived coordination mechanism (1 = implicit, 7 = explicit)	Self-rating; perceived coordination mechanism (1 = implicit, 7 = explicit)	Team / mission performance via self-rating; perceived effectiveness (1 = low, 7 = high)	-		No hypotheses. Battle-rostered crew pairings were viewed by the subjects as resulting in more implicit coordination (average rating of 4.2 vs. 4.9), *t*(22) -3.07, ≤ .01)
Urban, et al. [58]	S/L	Via communication behaviors** such as - *Question (requesting info)* - *Answers (Providing info)* - *Requests (request resources, assistance or specific action)* - *Answer forming request (offering explicit or implicit request for resources as an answer to a question)* - *Statement (provide info about status of task or status of team member)* **behaviors are not explicitly indicated as implicit coordination behaviors	-	Team performance - *Points for engaging enemy targets (accumulated team score per 30-min trial)*	-	Workload *(low/high)* Team structure *(non-hierarchical: team members are non-specialized, or share common information and capabilities / Product structure: team members, except the team leader, perform similar functions, but these functions are performed within different domains or on different products.)*	**Overall hypothesis:** Teams adapt their communication to the demands imposed by the various structure and workload levels. Effective communication differs depending on the condition in which teams are required to perform. **Manipulation:** - Product teams performed significantly worse than nonhierarchical teams in terms of points scored, F(1, 20) = 38.43, p < .001. - Significant structure by workload interaction was obtained, F(l, 20) = 6.09, p < .05. Subsequent range tests indicated that high workload product structure teams performed significantly worse than low workload product structure teams, who in turn performed significantly worse than nonhierarchical teams in both workload conditions. **Effects of structure, workload, and level of performance effectiveness on the eight types of communication** - Significant effect of structure, F(l, 9) = 37.71, p < .001 - Significant effect of level of performance effectiveness, F(1.9) = 5.67, p < .01 - Significant interaction of structure and level of performance effectiveness, F(1.9) = 6.60, p < .01 **Effects of structure, workload, and level of performance effectiveness on overall asking and responding behaviors:** - Significant effect of structure, F(1, 15) = 18.94, p < .001 - Significant interaction of workload and level of performance effectiveness, F(l, 15) = 4.46, p < .05. **Aspects of communication**:

							- **No main effect of workload** was obtained across any of the communication categories analyzed. - **Main effect of structure with respect to several aspects of communication**. Specifically, product teams asked significantly more questions, $F(l, 16) = 22.47$, $p < ,001$, and provided more answers that formed requests, $F(l, 16) = 77.52$, $p < .001$, than did nonhierarchical teams. Product teams also made significantly more requests, $F(l, 16) = 15.20$, $p < ,001$; provided more responses to requests, $F(l, 16) = 37.96$, $p < .001$; and made fewer statements, $F(l, 16) = 6.10$, $p < .05$, than did nonhierarchical teams. Overall, product teams engaged in significantly more asking behavior (sum of questions, requests, and answers that form requests), $F(1, 16) = 30.81$, $p< .001$, and more responding behavior (sum of answers and answers that form requests), $F(1, 16) = 15.12$, $p < .001$. - **Main effect of performance level** was obtained in some of the coded communication categories. The better performing teams asked significantly fewer questions, $F(l, 16) = 6.42$, $p <.05$; provided fewer answers that form requests, $F(l, 16) = 6.02$, $p < .05$; and provided fewer responses to requests, $F(1, 16) = 8.00$, $p < .05$, than did poorer performing teams. - A significant **Structure x Performance Level interaction** was obtained concerning answers that form requests, $F(l, 16) = 5.33$, $p <.05$. In the nonhierarchical structure, the better and poorer performing teams did not exhibit a significantly different amount of these behaviors. In the product structure, however, the better performing teams uttered significantly fewer answers that formed requests than did poorer performing teams. - A significant **Workload x Performance Level interaction** was obtained concerning overall responding behavior, $F(1, 16) = 5.78$, $p < .05$. Subsequent range tests

							indicated that under low workload, the better and poorer performing teams uttered approximately similar amounts of these behaviors. Under high workload, however, better performing teams exhibited significantly less responding behavior than did poorer performing teams.
Volpe, et al. [57]	S/L	Communication frequency - *Volunteer information (observation, command, or suggestion)* - *Request information*	-	Task performance - *Enemy in range* - *N° of enemy aircraft destroyed* - *Time to destroy first enemy* - *N° of enemies locked on by the team* - *N° of times team locked on by enemy* - *Overall team quality*	Teamwork process; 4 dimension (selection based on past work [131] and adapted from the Teamwork Rating Scale [132] - *Technical coordination* - *Interpersonal cooperation* - *Team spirit* - *Cross-monitoring* Communication[133] - *Indicating agreement or compliance* - *Task-irrelevant remarks* - *Acknowledgments*	Cross-training *(yes/no)* Team workload *(high, low)*	**H2:** Teams that received cross-training are predicted to communicate more appropriately than teams that were not cross-trained, i.e. - to exhibit more volunteering of information ✓ ($F(l, 39) = 7.46, p < .05$) - (…) to exhibit less requesting of information (…) ✗ No predicted effect on (…) information requests (…) ($F(l, 39) = 5.27, P < .05$) **H4:** Under high-workload conditions, teams that received cross-training were expected to exhibit significantly - better teamwork behavior ✗ workload significantly degraded teamwork process, ($F(l, 39) = 4.47, P < .05$) - communicate more appropriately (i.e. exhibit more volunteering of information […] exhibit less requesting of information) ✗ all communication frequencies decreased under high workload - perform significantly better on the team task than teams that were not cross-trained ✗ workload had no impact on any of the team task performance measures - Smaller differences were expected between cross-trained and non-crass-trained teams under low workload conditions ✗ only in two cases but in opposite direction
Cannon-Bowers, et al. [52]	S/L	Communication aspects - *Volunteer information*	-	Task outcomes - *Overall team score* - *Index of speed (total time assessing information)*	-	Cross-training *(yes/no)* Workload *(high, low)*	**H1:** Cross-training has a positive impact on team members' tendency to volunteer information before being asked but not on other aspects of communication behavior ✓ ($F(1, 34) = 3.98, p \leq .05$)

				- *Index of accuracy (number of contacts that were shot or cleared correctly)*			
Serfaty, et al. [54]	S/L	Category based anticipation ratios (e.g. upward information)	-	12 items based on the Anti-Air Warfare Team Performance Index and Behavior Observation Booklet [134]	-	TACT Training - team adaptation and coordination training – learning to anticipate need for information, instructed to give periodic updates to develop shared understanding) *(TACT, TACT+*, control)* **TACT+ = TACT training plus periodic situation-assessment briefings* *Workload (high / low)*	No explicitly stated hypotheses. Team anticipation ratio (ratio of transfers to transfer plus requests across all categories of communication): ✓ TACT and TACT+ interventions produced significantly higher rates of anticipatory behavior than the practice-only control group ✗ No significant differences in anticipatory behavior between low and high-stress conditions
Stout, et al. [23]	S	Rate of communication provided in advance	-	Mission errors based on standard operating procedures	-	Planning quality - *Creating open environment* - *creating an open environment* - *setting goals and awareness of consequences of errors* - *exchanging preferences and expectations* - *clarifying roles and information to be traded*	**H2:** Teams that engaged in better planning provide more information in advance during periods of high workload (scenario segments 3 and 4) ✓ (segment 3, $t(11) = 2.58$, $p < .05$, segment 4, $t(11) = 2.66$, $p < .05$) **H3:** Better planning teams perform better during periods of high workload. ✓ (segment 3, $t(11) = –3.90$, $p < .01$, segment 4, $t(11) = –1.92$, $p < .05$) **H4**: Teams that had greater SMMs communicate more efficiently during high-workload periods. Similarly, teams that developed a greater SMM perform better when workload is high, as a result of the more efficient communication strategies that they were enabled to use.

						- *clarifying sequencing and timing* - *unexpected events how high workload affects performance* - *pre-prepared information, and self-correcting*	✗ teams with a greater SMM of each other's informational requirements did not demon strate higher rates of information provisions during high-workload conditions **H5**: Teams that communicate more efficiently during high-workload periods perform better during these periods. ✓ (segment 3, $t(9) = –3.53$, $p < .01$, segment 4, $t(8) = –2.07$, $p < .05$)
Xiao [37]	F	Not systematically measured	Not systematically measured	-	-	-	**Study 1:** Four types of coordination without the use of explicit, verbal, or gestural communications, that enable smooth performance: 1. Coordination by following protocols; tasks to be done are predefined, established practices. 2. Coordination through monitoring of the leader; follow the attention foci of team leaders, help or material provided without explicit solicitation. 3. Coordination through anticipation; provide unsolicited assistance through anticipation of team leader's response to patient's physiological events (e.g. gagging sound > offer a suctioning catheter). Prerequisite is the ability to understand the significance of patient events. 4. Coordination through activity monitoring; monitoring gives lead information to prepare for next steps, team members infer what needs to be done from other's activities. Explicit verbal communication regarding situational assessment and future plans were rare. However, when such information flow was detected the team seemed to be at a decision point (e.g. when a patient was still not paralyzed 90s after injection of drugs > provide assessment of patient's condition and possible reasons without request).

							Coordination breakdowns are described in four forms: 1. Conflicting plans 2. Inadequate support in crisis situations 3. Inadequate verbalization of problems - when team coordination broke down, it often occurred when there was a lack of explicit communication. 4. Lack of task delegation **Study 2:** Most of uncertain items related to team activities and the organization as a whole - possibility to improve performance by better intrateam communication (e.g. standardization, checklists). Lack of standard operating procedures. Lack of communication among team members and the personnel working in different departments - reduce it by e.g. explicitly informing other members of one's intention and plans.
Zala-Mezo, et al. [43]	F	Self-developed observational categories based on Serfaty, et al. [54] *- Provide unsolicited information* *- Offer help* *- Provide unsolicited help*	Self-developed observational categories Serfaty, et al. [54] *- Provide information* *- Request information* *- Provide information on request*	-	-	Task load *(high, low)* Standardization *(low, moderate, high)*	**H1:** In highly standardized work phases, more implicit coordination (…) is expected compared with low standardization phases. ✓ (Pearson chi-square 17.05, $p < .001$) **H2:** In high-task-load situations, more implicit coordination (…) is expected compared with low-task-load phases. ✗ (n.s.)
Stachowski, et al. [55]	S	Anticipation ratio (however, used as an indicator of team effectiveness / performance) *	-	Team effectiveness (via anticipation ratio)** Unit supervisor's performance ratings based on 21 gradations (not further specified)			No specific hypotheses. Research question: Do average- versus high-performing teams differ on the basis of the nature of their interaction patterns? ✗ No difference in total behaviors between average ($M = 33.75$, $SD = 2.92$) and high-performing teams ($M = 39.60$, $SD = 10.36$), $t = 1.54$, $p = .15$. ✗ No differences in terms of how frequently teams provided information (average performing teams: $M = 17.89$, $SD = 5.46$, high-performing teams : $M = 20.80$, $SD = 4.21$, $t = -1.12$, $p = .29$), provided summary/recap (average performing teams: $M = 1.11$, $SD = 0.60$, high-performing teams : $M = 1.00$, SD

							= 0.71, t = -0.31, p = .76), provided feedback (average performing teams: M = 0.67, SD = 1.00, high-performing teams : M = 1.00, SD = 1.22, t = 0.51, p = .63), offers opinion (average performing teams: M = 0.67, SD = 0.71, high-performing teams : M = 0.40, SD = 0.55, t = -0.90, p = .39), or requests information (average performing teams: M = 0.44, SD = 0.73, high-performing teams : M = 0.60, SD = 0.89, t = 0.33, p = .75) X No relationship between anticipation ratio and average crew tenure (r = .16) and average tenure as a nuclear power plant control room operator (r = .27). ✓ Significant relationship between anticipation ratio and unit supervisor's performance ratings (r = .65, p < .05).
Shah and Breazeal [31]	L	Self-developed observational categories: Verbal: Anticipatory offering of information to a teammate - *Cue future action with implicit getter* - *Offer info on possible actions* Status updates - *Subtask completed* - *Subtask started* - *Subtask in progress* Efficient use of idle time - *Dynamic redistribution of workload* Non-verbal: - *finger point*	Self-developed observational categories: Verbal: - *Attempts to control teammates' actions (explicit command for future action (what to do, with what, where),* - *Prompts or requests for information (subtasks completed, started or in progress* Non-verbal: - *Not applicable*	Team effectiveness - *Time to complete building four structures in a synthetic task*	- Speed of response to each explicit and implicit communication - Specificity of each communication - Idle time (cumulative amount of time i.e. the teammate spent watching the actions of the other while not holding a building block)	Time pressure: *Stress vs. control group*	**H1a:** Teams exhibit increased use of implicit coordination behaviors as time pressure increases ✓ (Implicit communication control group teams: ø 4.5 (±0.1); stress group teams ø 7.6 (±0.1); df = 28, t = 3.64, p < .05). **H1b**: Increased use of implicit coordination behaviors (number implicit ÷ total number of communications in the trial) is positively correlated with improved team performance outcomes (team effectiveness) ✓ (In stress group teams: r = .78 ± .06), control group teams: r = .44 ± .04. ✓ (Decreased idle time (i.e., more efficient use of low-workload periods) with improved team effectiveness in both the stress and control group teams (r = .92 ± .03 and r = .90 ± .04) **H2**: **Speed of response.** Teammates exhibit *varying speeds* of response to communications depending on communication type, including implicit, explicit, verbal, and nonverbal cues. Nearly *all explicit communications will elicit an immediate response*. *Implicit communications* (including verbal and

							nonverbal cues) will elicit a *flexible-time response more often* than will explicit communications. ✓ (immediate response with next action: 80% of implicit communications, 99% of explicit communications; χ^2 = 15.95, *df* = 4, *p* < .005) χ (no difference between stress and control group; implicit behaviors: χ^2 = 0.02, *df* = 4, *p* > .05 Explicit behaviors: χ^2 = 0.03, *df* = 4, *p* > .05) χ (no difference between modes of communications: verbal, nonverbal, combined; ranges for pairwise comparisons, χ^2 = 0.02 – 2.68, *df* = 4, *p* < .005) **H3: Specificity.** The specificity of communications, measured by the number of possible actions to which each implicit, explicit, verbal, or nonverbal cue may refer, is dependent on communication type. Specifically, nearly all *explicit communications refer to one specific* action. I*mplicit communications refer to one specific action less often* than explicit communications. ✓ (53% of verbal and combined communications were specific, 100% of nonverbal-only implicit behaviors were specific. 90% of verbal and combined explicit communications were specific; ranges for pairwise comparisons, χ^2 = 4.37– 54.58, *df* = 4, *p* < .05) χ (no difference between stress and control groups; ranges for pairwise comparisons, χ^2 = 1.29 – 2.11, *df* = 4, *p* < .005)

Grote, et al. [33]	S/L	Self-developed observational categories: - *Provide unsolicited information* - *Offering assistance* - *Silence* - *Chatting*	Self-developed observational categories: - *Provide information* - *Request information* - *Request help* - *Provide information upon request* - *Reassurance* - *Discussion* - *Summary* - *Standard communication* - *Leadership is regarded as explicit coordination including:* - *Make plans* - *Assign task* - *Give or order* - *Make decision* - *Initiate action* - *Accept decision or initiated action*	Performance index (1 = very poor, 10 = excellent) based on: - *Instructor rating of crew performance (6-point scale; (1 = very poor, 6 = very good),* - *Correct execution of four compulsory tasks (rating from 1 - 4),*	-	Task load (T) *(low, high)* Standardization (S) *(low, high)* Work phases *1 T high, S low* *2 T low, S low* *3 T high, S low*	**H1:** In work phases with high **task load**, More implicit coordination (…) is found compared to low task load work phases ✓ (χ^2 (1, n = 2269) = 9.25, p < 0.01) ✗ Based on the relative frequencies of the different coordination mechanisms in the three work phases per crew: t(1,23) = -0.93, p > .05) **H2:** In work phases with high **standardization**, more implicit coordination (…) is found compared to low standardization work phases ✓ (χ^2 (1, n = 4354) = 82.46, p < .001) ✓ Based on the relative frequencies of the different coordination mechanisms in the three work phases per crew: t(1,23) = 5.22, p < .001) **H3:** The differential uses of coordination mechanisms as specified under (1) and (2) are linked to better performance ✗ (implicit coordination; r = -.39, p < .05) ✗ (implicit coordination; no significant work phase specific results)
Blickensderfer, et al. [56]		Relative position (the degree to which teammates adjust and adapt their positioning with respect to each other's positioning during team performance and maintain positioning half a court apart) on 4-point scale rating each point in the match; 1 = partner tends not to respond to the other partner's motion), 4 = immediate response to partner's repositioning, half a court apart	-	-	Task experience *Amount of coaching received in tennis doubles, 3 items; 5-point scale from 1 (little or none) to 5 (extensive lessons)* Team familiarity *4 items, 5-point scale from 1 (low) to 5 (high)* Shared expectations *Likelihood of various teammate responses if their team was faced with the respective scenarios; 5-point scale from 1 (unlikely) to 5 (highly likely)*	-	**H1:** The greater the **task experience** and **team familiarity**, the more similar teammates' **shared expectations** would be regarding their teams' responses to match situations. ✓ (R^2 = .21, F (2, 70) = 8.95, p <.01 ; Step 1: Task experience: β = .29, p < .05 Step 2: Team familiarity: β = .25, p < .05) **H2:** The more similar the **teammates' expectations** (i.e., the greater the shared knowledge), the greater the likelihood that the team would use **implicit communication**. ✓ (R^2 = .36, F (2, 70) = 8.95, p <.01; Step 1: Task experience: β = .26, p < .05 Team familiarity β = .25, p < .05 Step 2: Shared knowledge: β = .26, p < .05)

Badke-Schaub, et al. [63]	C	Frequency of *process* utterances - *Planning* - *Procedure* - *Reflection*	-	-	-	-	**H2:** Once **explicit coordination** has led to a shared mental model about how and when to do what, **implicit coordination** can occur. The frequency of process utterances should therefore decrease over time. ✓ (sign. decrease from 1st to 2nd meeting, no statistics reported)
St Pierre, et al. [47]	S/L	Categories adapted based on Grote, et al. [41]: - *Offers unsolicited information* - *Offers unsolicited assistance* - *Performs unsolicited supportive actions* - *Silence (and unsolicited support actions)*	Categories adapted based on Grote, et al. [41]: - *Makes orders* - *Standard communication (readback etc., confirmation of information and orders, phone calls)* - *Offers information* - *Offers information on request* - *Summarizes the current status* - *Calms, confirms, thanks* - *Ask for information* - *Request help* - *Discusses problem* - *Answers questions*	-	-	Briefing vs. control group	✗ Both groups showed no difference in the frequency of implicit vs. explicit coordination patterns (with briefing: explicitly 71%, implicit 29% without briefing: explicit 82%, implicit 18%)

Riethmuller, et al. [78]	S	Proportion of coded time for explicit and implicit coordination based on Kolbe and Boos [65]: Coordination of information - *Listening* - *Obtaining unsolicited task-relevant information* - *Providing unsolicited task-relevant information* Coordination of action - *Monitoring* - *Offers of assistance* - *Indications of satisfaction with fulfilment of task* - *Providing unsolicited task-relevant action* - *Declaring own needs*	Proportion of coded time for explicit and implicit coordination based on Kolbe and Boos [65]: Coordination of information - *Request for information* - *Providing information upon request* - *Assure information* - *Acknowledgement* - *Summary* - *Questioning information* Coordination of action - *Giving orders* - *Assigning tasks* - *Making plans* - *Decisions* - *Initiating actions* - *Providing actions upon request* - *Questioning decision* - *Assuring questions* - *Planning and procedural questions* - *Approval*	-	-	Routine phase (*patient care, standard anaesthetization*) vs. complication phase (*simulated crisis, sudden high-risk complication*)	**H1:** The more **routine phases** a team experiences together, the more implicit coordination occurs in the routine phase, meaning that the amount of explicit vs. implicit coordination shows a progressive negative correlation. ✓ (relative decreased duration of explicit coordination: $F_{lin}(1, 5) = 15.75$, $p < .05$, $Eta_p^2 = .76$), and relative increased duration of implicit coordination: ($F_{lin}(1, 5) = 14.64$, $p < .05$, $Eta_p^2 = 0.745$) in routine phases **H2:** The more **complication phases** a team experiences together, the more explicit coordination occurs in the complication phase, meaning that the amount of implicit vs. explicit coordination shows a progressive negative correlation. ✗ (No effect of the number of scenarios in the complication phases, neither for duration of explicit coordination: ($F_{li}(1, 5) = 1.56$, $p > .05$, $Eta_p^2 = .24$) nor for duration of implicit coordination: ($F_{lin}(1, 5) = 1.73$, $p > .05$, $Eta_p^2 = .26$). **H3 (Development of adaptivity of coordination)**: The **difference between explicit coordination** in routine vs. complication phases should decrease with the number of scenarios, while the **difference between implicit coordination** in routine vs. complication should increase ✓ (Effect of scenarios linearly influencing the difference of explicit coordination: ($F_{lin}(1, 5) = 15.05$, $p < .05$, $Eta_p^2 = 0.75$), which progressively decreased; and implicit coordination ($F_{lin}(1, 5) = 10.553$, $p < .05$, $Eta_p^2 = 0.68$), which progressively increased with accumulated scenarios.

Zheng, et al. [59]	L	Number of anticipatory movements *Scissors movement before the completion of thread holding*	-	Total task time *Time from lifting of the grasper off the start plate until cutting of the thread* Grasper time *Time from lifting of the grasper off the start plate until the jaws were firmly closed around the thread* Scissors time *Time the thread was held to the time the thread was cut*	-	Dyad group (*surgeon and assistant*) vs. single operator group (*bimanual performance with one hand on the grasper and the other hand on the scissor*)	**H1:** The overall **performance of a dyad team** would be superior to that of a single operator because anticipatory movement performed by the second team member would shorten the total task time. ✓ (Dyad team vs. bimanual performance by a single operator: Shorter durations of total task time for dyad team (12.1 ± 10.0 s vs. 18.3 ± 12.8 s, $p = .04$) and higher frequency of anticipatory movements (96% vs. 45%., $p < .001$) **H2: Anticipatory movement is observed more frequently in the later trials** than in the early trials because when practicing in a dyad team, team members would develop strategies for sharing information and mutual support ✗ (no effects of practice for any temporal variables (total task time, $p = 0.12$; grasper time, $p = 0.19$; scissors time, $p = 0.16$), nor were there significant group by practice interactions.
Methodology: Interviews							
Gjeraa, et al. [48]	F	-	-	-		-	Implicit information coordination takes place when team members are constantly informed about the situation or provide unsolicited updates. Implicit action coordination takes place when team members support or facilitate the efforts of others and when team members assess each other's capabilities during the process as part of risk management. Explicit information coordination takes place as part of problem solving in the team when challenges or problems are discussed between team members. Explicit action coordination takes place both preoperatively as part of the routine planning of the operation and during the operation, when suggestions from team members serve as important information in the joint problem-solving process.

Kolbe and Boos [65]	F	-	-	-	-	-	The temporal structure of coordination activities spans not only the actual group decision-making process but extends to the phase prior to group interaction. The experts prepare the meetings by negotiating their role and delivering written notes and schedules. They use implicit (e.g. eye contact) as well as explicit (e.g. summaries of what has been communicated) coordination mechanisms. The variety of coordination mechanisms that the experts reported in our study can be categorized by the taxonomy of coordination modes proposed by WITTENBAUM et al. (1998). The results suggest a significant extension of the conceptualization of explicit vs. implicit coordination. As postulated by ESPINOSA et al., the purposeful use of mechanisms is a defining characteristic of explicitness. However, our findings suggest that implicit coordination mechanisms can also be used purposefully. For instance, using eye contact instead of explicitly asking somebody to do something was reported as a face-saving and unobtrusive way of giving orders. Thus, the presence of a coordination intention might not be considered as the differentiating feature of explicit versus implicit coordination. [64]
Manser, et al. [45]	F	Information Management - Process information transfer - *Information request* - *Giving information without request (e.g. update)* - Team member information - *Request team member information* - *Give team member information* Task management - Assistance - *Verbal request for assistance* - *Non-verbal request for assistance*					No explicitly stated hypotheses regarding implicit coordination. Different coordination patterns would be observed in response to varying task requirements: a) during different phases of a cardiac anaesthesia case *Phase 1 from the time the patient is brought into the operating room until surgical incision;* *Phase 2 from surgical incision until heparin is administered to the patient for the purpose of anticoagulation during the cardiac procedure itself;* *Phase 3: from heparin administration until the beginning of the surgical wound*

		- *Offering (verbally)* - *Offering (non-verbally)* Coordination via work environment - *Coordination via artifacts (e.g. TEE, monitor)* - *Coordination by monitoring other crew members* - *Coordination by monitoring surgical team* * Behavioral codes not explicitly categorized into implicit and explicit coordination.					*closure;* *Phase 4 from the beginning of closing the surgical wound until the patient is transferred to the intensive care unit)* b) Depending on the type of procedure *Coronary artery bypass with cardiopulmonary bypass – the heart-lung machine (CPB) or – or without cardiopulmonary bypass (NOCPB)* An increase in coordination activity during segments of the case was hypothesized when the surgical and the anesthetic task are tightly coupled. Specifically: a) an increase in coordination activity will be observed during the surgical phase including coronary artery bypass grafting b) this increase will be stronger during coronary artery bypass grafting procedures on the beating heart; c) different patterns in clinical and coordination activities will be found for the anaesthesia resident vs. the anaesthesia attending due to their different work roles. During critical episodes that pose high coordination demands on the whole team, monitoring of other team members' activities was the prevalent coordination mechanism, even though there was a slight increase in more explicit coordination behaviours such as situation assessment, planning and decision making. Implicit coordination behaviour was the main coordination mechanism employed during periods requiring increased coordination in NOCPB cases (e.g. the actual coronary artery bypass grafting). Aanaesthesia attendings showed this coordination behaviour more than anaesthesia residents

Note. * Study design: F = Field study; S = simulation study; C = case study; L = Laboratory study.

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4.2 Article 2: Moving from explicit to implicit coordination in acute care teams: the role of verbal communication and coordination requirements

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Moving from Explicit to Implicit Coordination in Acute Care Teams:

The Role of Verbal Communication and Coordination Requirements

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Abstract

Implicit coordination is considered a particularly efficient form of coordination (e.g., Rico et al., 2008). Although the reduced need for, or even absence of, verbal communication is part of the most common definitions (e.g., Entin & Serfaty, 1999), this has not been systematically studied in detail. The assumption that verbal communication decreases in groups repeatedly coordinating the same task was investigated by examining the change in various quantitative (e.g., number of words) and qualitative communication indicators (e.g., ambiguity of communication) considering different task demands (loose vs. tight coordination). We analyzed simulation videos of 35 ad hoc teams working in groups of three to perform cardiopulmonary resuscitation of two consecutive cardiac arrest patients. Results showed a decrease in the amount of communication related to the different communication indicators with repeated performance of the task both within and between different contexts, suggesting a transfer effect of implicitness. Further, the decrease in word count could be explained by a decrease in the amount of information communicated (i.e., communication units) and a decrease in the number of words per communication unit (i.e., due to grounding/chunking processes). Greater implicit coordination was further characterized by increasing communication ambiguity. Again, a carry-over effect could be confirmed. Finally, subtasks with tight coordination requirements were more explicitly coordinated than subtasks with loose coordination requirements. We conclude that when examining implicit coordination, qualitative changes in communication and task demands must be considered in addition to quantitative changes.

Keywords: Implicit coordination, explicit coordination, grounding, verbal communication, team training, team coordination, high-fidelity simulation

Introduction

Groups and teams need to cooperate smoothly and efficiently, particularly if they are under high time pressure – examples are medical teams that have to treat a patient suffering a cardiac arrest. One often discussed aspect of team coordination is implicit or explicit coordination, with implicit coordination believed to be particularly efficient (Rico et al., 2008; Wittenbaum et al., 2002). Whereas explicit coordination is characterized by verbally communicated instructions, plans, requests for information, common definitions of implicit coordination include the reduced need or even the absence of verbal communication (Entin & Serfaty, 1999; Kolbe et al., 2013; Rico et al., 2008). A reduction of verbal communication is believed to be possible because during previous collaborations, groups build a shared understanding of the task, strategies, and the team processes. This common knowledge helps team members to anticipate next steps (Entin & Serfaty, 1999; Mohammed & Dumville, 2001; Rico et al., 2008), and allows them to adapt their actions to the requirements of the task and the needs of other team members without explicit coordination activities, and thus, without verbal communication.

Previous research has investigated differences in implicit and explicit coordination with regard to facilitating aspects such as team or task familiarity (Blickensderfer et al., 2010; Riethmüller et al., 2012, team level knowledge structures (e.g., shared mental models, SMM), (Fisher et al., 2012; Stout et al., 1999), or task characteristics (e.g., standardized or routine versus novel or complex tasks) (Burtscher et al., 2011; Grote et al., 2010) but also as result of team training (Cannon-Bowers et al., 1998; Entin & Serfaty, 1999; Serfaty et al., 1998; Volpe et al., 1996). Although it is widely assumed that the shift from more explicit to more implicit coordination happens over time, the process related to the development from explicit to implicit coordination is not widely investigated. Only a handful of studies have investigated if and how communication within groups changes over time (Badke-Schaub et al., 2011; Entin & Serfaty, 1999;

Riethmuller et al., 2012). However, in many of those studies, either group composition or the tasks to be coordinated were not held constant, which limits the comparison. Thus, a gap in previous research is that one of the main definitory aspects of implicit coordination, the reduction of verbal communication, was not very systematically investigated.

The shift from explicit to more implicit communication is gradual, and explicit and implicit coordination often coexist. The contention that groups coordinate over time using less verbal communication does not explain how this process unfolds. On the one hand, groups could coordinate simply with fewer words, or they could coordinate with exchanging less information. Those are similar, but not the same concepts. On the other hand, linguistic studies showed that during repeated interactions, groups change their way of communicating in that they chunk information into smaller units and thus using fewer words per unit of information exchanged. A known example is the grounding mechanism (Bangerter & Clark, 2003; Clark & Brennan, 1991) describing that interaction partners develop idiosyncratic communication habits and can communicate the same information in a denser way. While grounding allows to coordinate with fewer words, interpreting the resulting communication is dependent on having participated in the grounding process; this implies that coordination activities become more ambiguous for non-group members. We assume that both processes - less information exchange and denser/more ambiguous communication - play a role in the process of moving from more explicit to more implicit coordination for groups that repeatedly perform the same task.

In addition to the general process of groups moving from more explicit to more implicit coordination, two additional aspects are interesting. The first is to investigate whether all aspects of a given task follow the same development from explicit to implicit coordination over time. We contend that task coordination requirements may moderate this process, in the sense that subtasks with tight coordination requirements will (longer) be explicitly coordinated than subtasks with loose coordination requirement. In a similar way, changes in context may partially interrupt the process towards more implicit coordination.

The current study refers to medical teams that treat patients suffering a sudden cardiac arrest in a simulator setting, i.e., they perform advanced cardiopulmonary resuscitation. To study the process towards more implicit coordination, we analyze defibrillation, a central, complex task within cardiopulmonary resuscitation. In a nutshell, defibrillation consists of using a defibrillator to administer an electric shock to the heart in order to restore a normal heartbeat. During cardiopulmonary resuscitation, defibrillation is often repeatedly done, and collaboration requirements for all steps or subtasks of defibrillation are defined. In the simulation setting, all groups had to treat two patients sequentially, this is, they performed the same task in two different scenarios, which provide the context. This is an ideal setting to investigate the research questions.

In the following, we draw on theories of explicit and implicit or tacit team coordination and present the operationalizations used in previous research; we also discuss why the main definitory aspect, the amount of verbal communication, has not been studied yet over time. We then explain the reasons behind the operationalizations used in this study, and introduce the potential moderating variables related to coordination requirements and task execution in a different context. Lastly, we present our hypotheses.

Theoretical background

Explicit and implicit team coordination.

Groups have to coordinate their processes in order to achieve their goals, and better coordination is related to higher team performance (McGrath, 1991). Wittenbaum and colleagues (2002) classified group coordination activities on an axis of time and an axis of explicitness. The time axis indicates whether coordination is done before task execution (e.g., pre-planning) or while the task is executed (in-process coordination); the explicitness axis indicates whether the coordination happens implicitly (tacit coordination) or explicitly, described as "… based on verbal agreements or formally adopted plans" (Wittenbaum et al., 2002, p.17).

Scholars in small group and team research describe *explicit* coordination as directive, deliberate and unambiguous (Espinosa et al., 2004; Godart et al., 2001; Khan et al., 2010; Lowry et al., 2013; Rico et al., 2008). An important aspect of explicit coordination is that it is done verbally: Teams may express the problem at stake, discuss strategies for performing the task and assign task responsibilities, ask for information and respond to commands, etc. (Espinosa et al., 2002; Khan et al., 2010; Rico et al., 2008; Serfaty & Kleinman, 1990; Shah & Breazeal, 2010). *Implicit* coordination is not easy to define, because the main feature of 'implicit' is something that is not explicitly expressed and therefore cannot be assessed directly but must be inferred. Common dictionary definitions for implicit emphasize this aspect, stating "suggested, but not communicated directly" (Cambridge Dictionary[2]); "implied, rather than expressly stated" (dictionary.com[3]), "… expressed in an indirect way" (Collins Dictionary[4]).

2 https://dictionary.cambridge.org/dictionary/english/implicit

[3] https://www.dictionary.com/browse/implicit
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In group and team research, implicit coordination is typically defined as coordinated action based on shared knowledge or on a common script (Cannon-Bowers & Bowers, 2006; Eccles & Tenenbaum, 2007; Espinosa et al., 2007; Hoeft, 2006; Kleinman & Serfaty, 1989; Langan-Fox et al., 2000; Marks et al., 2002; Mohammed & Dumville, 2001; Poizat et al., 2009; Stout et al., 1999). It is the shared knowledge acquired before or during collaboration that allows team members to know or to extrapolate what (should) happen next, to anticipate task demands and the actions and needs of their teammates, and to adapt their own behavior (Converse et al., 1991; Fernandez et al., 2008; Rico et al., 2019).

Anticipation in turn allows coordinated action without, or with reduced, verbal communication (Entin & Serfaty, 1999; Espinosa et al., 2004; Rico et al., 2008; Serfaty, Entin, & Deckert, 1993; Serfaty et al., 1998; Serfaty, Entin, & Volpe, 1993; Wittenbaum, 1996; Wittenbaum et al., 2002). Indeed, a key defining factor of implicit coordination is the reduced need or even the absence of verbal communication, implying coordination of team activities "... without having to communicate directly with each other or plan the activity"(Rico et al., 2008, p.164); (Converse et al., 1991; Entin & Serfaty, 1999; Espinosa et al., 2004; Mohammed et al., 2017; Rico et al., 2008; Serfaty, Entin, & Deckert, 1993; Serfaty et al., 1998; Serfaty, Entin, & Volpe, 1993; Wittenbaum, 1996; Wittenbaum et al., 2002).

However, it seems that in most groups and for most tasks, explicit and implicit coordination coexist (Rico et al., 2019). Even for tasks with high standardization, which are typically coordinated more implicitly, explicit coordination constituted about 60% of coordinative action observed (Zala-Mezo et al., 2009). In a study investigating effects of pre-briefing on implicit coordination, around 70% of coordination remained explicit (St Pierre et al., 2016), with no significant difference between conditions. A study measuring coordination in terms the proportion of coded time related to implicit or explicit coordination found that explicit coordination decreased from 37% to 17% over four tasks in routine phases but increased from 22% to 30% in complex phases (Riethmuller et al., 2012).

All studies cited implicitly assumed that if groups repeatedly perform a task, a shift from more explicit to more implict coordination happens, this is the amount of verbal communication decreases.

Communication frequency and implicit coordination

If implicit coordination in groups is assessed via self-report (questionnaires or interviews), questions about the amount or decrease of communication exchanged are often used to operationalize the degree of implicitness (Fisher et al., 2012; Gjeraa et al., 2017; Kolbe & Boos, 2009; Leedom & Simon, 1995; Quintal, 2016). However, self-reports of frequencies are often unreliable (Schwarz & Oyserman, 2001), and in observational studies this basic, but important aspect is only rarely measured. Often used operationalizations of implicit coordination in observational studies focus on other indicators. For example, one of the most often used indicators is *anticipatory behavior*, such as to inform or to act without being asked to. Examples are providing or volunteering unsolicited information (Chen et al., 2010; Fisher et al., 2012; Marques-Quinteiro et al., 2013; Riethmuller et al., 2012). Some studies report or compare frequencies (Cannon-Bowers et al., 1998; Grote et al., 2010; St Pierre et al., 2016; Stout et al., 1999; Zala-Mezo et al., 2009) or relative frequencies of anticipatory behaviors (Grote et al., 2004). A more specific indicator is the *anticipation ratio.* Defined as the amount of information provided divided by the amount of information requested, it measures the proportion of unsolicited information transfer. The anticipation ratio was developed by Serfaty, Entin and Volpe (1993) for a simulation task where hierarchically structured teams had to integrate information to identify air targets, a task where a) information exchange was a key task requirement and b) the team members could rapidly learn which type of information had to be sent to whom. The anticipation ratio was used in many other studies (Butchibabu et al., 2016; Entin et al., 1993; Entin & Serfaty, 1999; Serfaty et al., 1998; Stachowski et al., 2009), all using tasks where information exchange was a key task requirement. *Anticipatory action-related* indicators assume that group members act based on their knowledge of task and coordination needs, and implicit coordination is assumed if a team member acts without being asked to. More generic anticipatory action categories are offering assistance, providing unsolicited task-relevant actions and monitoring each other's behavior (Kolbe et al., 2013; Riethmuller et al., 2012). Some research also investigated task-specific anticipatory movements (i.e. starting to move the scissors before cutting is needed in a surgical task) (Zheng et al., 2007).

Besides anticipatory communication and actions, researchers coded *providing spontaneous information* related to the advancement of the task or to a group member's own progression as implicit coordination. For example, Kolbe et al. (2014) used talking to the room, a spontaneous sensemaking verbal update which is not directed at a specific group member but addressed to the whole group (Tschan et al., 2009; Waller & Utitdewilligen, 2008), as well as *unsolicited updates* related to the own actions of a group member as implicit coordination.

Although all these operationalizations conform to the theories of implicit coordination, the main definitory aspect, the amount of communication itself, was rarely measured: Entin and Serfaty (1999) assessed the total communication rate - but found it to be too strongly influenced by task demands to be interpreted. Grote and colleagues (2003; 2004) coded silence as implicit coordination, provided that a task coordination could be observed while the team was silent. The dearth of observational research investigating the amount of communication is most likely due to an important limitation for the use of this indicator: the task (Kerr, 2017; Tschan & Cranach, 1996). It is evident that task requirements and task load influence how much a team communicates (Kerr, 2017), independent of the (non)-existence of a shared mental model. Thus, if the task cannot be held constant in a research design, the amount of communication is not a reliable indicator of implicit coordination. Indeed, previous studies compared tasks that differed in complexity and workload, for example routine versus non-routine tasks (Grote et al., 2010; Kolbe et al., 2014; Zala-Mezo et al., 2009). In studies that used the same type of task, workload differed across trials (Entin & Serfaty, 1999; Riethmuller et al., 2012), and in a study that measured communication across the progression of design meetings, teams were confronted with changes in membership as well as with emerging problems, and thus new tasks, in the second meeting (Badke-Schaub et al., 2011). Interestingly, in a linguistic study Isaacs and Clark (1987) held the tasks constant. They asked pairs of participants that did not share the same visual field to verbally identify the same pictures repeatedly. They found that the participants used fewer words to identify the same picture across subsequent trials. The largest decrease in words was between the first and second trial, with, no substantial decrease after the fourth trial.

To hold the task constant, in the current study, the repeated execution of the very same task but across different contexts is investigated. We will discuss aspects of the specific task later.

Amount of verbal communication in subsequent task executions

How does the amount of verbal communication change over repeated coordination? We consider two concepts of amount of verbal communication – (1) the number of words and (2) the amount of information exchanged. Furthermore, two operationalizations relate to information chunking – (3) the number of words per information unit and (4) the degree of communication ambiguity; the indicators are explained below. In accordance with concepts of implicit coordination the general assumption is that the frequency of these indicators decreases while ambiguity increases if a group executes the same task repeatedly.

(1) The first and simplest indicator is *the number of words a group uses to coordinate a specific task.* At first glance, this indicator is easy to measure. However, as only communication related to the task can be counted, using this indicator requires to distinguish between task-relevant and task-irrelevant communication.

(2) Reduction of verbal communication can mean that groups coordinate a task with fewer words, but it can also mean that they coordinate with *exchanging less information*. This is not the same, because the same information can be communicated with more or fewer words: “oh, look at the monitor - this patient here most likely suffers a cardiac arrest, we need to defibrillate” vs. “patient has cardiac arrest, we need to defibrillate” vs “arrest, defibrillate”; they all provide the same information, albeit with a different number of words. A simple indicator of the amount of information exchanged is to count communication units. Communication units are defined as spoken sentences containing several words that represent a single thought; they are often syntax-based (Bales, 1950; Reed et al., 2018; Weldon et al., 1991). Communication units are often used for unitizing the stream of communication for later coding (Reed et al., 2018), but they constitute an approximation of the amount of information exchanged (see the method section).

(3) Besides a quantitative reduction of communication or information transfer, verbal communication may be reduced by using fewer words per communication unit, this is to communicate the same information with fewer words (Gersick & Hackman, 1990). Teams interacting repeatedly adapt the way they communicate with their teammates by phrasing messages based on acquired common knowledge, this is they build common ground (Clark & Wilkes-Gibbs, 1986). Studies in psycholinguistics have shown that people who repeatedly interact may replace longer

explanations by specific words that reference the common ground they have established (Bangerter & Clark, 2003; Clark & Brennan, 1991; Clark & Wilkes-Gibbs, 1986), a process called grounding. Often, only a single word can then serve as a cue to activate an action pattern that initially required much more communication. For example, the message "Please, go get and prepare the defibrillator, we need to defibrillate the patient, because she has a cardiac arrest" may be replaced in later interactions by the word "defi!", or even “again”, “burn”, or “electricity” which can trigger the corresponding action pattern (Zacher et al., 2016). This condensation of meaning into short communications while preserving the information transmitted is also known as chunking, which refers to the process of grouping individual pieces of information into smaller units (Miller, 1956).

Assessing simultaneously the number of communication units (information transferred) and the number of words per communication unit (grounding) when coordinating the same action over time thus allows to investigate the mechanisms related to implicit communication; particularly the question if more implicit coordination means that less information is exchanged or if grounding takes place or if both processes are involved.

(4) The ability to understand and coordinate based on shortened communication depends on having established a common ground or a shared mental model within a specific group (Clark & Brennan, 1991; Mohammed & Dumville, 2001). From this it follows that non-group members would have greater difficulty to correctly interpreting the communication of an experienced group, because interpreting “grounded” communication requires to infer the inherent, longer, message. The communication thus is ambiguous for people that did not participate in the grounding process. Thus, the *degree of ambiguity* of the communication related to the coordination of the task can be assessed and used as an indicator of implicit coordination.

The importance of task coordination requirements

We emphasized that investigating the amount of communication as an indicator of implicit coordination requires to hold the task constant. We also assume that with repeated execution, a team uses fewer communication over time to coordinate the same task. However, how much co-ordination (explicit or implicit) is necessary also depends on the coordination requirements of and within a given task.

Each task (e.g., providing advanced life support to a patient) can be divided into several subtasks (e.g., diagnosing cardiac arrest, cardiopulmonary resuscitation, defibrillation, medication), and subtasks can further be divided in sub-sub tasks (e.g. for the subtask defibrillation to charge the defibrillator, adjust energy etc.) (Annett, 2003; Tschan, Semmer, Vetterli, et al., 2011; Von Cranach et al., 1986; Zacher & Frese, 2018). Subtask are embedded in the main task. However, different subtasks may have different coordination requirements (Arthur Jr et al., 2012; Bowers et al., 2009). For task-performing teams this means that some coordination and communication behaviors may be efficient for one sub-task but inefficient for another (Tschan, Semmer, Hunziker, et al., 2011). Therefore, there is a risk of biased conclusions with regard to coordination if the requirements of the subtask are not sufficiently considered.

In this research we distinguish between subtasks requiring tight vs loose coordination. We speak of “loose” coordination if no precise synchronization within the team is required, and team members can rather independently work on different subtasks. An example is that one person gets the defibrillator whereas another prepares the patient. Explicit (verbal) in-process planning during task execution (Wittenbaum et al., 2002) may not be necessary. Tight-coordination subtasks, however, require moment-by-moment coordination within the team, and are highly interdependent, implicit coordination may not be efficient for such tasks (Wittenbaum et al., 2002).

We contend that the coordination requirements of subtasks may have to be taken into account when investigating coordination processes.

This study and hypotheses

The goal of this study is to investigate whether and how groups shift from more explicit to more implicit coordination over time. We evaluate the change of the four communication indicators described above in a study including groups of three fourth year medical students that have to perform a cardiopulmonary resuscitation of two consecutive patients suffering a cardiac arrest in a simulator setting. Within each resuscitation, they apply an electrical shock to the heart using a defibrillator at least two times (for more details about the task, see the method section). This study concentrates on the coordination of this defibrillation task. Because defibrillation is often repeated within a cardiopulmonary resuscitation and because each team treats two different patients, we can study the process of moving from explicit to implicit coordination within the same as well as between two different situations.

Hypothesis 1 states that ***teams reduce verbal communication*** for coordinating the same task repeatedly (Hypotheses 1a, c, e, and g). Because we have no hypotheses about the trajectory of this process, we will test linear and nonlinear changes. We also hypothesize that a team that repeats the same task in a new context, the process of moving from more to less communication can be observed again. Because the task is essentially the same, the team should profit from the first context and thus coordinate in a less explicit way than during the first task execution in the first context (Rico et al., 2019) (Hypotheses 1b, d, f, h). These hypotheses are tested with the different operationalizations of quantitative communication, i.e., the number of words, the percentage of subtasks coordinated without any verbal communication, the number of communication units, and the number of words per communication unit. We refer to the task (defibrillation) in the first context as t1 and in the second context as t2; the repeated execution of this task within the same context is referred to as episodes (e,*n*).

Hypothesis 1a: The *number of words* a team uses to coordinate the repeated execution of the same task (i.e., defibrillation) decreases in the course of task repetitions, with a more important decrease between the first and the second defibrillation episode (t1 e1; t1 e2).

Hypothesis 1b: When the same task is performed by the same team in a new context, teams use *fewer words* to coordinate the first execution in the new context (t2 e1), than for coordinating their very first execution of this task (t1 e1).

Hypothesis 1c: The percentage of subtasks that are coordinated *without any verbal communication* increases over task repetitions, with a more important increase between the first and the second defibrillation episode (t1 e1 and t1 e2).

Hypothesis 1d: When the same task is performed by the same team in a new context, teams coordinate the first execution in the new context (t2 e1) *with a higher percentage of subtasks without any verbal communication* than for the very first execution of the task (t1 e1).

Hypothesis 1e: The *number of communication units* (i.e., amount of information) a team uses to coordinate the repeated execution of the same task subsequently decreases over task repetitions, with a more important decrease between the first and the second task episode (t1 e1 vs t1 e2).

Hypothesis 1f: When the same task is performed by the same team in a new context, teams use *fewer communication units* to coordinate the first execution in the new context (t2 e1) than for coordinating the very first execution of this task (t1 e1).

Hypothesis 1g: The *number of words per communication unit* (i.e., chunking or grounding) a team uses to coordinate the repeated execution of the same task subsequently decreases over task repetitions, with a more important decrease between the first and the second episode.

Hypothesis 1h: When the same task is performed by the same team in a new context, teams use *fewer words per communication unit* to coordinate the first execution in the new context than for coordinating the very first execution of this task.

Decreased communication *quantity* as a function of less and denser communication.

As developed above, the number of words used to coordinate a team task, communication units and words per communication units are not different manifestations of the same process. Communication units are defined as a unit of meaning or information (see above); however, “meaning” can be communicated with more or fewer words (due to more or less referential communication due to a grounding process), resulting in fewer words per communication unit. In the shift to more implicit coordination, we assume that both processes simultaneously influence the amount of communication: Fewer communication units are necessary because less information is needed and less meaning has to be communicated, – and fewer words are needed per communication unit, due to a grounding process.

Hypothesis 2: The decrease in the number of words between successive task executions within the same context is influenced by both, a decrease of *communication units* as well as by a decrease in the *number of words per communication units*.

Change of communication *quality* across repeated task execution.

As outlined above, a grounding process implies that a team develops a more idiosyncratic use of language over time that is bound to the specific social system. Such communication is characterized by a higher density of meaning, and to understand it correctly, it requires more shared cognitions and experience (due to training and / or experience as a team). Such grounded communication is more ambiguous and less easy to interpret to people who do not share the team's background and experience in a particular situation. Corresponding to the hypotheses concerning quantitative aspects of communication, we formulate the following hypotheses for communication quality:

Hypothesis 3a: *Communication ambiguity* to coordinate the repeated execution of the same task subsequently increases over task repetitions, with a more important increase between the first and the second defibrillation episode.

Hypothesis 3b: When the same task is performed by the same team in a new context, a teams' *communications ambiguity* is higher when coordinating the first task execution in the new context (t2 e1) than for coordinating the very first execution of this task (t1 e1).

Changes in communication quantity and quality for subtasks with *loose* or *tight coordination requirements*.

As outlined above, specific requirements of subtasks may moderate the degree of implicit coordination. We postulate that for subtasks with loose coordination requirements, the shift from explicit to implicit coordination is more pronounced than for subtasks with tight coordination requirements. To test the hypothesis, we use the percentage of subtasks of the defibrillation task that are coordinated without any verbal communication as a quantitative indicator and communication ambiguity as a qualitative indicator.

Hypothesis 4a: We expect a higher increase in the *percentage of subtasks coordinated without any verbal communication* across time for subtasks with loose coordination requirements than for subtasks with tight coordination requirements.

Hypothesis 4b: We expect a higher increase in the *percentage of subtasks with communication ambiguity* across the defibrillation for subtasks with loose coordination requirements than for subtasks with tight coordination requirements.

Methods

Participants

The 35 groups of thee fourth-year medical students (105 students) were chosen from a total of 68 groups (204 students) from an experimental medical simulation study reported elsewhere (citation omitted for peer-review). Eligibility criteria for groups to be included were that groups repeated the task of interest (defibrillation) at least twice during each of the simulations (Task 1 and Task 2), used the manual defibrillator, and did not ask the confederate nurse to play an active role during defibrillations. In Task 1, 12 groups defibrillated three times, in Task 2, 27 groups defibrillated three times.

The students volunteered for the study; no compensation was given. However, they had the opportunity to participate in an extended expert-led debriefing and instruction after data collection. The assignment of students to groups for the initial study was done based on the students' scheduling possibilities. None of the students within the same group reported having worked with another group member on a medical task before. All students signed a written informed consent; the study was approved by the local ethics committee (#85/04).

Material

The study took place in the medical simulator centre located in the ICU (Intensive Care Unit) of a European University Hospital. The simulator room was equipped as a standard ICU room, a defibrillator was placed in a corner of the room. A full-sized, high fidelity patient simulator mannikin (Human Patient Simulator, METI, Sarasota, FL, USA) was used as male patient in both tasks; clothes of the patient were changed between the two simulations. The simulator mannikin has realistic features, such as palpable pulses at various sites, visible breathing movements, pupil reactions to light, and breath and heart sounds. Through a microphone in the adjacent control room, the mannikin can communicate by loudspeakers in his head. It can be defibrillated with any standard defibrillator and reacts in real time to medical interventions. The simulation sessions were observed through a one-way mirror in the control room and recorded using two cameras and several microphones.

Procedure

In the first simulation (Task 1), the teams were asked to attend to an unresponsive male patient; they had to diagnose a cardiac arrest and provide advanced cardiopulmonary resuscitation. Staying in the same team composition, in Task 2, the teams were asked to interview a second male patient who became unresponsive during the diagnostic patient interview. Again, this patient suffered a cardiac arrest, and the team also had to provide advanced live support (Task 2). During the simulation sessions, a confederate scripted nurse was present in the room and could be asked for help but did not act on own initiative. Task 1 and Task 2 were identical in that teams had to diagnose the cardiac arrest and then follow the resuscitation guidelines for adult advanced life support (Soar et al., 2015), albeit on a different patient with a different history. After Task 1, the teams were asked to engage in a three-minute self-lead post-action briefing session (citation omitted for peer review) with three different experimental conditions. Eight groups were asked to reflect about the resuscitation tasks, 15 groups were asked to reflect about teamwork and 12 groups were asked to reflect about both, the task and teamwork. Because the experimental conditions are not of interest in these secondary analyses, data were pooled across the different experimental conditions.

Target task: Defibrillation as central part of cardiopulmonary resuscitation

Cardiopulmonary resuscitation provided by medical professionals follows the algorithm for Advanced Live Support (ALS) (Soar et al., 2015). Typically, a central part of ALS is defibrillation, which is the application of an electrical shock to the patient's heart using a defibrillator; a specialized medical device, with the aim to restore a synchronized heartbeat.

We chose to analyze the task of defibrillation for this study for the following reasons. First, during ALS, patients often must be defibrillated multiple times, if the first defibrillation attempt is not successful, which allows for the study of coordination development for this task over time. Second, defibrillating a patient clearly requires coordination among the team. Third, subtasks of defibrillation can be easily identified, because the process is clearly described. For these reasons, defibrillation is a perfect real-life task to study the progression from explicit to implicit coordination.

We performed a simplified Hierarchical Task Analysis (HTA), originally developed by Annett (2004) and Shepherd (2001), based on action regulation theory (Frese & Zapf, 1994; Von Cranach et al., 1986; Zacher et al., 2016) to *identify defibrillation episodes, identify subtasks, and derive coordination requirements for each subtask* as a basis for coding and analyses. The HTA (**Figure 1**) describes a task as a hierarchical (goals and sub-goals) and sequential (temporal) structure of executable goals; for collaborative tasks we included coordination requirements, i.e. the extent to which direct coordination is needed to perform this task (Arthur Jr et al., 2012; Bowers et al., 2009). The HTA was established based on the European resuscitation guidelines for advanced life support (Soar et al., 2015). It describes a defibrillation episode as a sequence of four distinguishable task stages that must follow each other if performed correctly. First, the team must *diagnose* (1) whether defibrillation is appropriate for this patient and decide about whether or not to defibrillate the patient. Once the decision has been made, defibrillation must be *prepared (2)* (with the subtasks of getting the defibrillator, turning it on, opening the patient's shirt, attaching defibrillation electrodes to the patient's chest, adjusting the energy level for defibrillation, and charging the defibrillator). The third task stage consists of properly *executing the defibrillation* itself (with the subtasks of assuring safe shock delivery and delivering the electrical shock). Finally, after the shock has been delivered, the team must *control* the execution of the defibrillation (i.e., technical assessment of shock delivery, assessment of the effect of the defibrillation on the patient, and determination of next steps).

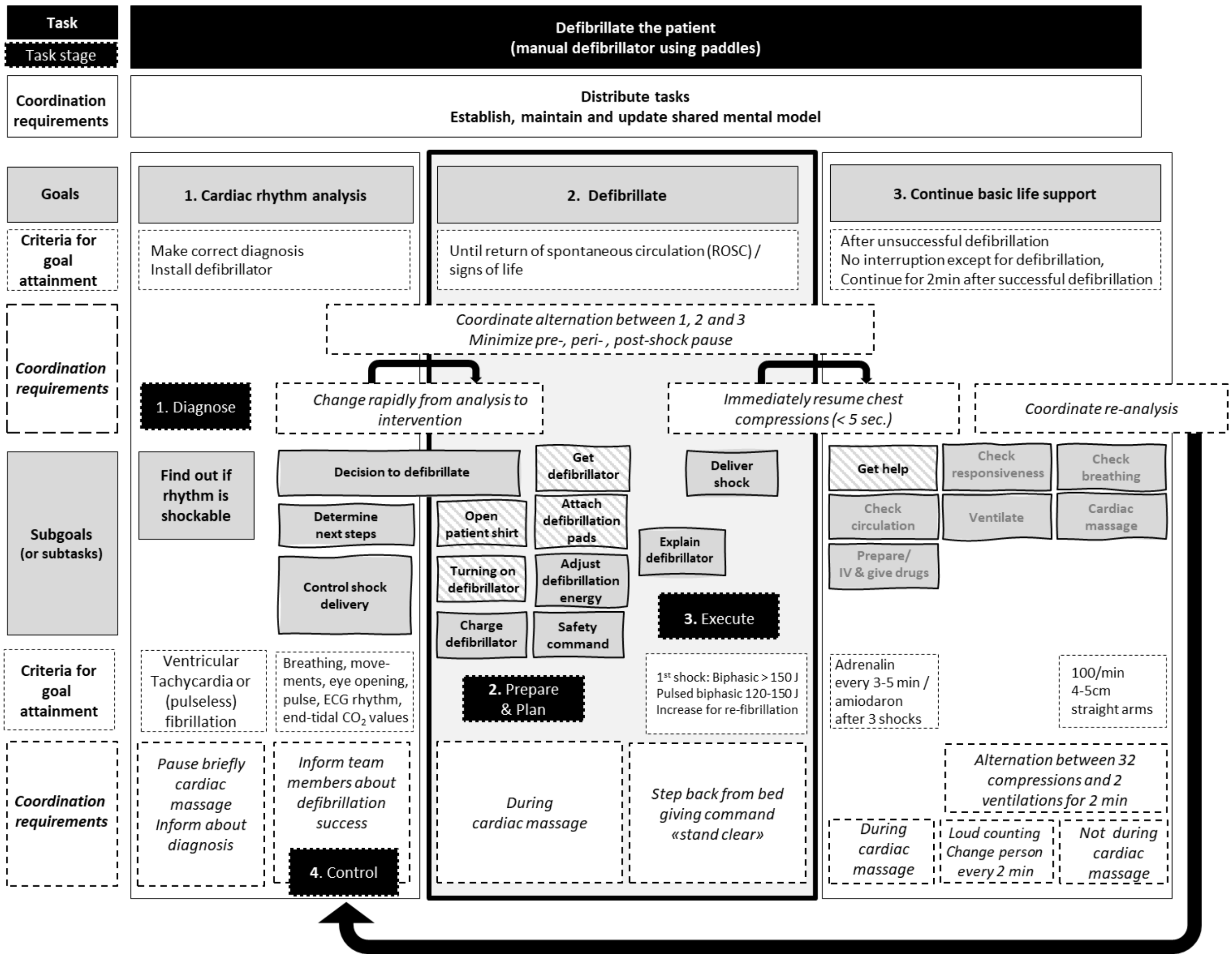


Figure 1: Simplified hierarchical task analysis for the defibrillation task, including coordination requirements. Subtasks to be performed only once are shaded. Subgoals related to resuscitation are grayed out. Sketched shape contour represents coding categories.

Measures

Data preparation

In this part, we explain how defibrillation episodes and subtasks within a defibrillation were identified and delimited, and we describe the different coding systems developed.

Identifying and delimiting defibrillation episodes. A defibrillation episode was defined as the time segment within which a team prepared, planned, executed, and controlled one single defibrillation. The start of a defibrillation episode was set if the team either verbally communicated the intention to defibrillate (e.g., "we need to defibrillate", "I am charging again") or gave a clear non-verbal signal indicating the intention to defibrillate (e.g., moving the defibrillation panels to the patient chest). The end of a defibrillation episode was set as the moment the team clearly ended the defibrillation episode (e.g., “do chest compressions!”, “it did not work”, “the patient has sinus rhythm") or moved to the next task. Defibrillation episodes were numbered within each Task as E1, E2, and E3, further defibrillations were not included. Aborted defibrillation attempts were not included. Note that within the time frame of a defibrillation episode, teams could also engage in tasks not related to defibrillation.

Identifying and coding of defibrillation subtask. Based on the resuscitation algorithm and the task analysis (Soar et al., 2015), a coding scheme to identify the subtasks of a defibrillation was developed. Based on the video-recordings, for each second within a defibrillation episode, it was coded whether at least one team member engaged in one of the following subtasks: a) getting the defibrillator (move the defibrillator towards the patient, plug in the defibrillator etc.), b) switch on the defibrillator (connect to current, press switch on button), c) open the patient shirt to free the chest), d) attach the defibrillation pads on the chest e) adjust or change the energy level (manipulate button related to adjusting joule level) (f) assure safe shock delivery (e.g. communicate warning verbally or non-verbally) (g) deliver the shock (press button on paddles/visible shock delivery on heart monitor) (e) control shock delivery (gaze to monitor); see **Table 1**.

Twenty-two percent of the material was independently coded by a second coder, inter-coder agreement was assessed using Cohen’s κ (Cohen, 1960); kappa values were between .63 (control shock delivery) and .97 (shock delivery), indicating moderate to excellent inter-observer agreement (Landis & Koch, 1977).

Repeated execution requirement: Recurrent (each time) and non-recurrent (once) subtasks. For repeated defibrillations of the same patient in the same environment using the same equipment, the subtasks “get the defibrillator”, “turning on the defibrillator”, “open patient shirt” and “attach defibrillation pads on patient chest” are subtasks that need to be performed *only once* in each simulation, whereas “adjust defibrillation energy level”, “charge defibrillator”, “assure safe shock delivery”, “deliver shock”, and “control shock delivery” have to be performed *for each defibrillation*.

Identifying coordination requirements of subtasks. For each defibrillation subtask we defined collaboration requirements in terms of loose or tight coordination (Manser et al., 2007). *Loose coordination requirements* were coded for subtasks that do not require all group members to focus on this task simultaneously; they may be carried out by a single team member, and other team members may focus their attention elsewhere or execute other tasks in parallel. *Tight coordination requirements* were assumed for subtasks requiring close spatial-temporal coordination between the actions of the team members so that they need to focus on the same subtask simultaneously. Only subtasks that have to be executed for every defibrillation were classified in this way. Subtasks with loose coordination requirement are “*decision to defibrillate”, “adjust energy level”, “charge defibrillator”,* and *”control shock delivery”*. Subtasks with tight coordination requirements are “*safety command (assure safe shock delivery)”* and *“shock delivery”*. The reason for the tight coordination requirement of these two subtasks is that if a person touches the patient (or bed) during shock delivery, the team member could get an electrical shock.

Table 1*: Overview of coding of communication, actions, repeated execution requirements and coordination requirements*

Communication codes	Subtask codes	Repeated execution requirement	Coordination requirements
Decision to defibrillate	Decision to defibrillate	Each time	Loose
Get help	Get help	Once	Na
Get the defibrillator	Get the defibrillator	Once	Na
Turning on the defibrillator	Turning on the defibrillator	Once	Na
Chest (open patient shirt)	Chest (open patient shirt)	Once	Na
Attach defibrillation pads on patient chest	Attach defibrillation pads on patient chest	Once	Na
Adjust defibrillation energy level	Adjust defibrillation energy level	Each time	Loose
Charge defibrillator	Charge defibrillator	Each time	Loose
Safety command (assure safe shock delivery)	Safety command (assure safe shock delivery)	Each time	Tight
Deliver shock	Deliver shock	Each time	Tight
Control shock delivery	Control shock delivery	Each time	Loose
Determine next steps		Na	Na
Explain defibrillator		Na	Na

Coding of verbal communication

All verbal communication during Task 1 and Task 2 was transcribed verbatim based on the recordings; filler words such as “ehm, err” were not transcribed. Communication was coded only within identified defibrillation episodes; coding was based on the video recording as well as the transcripts.

Unitizing. We unitized the stream of communication into communication units using the concept of a spoken sentence or spoken thought unit by a single person (e.g., Bales, 1950; Reed et al., 2018; Tschan, 1995) as a segment of communication related to a single topic (Bales, 1950). A communication unit is defined as a “sequence of a few words containing a single thought” and thus represents *one unit of meaning* (Weldon, Jehn, & Pradhan, 1991, p. 559). The starting time of each communication unit was noted in terms of time elapsed since the start of the simulation. We coded the speaker of each unit as student 1, 2 or 3 (numbering according to their entry into the simulation room), and confederate nurse.

Content coding of communication. *We coded each communication unit within a defibrillation episode with regard to the subtasks it referred to.*

Communication codes related to the defibrillation subtask. Communication codes relating to the defibrillation task were derived from the HTA described above and are similar to the codes used for subtask coding (see **Table 1**). The code *decision to defibrillate* was used if someone mentioned defibrillation or the defibrillator for the first time within a defibrillation episode as an option or decision to defibrillate (e.g., "we should defibrillate", "do we want to give another shock?"). However, "yes exactly, 5 cycles and then defibrillate" would not be coded as decision to defibrillate, because this communication is not about deciding whether to defibrillate but discusses the resuscitation algorithm. *Getting the defibrillator* included statements such as asking, "can you get the defibrillator?" or "bring it [defibrillator]here". If the decision to defibrillate was expressed with the command to get the defibrillator, double coding (decision to and get defibrillator) was applied. *Turning the defibrillator on* was coded for statements expressing that the defibrillator must be turned on or is turned on (e.g., "the defibrillator is switched on", or "turn it on"). The code *chest – open the patient shirt* was coded for communication related to open the patient's shirt to be able to position the defibrillation pads directly on the chest. *Attaching the defibrillation pads on patient chest (pads)* was coded for statements relating to the (correct) placement of the defibrillation pads. The code *adjust defibrillation energy level* was used for statements such as "How many joules?" or "360 joules". The code *charging the defibrillator* included statements related to charging or the charging state of the defibrillator. Examples are "I am charging", or "is it charged?". *Safety command (assure safe shock delivery)* was coded for statements such as "step back (from the bed)!", "caution!" indicating that emitting an electrical shock was imminent. *Deliver shock* could be either a commentary or an instruction to deliver the shock, for example "(…) press to shock now?" /"so, shock"/ "now¨!" or a general statement about the shock delivery while shocking (e.g., "good, shock". *Control effectiveness of shock delivery* was coded for communication relating to whether the shock was delivered or not (e.g., "yes, fired"). *Determine next steps* included statements related to how to proceed after shock delivery. This may also have included other resuscitation measures (e.g., "we will continue resuscitation" / "please resume cardiac massage immediately").

Two coders independently coded 22% of the material. Inter-rater agreement was calculated using Cohen's Kappa (Cohen, 1960). Values ranged between 0.64 (check shock effectiveness) and 0.95 (safety command), indicating substantial to excellent inter-observer agreement.

Communication not related to the defibrillation task. Communication codes not directly related to defibrillation were also derived from the resuscitation algorithm (Soar et al., 2015) and included *getting help, assessing responsiveness of the patient, checking breathing and signs of circulation, ventilating the patient, and chest compressions*. Interrater-reliability based on independent double coding of 22% of the material yielded Kappa values (Cohen, 1960) between 0.79 (check signs of circulation) and 0.96 (chest compressions), indicating substantial to excellent inter-observer agreement (Landis & Koch, 1977).

Coding of subtasks executed without verbal communication. Because subtasks could be executed without verbal communication, we identified for each subtask that was executed if it was accompanied by any verbal communication (1) or none (0).

Coding of communication ambiguity. Communication ambiguity, i.e., the degree to which "insider knowledge" was needed to interpret the communication (see **Table 2**) was coded for each defibrillation subtask; including all communication units that could serve to coordinate this subtask, that is, units communicated *before or during subtask execution* (Wittenbaum et al., 2002). For example, for the subtask "*turning on the defibrillator*" all related communication units up to the moment someone pressed the button on the defibrillator were included.

(2) Each communication unit related to a given subtask was then coded with *regard to communication ambiguity either as clear/specific or ambiguous/vague.* Examples for specific communication are “get the defibrillator”, “we need to defibrillate this patient”, or “we charge with 360 joules”.

Ambiguous/vague was coded if insider knowledge was needed to understand a statement. For example, “ventricular fibrillation” may substitute a clear statement such as “this patient has ventricular fibrillation, he needs to be defibrillated, therefore we need the defibrillator”, or the statement “clear” may substitute the safety statement “everybody, step away from the bed” before applying the shock. If a subtask was performed but there was no verbal communication, ambiguity was assumed.

Within each subtask, the total number of words for clear/specific communication units and for ambiguous/vague communication units was calculated, and an indicator of ambiguity was calculated representing the percentage of words coded as ambiguous on all words communicated.

An extensive training with a second, independent coder was performed on a different data set. The coding of communication ambiguity was done by the first author.

Indices

Subtasks included. Some subtasks have to be executed only once for each defibrillation (e.g., preparing the defibrillator). The reduction in communication due to these actions being omitted after the first episode cannot be interpreted as implicit coordination, as there is nothing to coordinate. The indices described below therefore are based on subtasks that had be executed for each defibrillation. Unless stated otherwise, all counts refer to each episode of each task separately.

Amount of verbal communication. *Word count and percentage of subtasks coordinated without any verbal communication.*

The number of words communicated across all defibrillation-related subtasks was counted, a) including subtasks that had to be performed only in the first defibrillation episode (see recurrent and non-recurrent defibrillation tasks in Table ; b) for subtasks that had to be repeated in each defibrillation episode.

To measure coordination without any verbal communication, we averaged, for each episode in Task 1 and Task 2, the percentage of subtasks that were executed without any verbal communication.

Amount of information transmitted: Count of communication units. All communication units related to recurring defibrillation subtasks were counted; as units of meaning, they represent the amount of information transmitted.

Quantitative indicator of grounding/chunking: Mean words per communication unit. Whereas communication units indicate the amount of information transmitted, the grounding indicator reflects the mean number of words per communication unit as an indicator of how many words are used to transmit a given information.

Qualitative indicator of grounding/chunking: Communication ambiguity. To develop a *measure of communication ambiguity* we calculated the percentage of words coded as ambiguous (and thus more implicit) per subtask per episode, based on the ambiguity coding described above. As shown in **Table 2**, the index can vary between 0% and 100%. For hypothesis testing, all proportions were arcsine transformed.

***Table 2**: Examples for the calculation of the proportion of ambiguous communication per subtask*

	Case	Example	N° words coded as clear	N° words coded as ambiguous	Proportion of ambiguous communication
1	Specific verbal communication	A: Prepare the defibrillator B: Gets the defibrillator	3	0	0 (0% ambiguous)
2	Ambiguous verbal communication	A: Ventricular fibrillation! B: Gets the defibrillator	0	2	1 (100% ambiguous)
3	(Ambiguous) non-verbal communication	No communication. B: Gets the defibrillator	0	0	0 (100% ambiguous)
4	Mix of clear and ambiguous verbal communication	A: Ventricular fibrillation! B (saying): get the defibrillator! C: gets the defibrillator.	3	2	0.6 (60% clear, 40% ambiguous)

Controlling for reflexivity conditions

Because the data stem from a study with three different reflexivity conditions (see above), we checked if the reflexivity conditions influenced any of the associations we analyzed. This was not the case; results can be obtained from the authors.

Results

All 35 teams defibrillated both of the patients (Task 1 and Task 2) at least twice. In Task 1, 12 teams defibrillated three times, in Task 2, 27 teams defibrillated three times; for the analyses, we included the first three defibrillation episodes. All analyses refer to the defibrillation task and/or its subtasks.

Descriptives

We argued that the analysis of the process from explicit to more implicit communication makes sense only for subtasks that are carried out repeatedly. Table shows that 36.42% of the words in the first defibrillation episode of Task 1, and 21.16% in Episode 1 of Task 2 referred to non-recurring subtasks; for communication units, percentages were 13.31 % (Task 1, Episode 1) and 21.85% (Task 2, Episode 1). For episodes 2 and 3 differences between recurrent and nonrecurrent subtasks were negligible. These results illustrate that counting all words, regardless of re-occurrence, would have considerably overestimated the shift to implicit coordination.

Table 3: Number of words / communication units related to all vs recurring defibrillation subtasks across tasks and episodes within tasks

	Number of words											
	Task 1						Task 2					
	Episode 1 (N = 35)		Episode 2 (N = 35)		Episode 3 (N = 12)		Episode 1 (N = 35)		Episode 2 (N = 35)		Episode 3 (N = 27)	
	M *(CU)**	*SD* *(CU)*	*M* *(CU)*	*SD* *(CU)*	*M* *(CU)*	*SD* *(CU)*	*M* *(CU)*	*SD* *(CU)*	*M* *(CU)*	*SD* *(CU)*	*M* *(CU)*	*SD* *(CU)*
Number of words / communication units related to *all* defibrillation subtasks	**101.23 (17.66)**	35.95 (5.39)	15.20 (4.77)	7.94 (2.06)	9.17 (3.17)	4.84 (1.47)	**34.40 (9.29)**	24.53 (6.24)	10.46 (3.37)	6.14 (1.33)	9.15 (2.96)	7.83 (2.21)
Number of words/ communication units related to *recurring* subtasks	**64.37 (15.31)**	20.38 (4.59)	15.03 (4.71)	7.72 (1.96)	9.17 (3.17)	4.84 (1.47)	**26.09 (7.26)**	19.47 (4.94)	10.46 (3.37)	6.14 (1.33)	8.96 (2.93)	7.92 (2.24)

Note. *CU: communication units; N = highest number of possible comparisons (not listwise deletion)

Decrease of communication quantity across repeated task executions within and across contexts (**Hypothesis 1**).

Hypotheses 1a, e and g stated that for successive defibrillations, the number of words, the number communication units, and the number of words per communication unit, respectively, would decrease. Correspondingly, hypothesis 1c stated that the percentage of subtasks without any verbal communication would increase across repetitions.

This was tested using repeated measurement ANOVA's, with episodes as the within factor, separately for Task 1 and Task 2. Greenhouse-Geisser correction was used if the assumption of sphericity was violated. Post-hoc tests with Bonferroni correction were used to compare defibrillation episodes. These analyses are based on 12 teams that defibrillated three times in Task 1 and 27 teams that defibrillated three times in Task 2.

The results for the number of words, number of communication units and mean words per communication units are presented in **Table 4**, for percentage of subtasks regulated with zero verbal communication in **Table 5**. **Figures 2, 3**, and **4** illustrate the findings. The *number of words* decreased significantly between Episode 1 and 2, but not between Episode 2 and 3 for both tasks; both, the linear and quadratic trend are significant, supporting **Hypothesis 1a**.

The *percentage of tasks coordinated without any verbal communication* significantly increased between Episode 1 and 2, but not Episode 2 and 3 for both tasks; for Task 1, the linear trend was significant for both tasks, the quadratic trend for Task 2; these results support **Hypothesis 1c**.

The *number of communication units* also decreased significantly between Episode 1 and 2, but not between Episode 2 and 3 in both tasks, and the linear and quadratic trends were significant; these results support **Hypothesis 1e**.

Finally, for *the number of words per communication unit*, again, for Task 1, a significant decrease was observed between Episode 1 and 2, but not between Episode 2 and 3, with a significant linear, but not quadratic effect. For Task 2, however, there was no significant decrease in the number of words per communication unit between Episodes 1 and 2 or 2 vs 3, and neither the quadratic nor the linear trend was significant for Task 2; these results support **Hypothesis 1g** only partially.

Table 4: *Change of number of words, communication units, and mean words per communication units across Episodes within Task 1 and Task 2.*

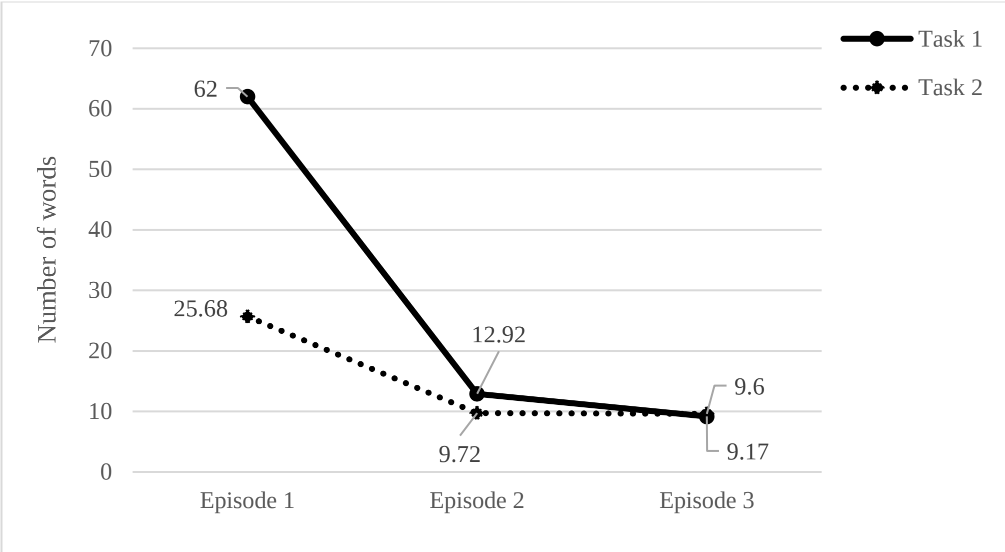
Task 1 (N=12)	Episode 1		Episode 2		Episode 3		ANOVA		E1 vs E2	E2 vs E3	linear trend		quadratic trend	
	M	SD	M	SD	M	SD	(df), F	P	P	P	F (1,11)	P	F (1,11)	P
Number of words	62	21.53	12.92	4.54	9.17	4.84	(1.09) 67.65	<0.001	<0.001	0.1	69.6	<0.001	60.71	<0.001
Communication units	14.83	3.46	4.17	1.34	3.17	1.47	(1.23) 114.47	<0.001	<0.001	0.078	135.43	<0.001	68.27,	<0.001
Words per communication unit	4.21	1.22	3.15	0.74	2.89	0.75	(1.29) 7.84	0.01	0.032	0.783	8.33	0.015	5.189	0.044
Task 2 (N=27)	Episode 1		Episode 2		Episode 3		ANOVA		E1 vs E2	E2 vs E3	linear trend		quadratic trend	
	M	SD	M	SD	M	SD	(df), F	P	P	P	F (1,26)	P	F (1,26)	P
Number of words	24.74	14.93	9.3	5.66	8.96	7.92	(1.49) 21.46	<0.001	<0.001	1	23.45	<0.001	16.8	<0.001
Communication units	6.85	3.51	3.04	1.1	2.93	2.23	(1.42) 25.04	<0.001	<0.001	1	27.9	<0.001	18.603	<0.001
Words per communication unit	3.54	0.88	3.09	1.58	2.85	1.79	(1.821) 1.60	0.214	0.562	1	3.094	0.09	0.101	0.754

Note. E1 = Episode 1, E2 = Episode 2, E3 = Episode 3. E1 vs E2 and E2 vs E3 were estimated using Bonferroni corrected post hoc comparisons.

Table 5: *Percentage of subtasks regulated without any verbal coordination For Task 1 and Task 2.*

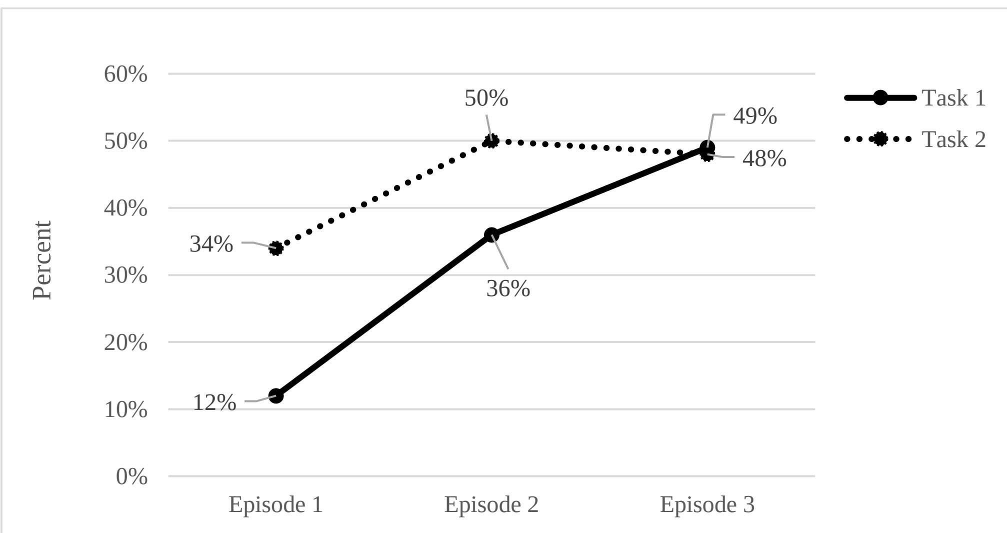
	Episode 1		Episode 2		Episode 3		ANOVA		E1 vs E2	E2 vs E3	linear trend		quadratic trend	
Task 1 (N=12)	%	SD	%	SD	%	SD	(df), F	P	P	P	F (1,11)	P	F (1,11)	P
% subtasks regulated without verbalization	11.9%	8.2	35.7%	15.5	48.8%	20.6	(2) 34.67	<0.001	0.001	0.122	75.47	<0.001	3.920	0.073
Task 2 (N=27)														
% subtasks regulated without verbalization	34.4%	17.8	50.3%	17.9	47.6%	17.7	(2) 10.430	<0.001	0.003	1.00	12.33	0.002	8.42	0.007

Note. Statistical analyses are based on arcsine transformed proportions.



Note: $p \leq .001$***; $p \leq .01$**; $p \leq .05$*;
Task 1: Episode 1 > (***) Episode 2 = episode 3; Episode 1 > (***) episode 3;
Task 2: Episode 1 > (***) Episode 2 = episode 3; Episode 1 > (***) episode 3;

Figure 2: Number of words across three defibrillation episodes, separately for Task 1 and Task 2.



Note: $p \leq .001$***; $p \leq .01$**; $p \leq .05$*;
Task 1: Episode 1 > (**) Episode 2 = Episode 3; Episode 1 > (***) Episode 3;
Task 2: Episode 1 > (**) Episode 2 = Episode 3; Episode 1 > (**) Episode 3;

Figure 3: Percent of tasks that are coordinated non-verbally over time across episodes for Task 1 and Task 2

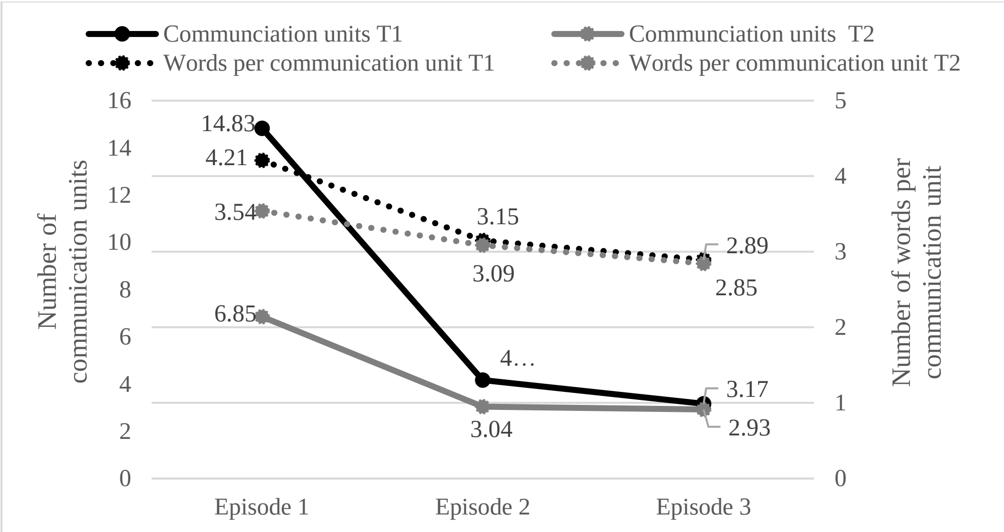


Figure 4: Communication units and words used per communication unit across three defibrillation episodes for the first and the second task.

Hypotheses 1b, 1d, 1f, and 1h postulated that implicitness would "carry over" from Task 1 to Task 2, implying that performing defibrillation for the first time in a new context (i.e., Task 2) would be associated with a reduced communication quantity, respectively an increase in subtasks coordinated without verbal communication, as compared to the first defibrillation in Task 1.

Comparing the first defibrillation episode for Task1 and Task 2 by way of paired t-tests yielded a significant reduction of *the number of words in* Task 2 ($M_{T1\ E1}$ = 64.37, SD = 20.39 vs. $M_{T2\ E1}$ = 26.09, SD = 14.50; $t(34) = 7.79$, $p < .001$); a significant increase of *subtasks that are coordinated without any verbal communication* ($M_{T1\ E1}$ = 14.3%, SD = 12.5 vs. $M_{T2\ E1}$ = 33.9%, SD = 18.0; $t(34) = 5.822$, $p < .001$); a significant decrease of the *number of communication units* ($M_{T1\ E1}$ = 15.31, SD = 4.59 vs. $M_{T2\ E1}$ = 7.26, SD = 4.94; t(34) = 6.997, $p < .001$); and a significant decrease in the *number of words per communication unit*, ($M_{T1\ E1}$ = 4.26, SD = 0.91 vs. $M_{T2\ E1}$ = 3.48, SD = 0.83; t(34) = 3.543, $p = .001$). These results fully support **Hypotheses 1b, 1d, 1f, and 1h.**

Explaining the decrease of communication (Hypothesis 2).

We hypothesized that the decrease of words as a general indicator of more implicit coordination can be explained by two processes a) a decrease in information communicated (communication units), b) grounding or chunking processes, i.e., a decrease of words per communication unit.

We tested this hypothesis by way of multiple regression analyses, separately for Task 1 and 2. **Table 6** shows the descriptive statistics and intercorrelations among the variables separately for Task 1 and Task 2; **Table 7** shows the results of the regression analyses. As postulated in **Hypothesis 2**, both the decrease of communication units and the decrease of the mean number of words per communication units predict the decrease in the number of words overall in all analyses**.**

Table 6: *Descriptive statistics and intercorrelations*

TASK 1	Between Episode 1 and 2					Between Episode 2 and 3				
				correlation					*correlation*	
Predictor	*n*	*M*	*SD*	*1*	*2*	*n*	*M*	*SD*	*1*	*2*
1 Decrease # of words	35	49.34	19.44			12	3.75	5.34		
2 Decrease # of communication units	35	10.60	4.41	0.793*		12	1.00	1.35	0.820*	
3 Decrease mean words per communication units	35	1.04	1.25	0.409*	-0.022	12	0.26	0.75	0.525*	0.015
TASK 2	Between Episode 1 and 2					Between Episode 2 and 3				
				correlation					*correlation*	
Predictor	*n*	*M*	*SD*	*1*	*2*	*n*	*M*	*SD*	*1*	*2*
1 Decrease # of words	35	15.63	19.28			27	0.33	9.39		
2 Decrease # of communication units	35	3.89	4.81	0.941*		27	0.11	1.99	0.723*	
3 Decrease mean words per communication units	35	0.36	1.65	0.367*	0.070	27	0.24	2.31	0.725*	0.160

Note. n refers to the number of comparisons available; positive numbers represent a higher decrease.

Table 7: *Results of the regression analyses*

TASK 1	Decrease of words between E1 and E2						Decrease of words between E2 and E3					
				95% CI						95% CI		
	B	SE	Beta	LO	HI	P	β	SE	Beta	LO	HI	P
Intercept	5.04	4.11		-3.33	13.40	0.229	-0.41	0.57		-1.70	0.88	0.494
Decrease of communication units	3.53	0.34	0.802	2.84	4.23	0.000	3.22	0.34	0.812	2.46	3.98	0.000
Decrease of mean words per communication unit	6.59	1.19	0.425	4.16	9.02	0.000	3.67	0.61	0.513	2.29	5.04	0.000
R2	0.8						0.92					

TASK 2	Decrease of words between E1 and E2						Decrease of words between E2 and E3					
				95% CI						95% CI		
	B	SE	Beta	LO	HI	P	B	SE	Beta	LO	HI	P
Intercept	0.04	0.66		-1.30	1.38	0.956	-0.60	0.58		-1.81	0.60	0.313
Decrease of communication units	3.69	0.11	0.920	3.47	3.90	0.000	2.95	0.30	0.623	2.32	3.57	0.000
Decrease of mean words per communication unit	3.54	0.31	0.303	2.90	4.17	0.000	2.54	0.26	0.626	2.01	3.08	0.000
R2	0.98						0.9					

More implicit coordination is characterized by increasing communication ambiguity (Hypothesis 3).

Hypothesis 3a stated that communication ambiguity increases across defibrillation episodes in Task 1 as well as in Task 2. Results are presented in **Table 8** and illustrated in **Figure 5**. The analyses showed that communication ambiguity increased significantly between Task 1 Episode 1 and 2, but not between Episode 2 and 3 in both tasks, with the linear and quadratic trends being significant, fully supporting **Hypothesis 3a**.

Hypothesis 3b stated that communication ambiguity was higher for the first defibrillation episode of Task 2 as compared to the first defibrillation episode of Task 1. Paired t-tests based on all groups (N=35) showed a significant increase in communication ambiguity of 22.8% (SD = 22.52) $t(34) = 5.04$, $p < 0.001$; *(M_{t1E1} = 37.36% SD = 16.60; M_{t2E1} = 60.17% SD = 18.25),* fully supporting **Hypothesis 3b**.

Table 8: *Change of the degree of ambiguity across episodes 1, 2 and 3 for Task 1 and Task 2.*

Task 1 (N=12)	Episode 1		Episode 2		Episode 3		ANOVA		E1 vs E2	E2 vs E3	linear trend		quadratic trend	
	M	SD	M	SD	M	SD	(df), F	P	P	P	F (1,11)	P	F (1,11)	P
Communica-tionambiguity	36.48	15.09	59.76	15.61	67.76	13.27	(2),31.15	<0.001	<0.001	0.178	63.97	<0.001	4.19	0.065
Task 2 (N=27)	Episode 1		Episode 2		Episode 3		ANOVA		E1 vs E2	E2 vs E3	linear trend		quadratic trend	
	M	SD	M	SD	M	SD	(df), F	P	P	P	F (1,11)	P	F (1,11)	P
Communication ambiguity	60.22	15.66	69.60	14.17	66.91	14.79	(2) 5.01	<0.05	<0.05	1.000	6.27	<0.05	4.22	0.05

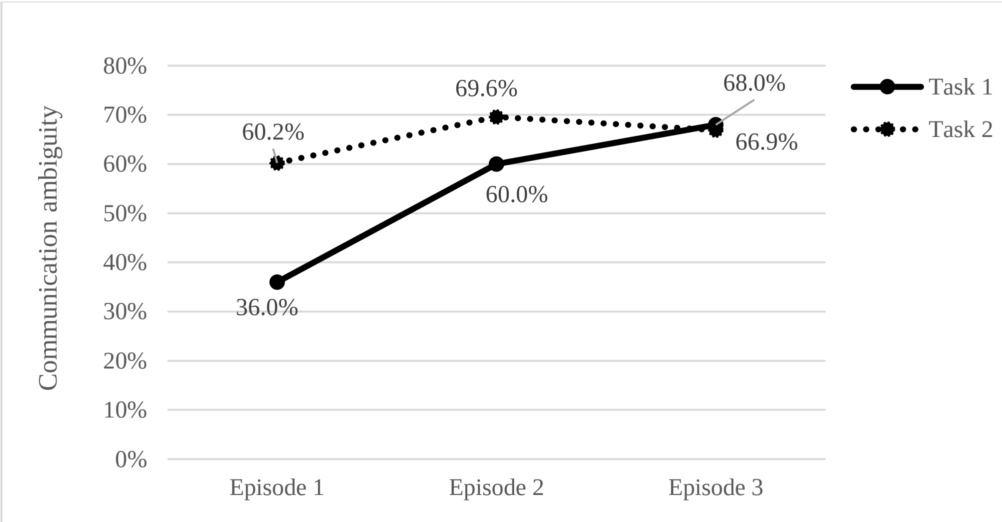


Figure 5: Change in communication ambiguity across three defibrillation episodes for the first and the second task execution.

Note: $p \leq .001$***; $p \leq .01$**; $p \leq .05$*;
Task 1: Episode 1 > (**) Episode 2 = episode 3; Episode 1 > (***) episode 3;
Task 2: Episode 1 > (*) Episode 2 = episode 3; Episode 1 = episode 3

Subtasks with tight coordination requirements are coordinated more explicitly than subtask with loose coordination requirements (Hypothesis 4).

As outlined above, we distinguished between subtasks with tight (all team members need to be focused in parallel on the same subtasks) and loose (subtasks can be done in parallel to other subtask) cooperation requirements. In general, *Hypothesis 4* states that subtasks with tight cooperation requirements are coordinated in a more explicit way than subtasks with loose cooperation requirements. We tested this hypothesis with a quantitative indicator (percent of subtasks coordinated without any verbal communication; *Hypothesis 4a*) and a qualitative indicator (percent of subtasks with ambiguous communication, *Hypothesis 4b*) using repeated measurement ANOVAS separately for subtasks with loose and tight cooperation requirements, for Episodes 1 to 3 for Task 1 and Task 2. Results are presented in **Table 9**; the effects are illustrated in **Figure 6**).

The results show support for the hypotheses. With the exception of the first defibrillation episode in Task 1, subtasks with loose coordination requirements show clearly higher ambiguity; this is accentuated in Task 2. This supports **Hypothesis 4.**

Table 9. *Descriptive statistics, overall and linear and quadratic effects for* ***percentage of subtasks regulated without verbal*** *communication* ***and percentage of communication ambiguity*** *for subtasks with loose and tight coordination requirements.*

		Episode 1		Episode 2		Episode 3		Overall effect		linear trend		quadratic trend		Post-hoc 1 vs 2	Post-hoc 2 vs 3
		M	SD	M	SD	M	SD	F(2)	P	F(1)	P	F(1)	P	P	P
% no verbali-zation															
Loose	T1	13.3	13.03	46.7	17.8	56.7	23.9	25.45	<0.001	27.73	<0.001	16.75	0.002	<0.001	0.571
Tight	T1	8.3	19.46	8.3	19.5	29.2	36.7	2.38	0.116	3.520	0.087	1.205	0.296	1.0	0.454
Loose	T2	38.5	18.34	63.0	19.8	57.0	22.7	15.0	<0.001	15.7	0.001	14.32	0.001	<0.001	0.597
Tight	T2	24.1	32.14	18.5	34.4	24.1	29.0	0.846	0.434	0.025	0.876	1.519	0.229	0.949	0.767
% ambiguity															
Loose	T1	31.37	18.22	62.57	22.91	68.75	18.84	14.56	<0.001	19.55	0.001	5.84	0.034	0.01	0.898
Tight	T1	29.62	20.35	44.44	14.79	58.33	19.46	7.32	0.004	11.29	0.006	0.08	0.786	0.122	0.287
Loose	T2	63.89	22.29	74.18	20.07	72.98	22.73	2.68	0.078	2.93	0.099	2.36	0.137	0.077	1.0
Tight	T2	39.8	30.36	39.69	33.34	46.3	23.72	1.08	0.346	2.08	0.161	0.49	0.489	1.0	0.649

Note. Task 1: N=12, Task 2 N=27; post-hoc comparisons are based on Bonferroni correction; statistical analyses are based on arcsine transformed proportions.

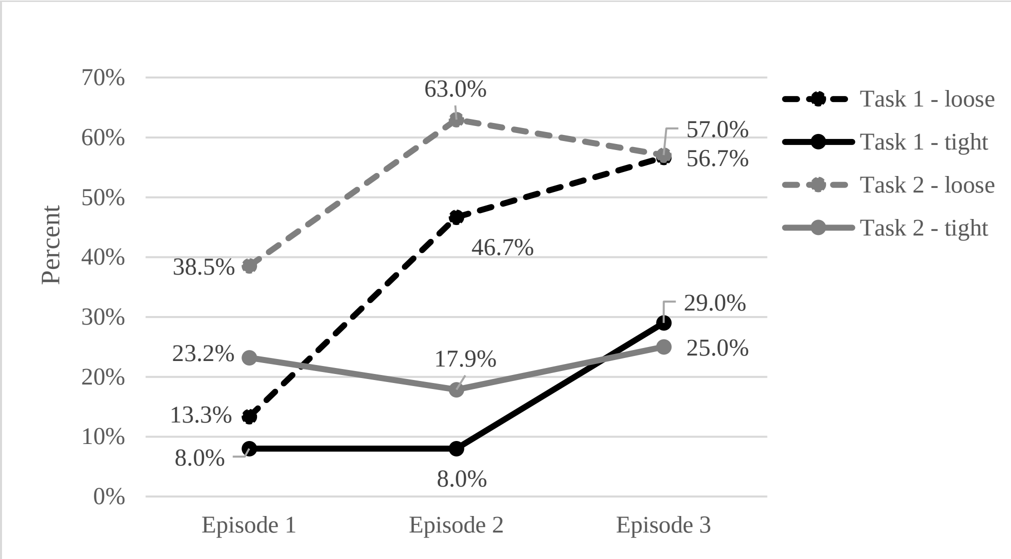


Figure 6: Percent of loosely and tightly coupled tasks that are coordinated non-verbally over time.

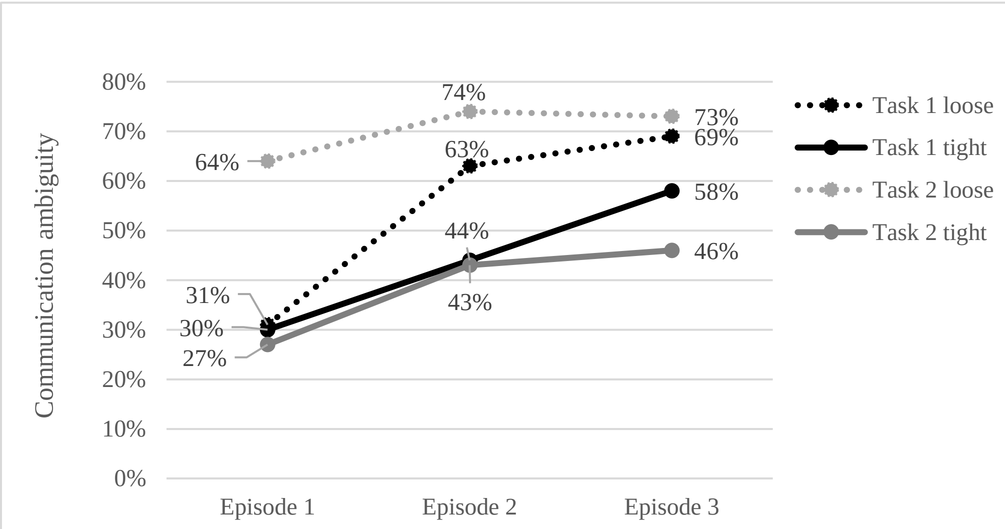


Figure 7: Change in communication ambiguity across three defibrillation episodes for loosely and tightly coupled tasks for the first and the second task execution.

Note: $p \leq .001$***; $p \leq .01$**; $p \leq .05$*; $p \leq .10$†;
Task 1 *loose*: Episode 1 > (**) Episode 2 = episode 3; Episode 1 > (***) episode 3;

Task 1 *tight*: Episode 1 = Episode 2 = episode 3; Episode 1 > (*) episode 3;
Task 2 *loose*: Episode 1 (†) Episode 2 = episode 3; Episode 1 > (*) episode 3;
Task 2 *tight*: Episode 1 = Episode 2 = episode 3; episode = episode 3;

Discussion

In this observational study, we investigated one of the very basic aspects of implicit group coordination – that verbal communication should decrease in groups that repeatedly co-ordinate the same task. This contention is simple, and uncontested. However, it has not yet been adequately empirically assessed by earlier studies, mostly because task demands could not be held constant (Entin & Serfaty, 1999; Grote et al., 2003; Grote et al., 2004). The task we studied was cardiopulmonary defibrillation.

From explicit to implicit communication

The results support the claim that groups use less verbal communication when coordinating the same task repeatedly, as indicated with regard to the three indicators amount of verbal communication (number of words), amount of information exchanged (number communication units) and grounding (number of words within a communication unit). Interestingly, the decrease of verbal communication showed a curvilinear pattern, with a steeper decrease between the first and the second defibrillation episode, and no significant decrease between the second and the third episode, with both the linear and the quadratic trend significant. The same pattern was found for the second context, when the same groups had to treat and defibrillate another patient. This indicates a rapid shift from explicit to more implicit coordination. Although this curvilinear pattern may well depend on the specific group composition (in our case: equal status of group members and considerable prior knowledge about the task) and the task itself, it is interesting to note that a similar pattern was observed in a study on grounding processes for a completely different task (Isaacs & Clark, 1987). This suggests that teams can build a shared understanding relatively fast. However, comparisons to different tasks and different group composition are needed to determine to what extent this decrease pattern is generalizable.

We hypothesized that even when coordinating the task in a new context (i.e., the new patient), coordination would be more implicit than coordinating the same task for the very first time, suggesting that the shift from explicit to more implicit coordination continues across contexts. As expected, there was a significant decrease of explicit communication between the first defibrillation of the first and the first defibrillation of the second patient in all three indicators. This indicates that a shift to more implicit coordination can "carry over" across contexts, and this corresponds to earlier research comparing coordination activities for standard and routine tasks, finding that routine tasks executed in different contexts are coordinated more implicitly than novel tasks.

However, **Figure 2** to **Figure 4** also suggest that changing context to some degree disrupts the decrease of implicit coordination, indicating that more explicit coordination can also be an indicator of adaptation to a different situation. We therefore performed additional analyses comparing the second defibrillation episode of the first task (T1 E2) to the first defibrillation episode of the second task (T2 E1). We chose the second episode of the first task (T1 E2) as point of comparison. These analyses could be based on all data and there were no significant differences between the second and the third defibrillation within one task. The additional analyses revealed a significant increase of explicit coordination for the first episode in a new context for number of words ($M_{T1\ E2}$ = 15.03, SD = 7.72 vs. $M_{T2\ E1}$ = 26.09, SD = 19.47; $t(34) = -3.040$, $p = .005$); and the amount of information (communication units) ($M_{T1\ E2}$ = 4.71, SD = 1.96 vs. $M_{T2\ E1}$ = 7.26 SD = 4.40; $t(34) = -2.851$, $p = .007$); but no differences between grounding (words per communication units ($t(34)=-0.995$, $p = 0.347$) or the percent of tacitly coordinated tasks ($t(34)=1.339$, $p=0.189$). This indicates that some aspects of implicit coordination (the grounding) were maintained in the new context whereas the increased amount of information exchanged is due to the adaptation to the new context; this corresponds to the finding that information, but not task management is increased when adapting to a critical event (Burtscher et al., 2011; Waller, 1999; Zala-Mezo et al., 2009).

Fully tacitly coordinated tasks

Early theoretical papers on implicit coordination emphasized the possibility that teams coordinate without any verbal communication (Entin & Serfaty, 1999; Kolbe et al., 2013; Rico et al., 2008); more recently it is assumed explicit and implicit coordination coexist (Rico et al., 2019). Although the decrease of explicit coordination was important in this study (for example, the third episode of Task 1 was coordinated with 15% of the words used for the first episode), explicit communication remained present.

The analyses on the subtask level (i.e., evaluating which subtasks were coordinated fully implicitly) showed that the percentage of subtasks coordinated without any verbal communication increased from 12% to about 50% across episodes within the first task and from 36% to about 50% across episodes in the second task. This indicates that fully implicit coordination is possible and not rare. The results are comparable to a study reporting 40% of implicit coordinative actions (Zala-Mezo et al., 2009). However, fully implicit coordination depends on task and collaboration requirements. The results showed that subtasks with tight coordination requirements (e.g., delivering the shock) were significantly less often fully implicit (between 8% and 30%) than subtasks with loose coordination requirements (between 13.3% and 63%). This is an important finding because it shows that more implicit coordination is not only dependent on prior experience that allow anticipation, but also on task requirements. Communication during subtasks with tight coordination requirements often entailed temporal coordination markers (such as “now”), it is indeed those aspects of coordination that are particularly difficult to do implicitly.

Another typical communication during tight coordination requirement subtasks were safety commands, such as “clear” before delivering a shock, alerting all team members to not touch the bed or the patient. Although verbal communication may not be necessary to execute this subtask for teams familiar with the task, it may nevertheless be useful to explicitly coordinate in order to avoid errors or dangerous situations. In such a case, verbal communication mainly serves safety purposes and ensures the attention of all team members. It is interesting to note that resuscitation guidelines specify the safety command as necessary subtask (Soar et al., 2015), supporting this contention. Demanding explicit coordination for safety reasons is not unusual for medicine and other high-risk domains, because the risk of coordination errors may be more important than the process gains due to implicit coordination. Indeed, if no explicit verbal coordination takes place, it is often difficult to distinguish between tacit coordination and the omission of necessary coordination. A specific emphasis on explicit coordination (for example closed-loop communication) has indeed been found to enhance performance in high risk emergency situations (Diaz & Dawson, 2020), and has emphasized the importance of explicit coordination (Grote et al., 2010). In safety-critical operations, the requirement for redundancy may counter the advantages of implicit coordination to some degree (Tjora, 2004).

Reduction of quantity of communication vs change of quality of communication

A reduction of the quantity of communication (number of words) in the process of more implicit coordination may be due to two processes. 1) A reduction of information exchange is postulated and plausible because group members develop a shared mental model of the task and the cooperation needs and can adapt their behavior (Hoeft et al., 2005; Rico et al., 2019). 2) A reduction of words communicated is also likely due to grounding processes, where the same information can be transmitted with less words (Clark & Brennan, 1991). This was supported by the results of this study using the number of words per communication unit as indicator of grounding. The analysis regarding the second indicator of grounding (communication ambiguity) confirmed that when moving from explicit to implicit communication, not only the quantity, but also the quality of verbal communication changes. This indicates that qualitative changes in communication, and particularly grounding processes should be considered when analyzing implicit coordination.

Limitations

There are important limitations of this study. First, the sample size was relatively small, suggesting that only large effects could be detected. Second, the group composition (equal status medical students), their previous level of expertise (Rico et al., 2019), the fact that groups reflected between the first and the second task and, finally, the task itself limit the generalizability of the results. Another limitation may lie in the definition of verbal coordination: Although we excluded non-task-related communication, we did not directly code the specific coordinative function of communication (Kolbe et al., 2013) but assumed that all communication in this context was coordinative.

Conclusions

With this study we addressed an important gap in the research on explicit and implicit coordination: A detailed empirical analyses of the process from explicit to implicit coordination over time and across similar contexts, in a realistic environment, and holding the task constant. This was possible because groups performed the exact same task repeatedly in different context and because we identified and excluded subtasks that were only performed for the first defibrillation. Task type and task complexity are evidently an important influence on the amount and type of coordinative communication. In many of the earlier studies, a direct comparison of the amount of communication between repeatedly performed task was not possible.

Although the results of this study were largely to be expected and are in general very compatible with the basic contentions of theories about explicit and implicit team coordination, it is important to provide detailed empirical support for generally plausible claims. In addition, we could show that besides of the quantitative changes in communication, qualitative changes have to be considered.

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Supplementary material

Additional analyses comparing the second defibrillation episode of the first task (T1 E2) to the first defibrillation episode of the second task (T2 E1); Paired T-test (N = 35).

df=34	T1E2		T2E1		t	P
	mean	SD	mean	SD		
Number of words	15.03	7.72	26.09	19.47	-3.040	0.005
Communica-tion units	4.71	1.96	7.26	4.394	-2.851	0.007
Words per communica-tion unit	3.22	1.17	3.48	0.83	-0.955	0.347
Percent fully nonverbally regulated	32.37	16.89	33.88	17.70	1.339	0.189

4.3 Article 3: Rules for Coding Scheme Development

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Rules for Coding Scheme Development: DIY

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Abstract

In this chapter, we provide advice and guidelines on how to develop a coding scheme for assessing observed group communication and behavior. Three general rules (do not develop your own coding scheme unless you have to; do not just take a coding scheme from somebody else unless it is perfect for the task and the research question; and know very well what you want) are followed by six basic steps to consider when developing a coding scheme. They include task analysis, defining the data source, unitizing, developing content codes (with the sub-steps when-who-what-how much), coding manual and training, and assuring interobserver agreement.

102 Words

Keywords: behavioral observation, coding interaction, coding techniques, coding schemes, team processes, group process analyses

Rules for Developing Coding Schemes: DIY

This chapter is intended for group researchers interested in assessing group processes through behavioral observation. We assume that the researcher sees this as the best way to proceed (Weingart, 1997) and either has access to the group process in vivo, or has video or audio recordings. We further assume that the researcher contemplates developing a specific coding scheme for the group process. We will guide through the process of developing such a coding scheme and illustrate the development steps with examples of our work: We observe real surgical teams in vivo, and we code behaviors of medical teams performing tasks in simulators from recorded video-tapes.

We will concentrate on how to develop a coding scheme that can be used for quantitative analyses. We therefore refrain from discussing methods based on qualitative approaches. This does not imply, however, that ethnomethodological or other qualitative approaches are problematic. Some of the most interesting group process analyses - for example of surgical teams - are based on field notes observers took during observations (Cristancho et al., 2013; Lingard et al., 2004; Lingard et al., 2002). We also do not discuss behavioral rating scales or checklists that are used to assess the group process as a whole or in large chunks, such as the behavioral rating scales for observing non-technical skills during surgeries (NOTTS) (Yule et al., 2008).

We start the chapter by outlining three general rules that help deciding whether, and to what extent, a researcher should develop a coding scheme (General Rules #1 to #3). We then describe the development of a coding scheme in six steps.

Three General Rules to Consider before Developing your Own Coding Scheme

General Rule #1: Do not Develop Your own Scheme Unless you have to

Coding schemes for assessing group process behaviors have a long tradition. Carr suggested analyzing group discussions using categories such as suggestion, opposition to or acceptance of solutions, questions and replies as early as 1930 (Carr, 1929). Since then, innumerous coding schemes have been developed; the best known is Bales' interaction process analysis (Bales, 1950a). Part IV of this book presents the IPA coding scheme as well as a representative selection of classic as well as newer coding schemes. Thus, before developing a new scheme, we urgently recommend consulting these as well as method sections of papers that use behavioral coding, because many excellent schemes have not been published separately.

There are two main arguments for this position: First, developers of schemes have made the effort to go through all the steps, and they have dealt with most of the mistakes one is likely to commit when developing a new coding scheme. They have tested feasibility and addressed validity and reliability issues. So, it simply saves time and effort to adopt a previously developed scheme. Second and more importantly, using an existing scheme has the advantage of making one's research comparable with previous research. This facilitates reviews and meta-analyses (Bakeman, 2000; McGrath & Altermatt, 2001; Waller & Kaplan, 2016; Weingart, 1997).

The first general rule in coding scheme development is thus to carry out a thorough literature search with the aim to find an already developed and tested, suitable coding scheme. It may also be worth extending the literature search to other fields than small group or team research. Schemes exist for coding marital interactions (Bakeman, 2000; Filsinger, 1983), interactions between patients and caretakers (Roter & Larson, 2002), medical teamwork

(Kolbe, Künzle, Zala-Mezo, et al., 2009), and negotiations (Brett et al., 2004; Weingart et al., 2004), to name just a few. However, consider also General Rule #2.

General Rule # 2: Do not Just Take a Coding Scheme from Somebody Else Unless it is Perfect for the Task and the Research Question

Coding schemes need to be based on theoretical considerations and have to be adapted to the type of task, the type of group, and the situation to be studied, because the researcher needs to be sure to capture all relevant behavior. Using an existing coding scheme is only recommended if it is compatible with these requirements. If this is not the case, it bears the risk of missing important behaviors, or of coding behaviors that are not important for the research question. However, beware of the narcissism of small differences: At first, no scheme may look like it fits the researcher's purpose really well, for instance because one uses somewhat different terms or distinguish between subtypes of a given category. However, the similarities may be much more striking than the differences. Even if the researcher decides that a new scheme has to be developed, existing schemes can be adapted, combined or used as inspirations for the new scheme; properly citing resources and documenting the adaptations is mandatory.

General Rule # 3: Know very well what you want

Some scholars fascinated with group processes may be tempted to start their research and collect data with only a vague idea about which aspects of the group process they eventually want to assess (e.g. "coordination") and how. Others start developing a coding scheme before deciding which behaviors are of interest and thus include "all possible" behaviors. These strategies often backfire and lead to unnecessary work. Developing the coding scheme is part of the operationalization and measurement process: One translates a concept into observable (behavioral) indicators and decides how these indicators are to be measured. The main challenge of a good operationalization is its fit with the concept it is supposed to represent. The better and the more precisely researchers know what they want, the more focused the coding scheme will be. It is therefore useful to develop the coding scheme on pilot data.

It is also important to have an informed idea - before the coding scheme is developed - of how the data will be analyzed. Behavioral data can simply be aggregated (e.g. how many questions were asked during a process); they may be expressed as proportions (e.g. of all the questions asked, what proportion was asked by nurses or physicians), as density (e.g. how many questions per minute), but also as sequences (e.g. to what percentage of questions asked did someone provide an answer; what happens before or after a question is asked) or as regularities in the interaction process (e.g. is there a temporal regularity between questions and answers, etc.). Knowing how the data will be analyzed influences the construction of the coding scheme (see Part III of this book for various options for data analysis).

How to: The Practical Steps

We suggest a six-step development procedure for the construction and testing of a self-developed coding scheme. For the presentation of the steps, we draw on our own experiences, and on publications describing this process in greater detail (Bakeman, 2000; Bakeman & Gottman, 1997; Brett et al., 2004; Chorney et al., 2015b; Donohue et al., 1984; Kerr et al., 2000; McGrath & Altermatt, 2001; Meyers & Seibold, 2012; Weingart, 1997; Yoder & Symons, 2010). Coding scheme development is an iterative process, guided by theoretical aspects, and limited by practical feasibility. Once developed, schemes should be extensively pilot tested, and altered, if necessary, but finalized before the coding process starts (Kerr et al., 2000; McGrath & Altermatt, 2001; Weingart et al., 2004).

Step 1: Know Your Task: Task Analysis

When studying group processes, the task is often not in the center of interest, it is rather seen as a necessary condition to study a specific hypothesis: We can only observe group processes if the group is actually doing something. In experimental research, researchers often choose a task because can be easily performed by groups of unacquainted people, does not need excessive preparation or material, is motivating, and can be completed within reasonable time, and furthermore allows an easy assessment of group performance - given the restrictions of subject pools and researcher’s time. Things are different in applied research. There, task performance may be at the center of interest, for example, if process aspects related to performance are studied (Hunziker et al., 2010). However, real world tasks can be very complex, and it can be difficult to understand what the team is actually doing, and even more difficult from an outsider’s perspective know when and whether they are doing it well.

It is tempting to assume that we can ignore the task and - regardless of the task - expect that similar processes in groups are related to performance, and thus similar behaviors can be observed. However, group processes do not exist independently of the specific group task (Kerr, 2010; McGrath, 1984; Tschan et al., 2000; Tschan & von Cranach, 1996), and a specific behavior may be positively related to performance for one task, but detrimental in another task (Tschan, Semmer, Hunziker, et al., 2011). Tasks influence the group process (Hackman & Morris, 1975; McGrath, 1984). Morris (1966) compared the frequency of specific observational codes across tasks and showed that the type of task was the major influence on the frequency of most of the behaviors observed. Thus, the task has to be taken into account when developing a coding scheme, and existing coding schemes have to be adapted to the tasks used or studied. Such adaptations have been done for decision making tasks (Poole, 2009); in view of the structure of arguments in communication (Meyers et al., 1991); with regard to problem solving in real meetings (Kauffeld & Lehmann-Willenbrock, 2011); and for negotiation tasks (Brett et al., 2004), to name only a few.

In order to tailor a coding scheme to a task, a task analysis can be helpful (Futoran et al., 1989). In our research, we use a variant of the Hierarchical Task Analysis (HTA) technique (Gurtner et al., 2007; Tschan, Semmer, Vetterli, et al., 2011b), a relatively straight forward method developed in ergonomics (Annett, 2003; Stanton, 2006) and also adapted for team tasks (Annett et al., 2000). The first step of a HTA consists of decomposing a task into parts by describing it as a structure of goals and sub-goals. For a project investigating team performance in cardiopulmonary resuscitation (Tschan et al., 2012; Tschan, Vetterli, et al., 2011), we identified the main goal “resuscitating the patient”, with sub-goals of diagnosing the cardiac arrest (assessing the patient), oxygenating the brain (cardiac massage and ventilation) and attempting to reestablish spontaneous circulation (defibrillation and medication). In a second step, we defined coordination-relevant criteria for each goal (e.g. interruptions should be minimized between cardiac massage and ventilation) and direct coordination requirements (i.e. parts of the task where mutual adaptation of two or more team members is particularly important). An example of such a coordination requirement is that cardiac massage and ventilation should not be done at the same time, but rather in an alternating, gapless sequence (Tschan, Vetterli, et al., 2011).

Analyzing the task and its coordination requirements helps to make an informed decision about the behaviors to be coded and serves as a base for identifying task phases, turning points, and other temporal aspects. In the resuscitation task, a turning point occurs when the team is sure that the patient has indeed a cardiac arrest. At this point, the team changes from deliberation to action (Gollwitzer, 2012), and team behaviors are very likely to change markedly. In sum, tasks influence, guide, and restrict the behavior of the team; this should be taken into account.

Step 2: Define the Data Source

Which type of coding can be done depends on the source of data. If the group process can be recorded, researchers can rewind, and thus observe the group interaction several times. This allows for multiple rounds of coding and allows for assessing more fine-grained aspects. If, however, recording is not possible and group interaction has to be coded in vivo, the coders have to assess the process as it occurs; this limits the number of codes to be included in the coding scheme. For example, in the coding scheme for in vivo observations of surgical teams (Seelandt et al., 2014), we defined only four codes for communication: patient-relevant communication, teaching, problem-solving, and non-patient-relevant communication. For in vivo observations, the coding scheme has to be adapted to the cognitive and attentional limits of observers: An observer may not see or hear in detail what is happening; team members may work or talk in parallel, and the density of actions to be coded may be very high (Seelandt et al., 2014).

Step 3: Unitize the Group Process

One of the first decisions in coding interactions is to decide on the start and the end of an observational unit (McGrath & Altermatt, 2001), and to assure that these units are comparable (see Chapter 11 in this book). Which unitizing of the group process one chooses is crucial because it influences the coding and impacts the analyses.

When coding communication, unitizing can range from identifying “sentences” to speaking turns, or even longer phases. Some researchers choose turns as observational units. This has some disadvantages, because for longer turns, multiple coding categories may apply (McGrath & Altermatt, 2001). Often, a “spoken sentence” is chosen as a unit - also called “thought unit” - which is a “sequence of a few words containing a single thought” (Weldon et al., 1991, p. 559). Such a definition is useful, because people do not speak in whole sentences with correct grammar and punctuation, and incomplete sentences have to be considered for coding if they contain meaning (Meyers et al., 1991). In our research (Tschan, 1995), we segmented spoken language (of word-by-word transcripts) around the predicate (the main verb): We identified the verb as the center of meaning and considered everything directly linked to it as part of the thought unit. This method has the advantage that communication linked to manual tasks can be unitized. While performing a task, group members often use multiple channels of communication, and they often „substitute" the verb with an overt action (e.g. a communication such as "this…here", accompanied by putting something on the table, substitutes the verb with an overt action, and can be interpreted as the unit "this [goes] here").

Defining units in terms of meaningful behavior or communication inevitably creates units of different length. An alternative way of unitizing is to divide the process into fixed time segments (for example 10 seconds), and then code the time-based units (Hirokawa, 1983; Waller, 1999; Waller & Kaplan, 2016). The disadvantage of time-based unitizing is that the units most often do not coincide with the natural sequence of an interaction; coding thus requires very high concentration from coders, because they have to pay attention to the predefined time segment as well as to the natural flow of the interaction.

The decision about unitizing is very important. "Smaller" units allow for more precision, but coding is more labor-intensive, thus limiting the number of interactions that can be coded, often resulting in small sample sizes and less generalizable results (Koeszegi & Vetschera, 2010). If larger units are chosen, several codes may be needed to describe a single unit, which, in turn, limits the possibility of expressing results in proportions or performing sequential analyses of the group process.

There is no general rule on how to unitize - it, again, depends on the research question and the theoretical background. Finally, the reliability of the unitizing process itself has to be assessed (for a short description on how to calculate unitizing reliability, see for example Weingart and colleagues, (2004).

Step 4: Develop Coding Contents

For this part, we adopt the framework laid out by McGrath and Altermatt (2001). They suggested considering the following aspects: (1) the time (when); (2) the actors - the group member(s) involved (who); (3) the behavior to be observed (what) and (4) (how much) whether the coding is nominal (a behavior is shown or not) or includes qualifiers, such as intensity ratings (Chorney et al., 2015b).

Step 4.1: When - Coding temporal aspects

Group interactions develop over time, and coding is an excellent opportunity to capture temporal aspects of group processes (Ballard et al., 2008). However, if neither temporal location of behaviors, nor group interaction phases, duration of behaviors, behavior cycles, sequences or behavioral density are of interest, temporal information can be neglected. If any of these aspects are of interest, the appropriate temporal information needs to be captured through coding.

How to include temporal information? A simple method is to project the actual time within the video frame of recordings. If this is not possible, video players display times, and time can be included as information, if transcripts of group communication are made. We write a transcript of communication into spreadsheets, using a separate row for each (thought) unit. We prepare these rows in advance and include time information (one row per second), and then transcribe the unit in the row with the appropriate onset time. Although this leads to many empty rows, it is a simple method that allows to automatically preparing time information in advance instead of manually noting times - and empty rows are rapidly deleted. Note that the timing information using this method is not really precise, we actually accept a difference between the real and the coded onset time of a unit of up to five seconds, because more precise timing is not important for our research goals. Note too, that this method does not allow for capturing interruptions and parallel talk. If a higher level of precision of transcripts is necessary, we refer to the methods of transcription and timing developed in linguistics (Jefferson, 2004).

Coding programs (for example CowLog[5]), that can be used to directly code recordings without transcripts, usually automatically timestamp codes. For in vivo observations, we use an application that automatically timestamps every event the moment we code it (Seelandt et al., 2014). Note, that these time codes are not perfect representations of the time the behavior actually occurs. Such time stamps are always delayed and often indicate the end, rather than the beginning of a behavior or an event. This is because observers must first observe, interpret, and categorize the behavior in order to be able to choose the appropriate code. The coding of a behavior can well be delayed 30 seconds or more in comparison to its actual occurrence. For our research, this is accurate enough, but timings have to be adapted if more exact timing information (for example noise measures) are matched with observations (for an example, see Keller et al., 2016).

If we need to distinguish phases of the group interaction, and/or if specific turning points in the group process have to be considered, we define turning points or phases using specific codes. For example, we have codes indicating that a new surgeon joins the group or leaves the surgery. Such information can be used to segment the group process for analyses of different task phases.

Step 4.2: Who - Coding actors

„Who" refers to the question to what extent actors will be coded. McGrath and Altermatt (2001) distinguish four possibilities: (1) If only the group behavior itself is of interest, information about individual actors does not need to be gathered; (2) actors are coded if the researcher is interested in the person who shows the behavior; (3) if action and reaction

[5] CowLog is an open source software for coding behaviors from digital video (for more information go to http://cowlog.org/)

are of interest, the source and receiver or target of a behavior are coded (for example, who addresses whom with a communication, or who reacts to a specific communication), and finally (4) if joint activity is of interest, co-acting between different group members is coded. Again, it depends on the research question whether and which information about actors is included.

Whether actor information can be reliably coded depends on the group process and the quality of the data: If the group behavior is coded in vivo and the group has many members, it may be difficult to distinguish actors and co-acting. For example, during surgeries there are often ten or more people in the room, all wearing similar clothing, surgical caps, and face masks - in such a situation it is often impossible to determine who exactly is talking and to whom. A possible solution to this is to have people wearing headsets and separate microphones. The participants in our patient simulator studies wear t-shirts with numbers printed on the back, front, and both arms to be able to identify them at any time while they are moving around the patient.

Step 4.3: What - Developing content coding categories

Defining content coding categories is the most important part when developing a coding scheme. We first describe the process of defining coding categories; suggest considering content, process, and non-task related categories as well as coding for task aspects. We then discuss issues related to interpretation of codes.

Defining the categories. The choice of content coding categories will be influenced by theoretical considerations (e.g. theories about the group process, member behavior, and their relationship with the other variables to be studied). As described above, it will also be influenced by the task and the unitizing decisions taken in step 3. In addition to a top-down, theory-driven approach, some content categories are defined when trial material is coded because it may be difficult to conceptually foresee all relevant behaviors. Therefore, an initial, theory-driven coding scheme will likely be refined and changed during the development phase (Weingart et al., 2004). We used such a hybrid approach when developing the coding scheme for observing surgeries (Seelandt et al., 2014): We went to the operating room (OR) with codes derived theoretically and codes we thought to be important based on a literature review. As a next step, we conducted interviews with surgeons, nurses, and anesthetists, which led to a task analysis of the surgical process. This helped to refine the codes. In addition, we used codes adapted from another scheme (Healey et al., 2006). We started in vivo observations with this preliminary scheme, and adapted it during 15 pilot surgeries (about 60 hours of observation). The next five surgeries of the developing phase were used to pilot the final system and to assess initial interobserver agreement.

Consider content, process, non-task related categories, and coding task aspects. There is a wide variety of possible content categories, because most observable behavior can be coded in some way. In groups, content categories can include verbal and nonverbal behavior, task handling, positional movements, and so on. As most group researchers code verbal behavior, we will concentrate our discussion on coding communication and contextual aspects.

For coding verbal behavior, McGrath and Altermatt (2001) and Futoran and colleagues (1989) suggest distinguishing between (1) task-related and (2) non-task-related communication, and (3) contextual aspects.

(1) Within *task-related communication* Futoran and colleagues (1989) distinguish *content* and *process* categories. *Content categories* refer to functions related directly to the task (e.g. agree, clarify, modify), *process categories* refer to how the task is or should be done (for a similar distinction see Weingart et al., 2004). Note that this differentiation is very compatible with conceptual frameworks that distinguish between taskwork and teamwork (e.g. Marks et al., 2001; McGrath & Tschan, 2004b). The inclusion of process categories may

easily be overlooked when developing a content coding scheme because process-related communication is often relatively rare (e.g., a group may distribute tasks among its members only once at the beginning of the process, and never afterwards), but such behavior may have a very important influence on the group process, so it is well worth coding it.

(2) Group members do not always work on the task, they may digress; and even while working on the task, they can talk about other things (e.g., the schedule for the next day). Futoran and colleagues (1989) suggest different codes to capture such non-task-related communication; other researchers do not code such behavior. Again, the decision depends on the research purpose. In our surgery coding scheme, we measure non-patient-related communication (i.e., talking about weekend activities), because we are interested in its effects on team performance (Seelandt et al., 2014; Tschan et al., 2015).

(3) As groups work on different aspects of the task, it is often useful to code task content in parallel to communication as separate categories. Futoran and colleagues (1989) code cycles (changes in task content), which they defined as periods of working on the same aspect of a task; a new cycle indicates that the group turns its attention to a new part of the task. This scheme thus includes topic changes, but not the content of the topic. In our research (Tschan, 2002), we identified different task contents, and we coded for each unit to what part of the task it refers, as did other studies (Weingart, 1992; Weldon et al., 1991).

Interpretation of codes. Some behaviors are easier to define and code than others. If visible behavior can be coded in clear-cut categories (points at the monitor; laughs; moves in the room), little interpretation is needed to code such behavior reliably. Other codes require more judgment because the coders have to interpret what the actor intends to communicate with an utterance or an action - this is what Bakeman and Gottman called socially based categories (Bakeman & Gottman, 1997), and Ray and colleagues called functional categories (Ray et al., 2011). To be able to interpret the behavior of interest correctly, the specific situation and context may be important. Therefore, coders have to be familiar with the relevant aspects of the situation. Because one is often interested in categories that require a fair amount of interpretation, particular attention has to be given to clear and distinct definitions of the categories, an elaborate codebook, and extended coder training.

Group process behavior is very rich and often much nuanced, and a great number of categories can potentially be developed and coded. However, coding has to be feasible. The number of different categories to be included in a coding scheme is limited by the coders' capability of reliably distinguishing different behaviors and by other aspects influencing the coder's cognitive load. To summarize this part, we cite a short checklist to consider when defining the coding categories, developed by Weingart and colleagues (2004, page 446): "Can coders differentiate between the categories when applying them? Are there categories for all relevant behavior? Can the scheme be applied reliably?"

Step 4.4: How much: Qualifying codes

The simplest way to code a behavior is to indicate whether or not it has been observed within a predefined unit. This is a binary "present or absent" decision. If it is necessary to code more than whether a behavior has been shown, a qualifier can be added to a code. For example, an expressed "tension" (code) can be qualified as low, medium or high intensity. Adding qualifiers makes coding more difficult, because the coder has to make two decisions - first, he or she has to indicate which behavior is shown and second, he or she must evaluate an attribute of the behavior. Evidently, this takes more time and entails a higher cognitive load for the observer. As with any other coding, interobserver agreement has to be established for qualifiers.

Step 5: Writing the coding manual

During the development and testing of the coding scheme, the coding manual is written. It is a highly important document that describes the operationalization of the variables, serves as extensive guideline on how to code the material and is thus also a training manual. An optimal coding manual should be a specific enough instruction to allow a new coder to code the same or similar material reliably without further instruction.

The coding manual specifies all codes and describes in detail the coding process; it instructs on all steps of the coding. It starts with transcription rules, and explains unitizing rules. The most important part concerns the clear definitions and specific descriptions of each code. Examples are provided, and rules for using the context to interpret the meaning of a particular behavior are described (Brett et al., 2004; Weingart et al., 2004; Weingart, 1997; Yoder & Symons, 2010). It is useful to provide prototypical examples of behaviors for each code, but also to describe less typical as well as close non-examples, including the rationale for their inclusion or exclusion for a specific code (Chorney et al., 2015b). In our coding manuals, we also include the source if a code was adapted from another coding scheme.

Coding manuals are often changed and adapted during the development and piloting process to include solutions to problems detected during pilot coding. In our coding manuals, we note the solution to each problem coders bring up. Weingart (1997) called coding manuals “living documents” during the development and testing period that are closed once the final coding starts. The coding manual is the essential document for coder training; in addition, we ask the coders to re-read the coding manual each time before they start coding - as additional reminder and training.

Step 6: Train observers and assure interobserver agreement

One of the most important aspects of a coding scheme is its reliability - independent coders have to code the same material in a similar way. Bakeman stated that “agreement is the sine qua non of observational research” (2000, p. 149). Interobserver agreement depends on clearly distinguishable codes and a good coding manual, but mostly, it depends on coder training.

Training coders takes time. For example, for our in vivo coding of surgeries, a minimum of 35 hours of (often one-to-one) training was needed to obtain acceptable reliability (Seelandt et al., 2014). Training time estimations are similar for other projects: 40 hours of training for a scheme containing 17 categories (Meyers et al., 1991), and 60 hours for a 14 category scheme (Weingart, 1997).

As an example, the procedure for training new observers to code surgeries in vivo has several steps: First, a theoretical training introduces to the task environment and to the codes. Observers then individually study and memorize the codes and the definitions; they then familiarize themselves with the coding technology with the goal to automatically localize the code on the tablet computer; this needs to be highly overlearned. After this phase, they accompany experienced observers to the operating room: In a first surgery, they mainly look over the observer’s shoulders and start coding a subset of behaviors. In a second (and often third) surgery, the trainee and the experienced coder code shoulder to shoulder, which allows to compare codes on the spot. The next step is independent parallel observation - after which trainees compare the two codings line by line; systematic disagreements are discussed immediately after the coding phase, when memory is still relatively fresh. As a last step of training, trainee and expert code independently; observations are matched, and interobserver agreement is calculated for each code. Training is only completed if trainees code highly reliably.

The methods to assess coder reliability are discussed in Chapter 10 in this book. Coder agreement has to be assured for all steps - for unitizing, for content coding, and, if the data are used to do sequential analyses, also for sequences (Ray et al., 2011; Waller & Kaplan, 2016). Interobserver agreement based on previously unitized material can directly be calculated. Things are different with event-codes that are automatically time-stamped, because time-stamps for the same event between two coders are almost never exactly the same. To assess interobserver agreement, we manually align the events before calculating agreement. In the surgery study, we allowed for a time difference between the coders of up to 30 seconds for the same event. This is realistic if dense coding is necessary, and it is admissible because we do not analyze time segments shorter than five minutes.

Coder agreement needs to be assessed throughout the study because the interpretation of the codes can change over time. If specific circumstances can influence coding, interobserver agreement should be tested under these circumstances. For example, in the surgery study, we observed very long surgeries (several hours); we were thus concerned about observer fatigue. We therefore assessed coding reliability after three hours into the surgery between a tired coder (who had observed since the beginning) and a fresh coder who joined at this time (Seelandt et al., 2014).

Conclusions

Observing behavior is the gold standard to assess group processes. Retrospective reports of group members as well as generalized observer reports are likely to be biased (Guzzo et al., 1986; Staw, 1975). Developing a coding scheme corresponding to high methodological standards is a labor-intensive, non-trivial multistep process. We therefore recall our first rule: Don’t do it unless you have to. However, when creating a coding scheme from scratch, attention to the details outlined in this chapter can help to avoid excessive work and regrets when starting data analysis. Figure 12.1 gives a final overview of the coding scheme development process.

<Figure 12.1 here>

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FIGURES

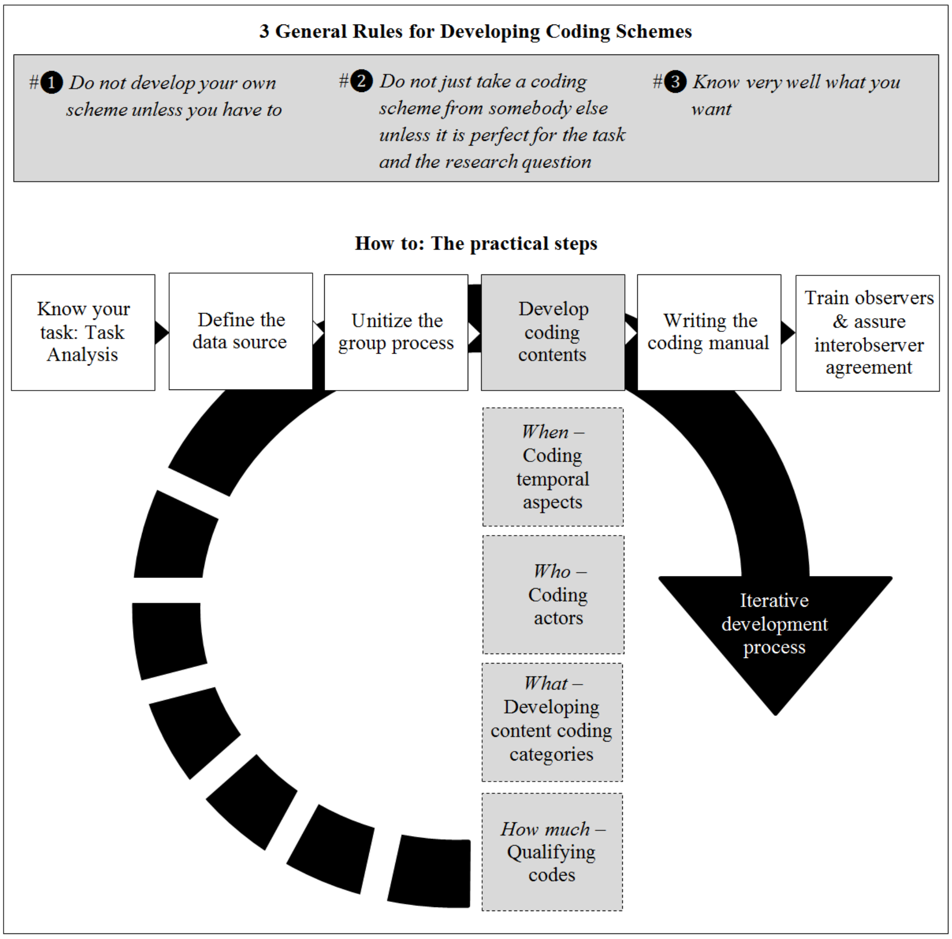

Figure 12.1 Overview of the coding scheme development process

4.4 Study 4: The patient who fell out of bed: A simulation scenario combining technical and non-technical skills for multidisciplinary ICU teams in a non-standard emergency situation

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The patient who's fallen out of bed: A simulation scenario combining technical and non-technical skills for multidisciplinary ICU teams in a non-standard emergency situation

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CASE INFORMATION

Case title: The patient who's fallen out of bed: a non-standard ICU emergency

Simulation Developers: Marc Breuer, Stephan U. Marsch, Franziska Tschan, Norbert K. Semmer, Sabine Schweitzer, Jasmin Zimmermann

Target Audience: Experienced, Intensive Care Unit nurses and physicians, ad-hoc formed teams.

Case Description and Diagnosis: A 63-year old patient, Mr. Tumbleson with a temporary pacemaker due to a 3rd degree AV block was admitted to the Intensive Care Unit (ICU) following postoperative complications after elective laparoscopic cholecystectomy. He fell out of his hospital bed and is found lying on the floor. The responsible nurse is informed about the history of the case and can ask two colleagues to attend to the situation. The team of nurses must diagnose accidental extubation, and a bradycardia due to the disconnection of the internal pacer. A defibrillator with pacing-function allows external pacing. After the team of nurses decides to externally pace the patient, a physician joins the group, handover must take place and the physician must take the lead. After stabilizing the patient, the team moves the patient into the bed using a scoop stretcher.

CURRICULAR INFORMATION

Educational Rationale:

In order to prepare advanced Intensive Care Unit (ICU) medical professionals for managing emergencies, simulator training must include the unique elements of the ICU working environment. These are multidisciplinary, ad-hoc formed teams, often without the possibility to plan prior to cooperation; a highly dynamic environment, and complex medical tasks[1-5]. Yet, many simulation scenarios entail relatively simple tasks, concentrate solely on technical or medical skills, and, if they include teams, provide monodisciplinary training. They are thus well suited for less experienced personnel. For effective training of advanced medical professionals and teams, simulation scenarios need to reflect the complexity of the clinical reality, and ideally combine task- and skills-related training with the training of non-technical skills in interdisciplinary composed teams [6-9].

Immediate briefing after scenario completion should be based on objective assessment of technical and non-technical aspects. It is therefore necessary to develop a checklist to assess technical as well the non-technical aspects for a scenario; such a checklist needs to be reliable and easy to use for trained observers.

Learning Objectives

The learning objectives are based on the Accreditation Council for Graduate Medical Education (ACGME) core competencies[10] relevant for this scenario. Scenario-phase-*specific* core competencies include Patient Care (PC), Medical Knowledge (MK), Practice-based Learning and Improvement (PBLI), as well as Interpersonal and Communication Skills (ICS); see Table 1. Scenario-phase-*unspecific* core competencies include Systems-based Practice (SBP) and Professionalism (P). Learning objectives based on these two ACGME core competencies include

- the ability to evaluate challenges and opportunities of working in an ad-hoc formed interdisciplinary team during an emergency to increase patient safety and improve the quality of patient care in a de-briefing session (SBP),
- assertiveness in relation to a patient safety issue (P)
- participating in the interdisciplinary care of an unusual medical situation (P) and

- the ability to interact effectively and respectfully with members of an interdisciplinary team (P).

Guided Study Questions:

- To develop and test a simulation scenario
  - suited to train *ad-hoc* formed interdisciplinary teams
  - of *advanced* ICU nurses and physicians
  - in an *unusual* (i.e. non-routine) but realistic medical task
  - that *challenges* the team and
  - that requires *medical/diagnostic*, *technical* and *teamwork/coordination* proficiency simultaneously

To provide feedback on simulation training, it is necessary to develop appropriate (performance) assessment tools, which are used as feedback to participants and provide a basis for discussing limitations and knowledge gaps[11,12]. Performance measures need to be developed for all aspects of the simulation (diagnostic, technical, and teamwork). Event-based assessment techniques (EBAT) are best suited for assessing complex simulation scenarios[13-15]; event-based checklists facilitate reliability and reduce workload for raters[16]. An additional guided study question therefore was

- To develop and test a *performance marker checklist* for observers that allows for an immediate first assessment of relevant aspects of task as well as team performance.

Assessment Instruments

A performance marker checklist was developed for this scenario based on medical literature, a task analysis, and an analysis of the coordination requirements for the medical or technical tasks involved [17 18]. The performance markers define the appropriate actions for treating the patient and collaborating in a team for the specific scenario in terms of medical, coordination and patient and staff safety aspects. The checklist consists of dichotomous items, desired behavioural responses can be marked as present (yes) or absent (no); this facilitates in-vivo assessment. ICU experts reviewed performance markers for medical performance.

The scenario and the performance assessment checklist were tested on twelve teams of three ICU nurses and one ICU physician each (36 participants). To assess inter-observer reliability, two observers independently assessed eight of the 12 simulations (66.6%). Inter-observer reliability was calculated using Cohen's κ[19] applied to each phase of the scenario (Table 1). With one exception ("Physician assumes the leadership role" with a moderate a κ -value of 0.50), all Cohen's κ ranged between $\kappa \geq 0.68$ and $\kappa = 1.00$ indicating substantial to excellent inter-observer agreement[20].

To illustrate performance variation, we present diagnostic, technical and team performance in percent of maximum performance (Table 1).

PREPARATION

Simulator

Sim Man, Laerdal,Norway.

Displaying on the patient monitor:

- Pulse oximeter
- Non-invasive BP Cuff
- Arterial Line
- CVP

- 5 lead EKG
- Temperature Probe
- Capnograph

Other equipment required

- Endotracheal tube (ETT)
- Laryngoscope
- Defibrillator with pacemaker function
- Bag-valve-mask device
- External pacemaker with extension cables and temporary pacing leads
- Extrication Collar
- Scoop stretcher
- Drugs available in normal ICU setting

Staff required

- Confederate nurse
    - hands the patient over to the responsible nurse.
    - will re-enter in the room during the simulation session if participants get "stuck" in the scenario (unable to successfully complete a sub-task within a predefined time interval), require information about the mannequin that is not available in other ways[21] or need assistance in locating equipment.
- Simulator operator
- Observer, to evaluate the medical, technical and teamwork skills during the scenario using the performance marker checklist; may be the simulator operator
- Debriefer, may be the simulator operator

Room / Mannequin Setup

- The patient "fell from bed" and is positioned on the floor, one leg hanging on the edge of the bedside. The bed of the patient is deliberately positioned such that the teams have to work within a very narrow corridor between the bed and the wall of the room, unless they move the bed.

Supporting materials

- Checklist for initial handover to responsible nurse, containing patient history

Duration

- Preparation: 30min.
- Simulation: 20min.
- Debrief: 45min.

CASE PROCEDURE

Each team is composed of three nurses and one physician. Prior to the scenario, they receive an instruction on the technicalities of the simulator mannequin and see the technical devices available in the room. They are told that they "start their shift after a few days off" (so it is plausible that they don't know the patient) and are informed that they are responsible for several patients in the ICU. One of the nurses is randomly assigned to be the responsible nurse for the patient. The other nurses and the physician are told that they could be summoned to help, but they are not present at the handover. The responsible nurse receives the patient handover from the confederate nurse in form of the unit's standard procedure (see below for the patient handover information). Upon entering the room, the nurse finds the patient lying on the floor. The fall caused several installations to be dislodged and no longer functional:

- The endotracheal tube is no longer connected to the patient; the tube is hanging down from the respirator. Because the respirator is still connected to the tube and delivers the set tidal volume, the tube rhythmically moves in the air, while the external respirator produces a visible and audible alarm indicating the disconnection of the tube.
- The lead of the pacemaker, which was formerly located in the patient's heart and inserted via the left femoral vein, is now hanging in the air completely outside of the body, indicating that the pacer is no longer functioning.
- The plug formerly connecting the ECG electrodes attached to the patient's chest with the lead of the monitor is dislodged, with plug and lead lying on the bed.
- The pulse oximeter, formerly attached to the index finger of the patient's right hand, is dislodged and lying on the floor.
- However, an arterial pressure line remains functional and confirms the presence of blood pressure on the monitor.
- If reattached, both pulse oximeter and ECG are functional and produce clear signals on the monitor.

When the responsible nurse calls for help, the other two nurses are immediately sent to the simulator room. However, the arrival of the physician is delayed until the nursing team has decided to externally pace the patient.

Patient Data Background

Patient History (information for handover)

The patient history (including the review of systems, current medication and allergies, physical examination, and laboratory, radiology, and other relevant studies) refers to the patient state *before* the fall and is communicated verbally to the responsible nurse at the handover. The structure of the handover should be adapted to the ICU the training takes place.

The patient is a 63-year old male with a successfully resuscitated cardiac arrest due to ventricular fibrillation caused by an acute myocardial infarction on the first postoperative day after elective laparoscopic cholecystectomy. He was admitted to ICU after successful resuscitation and stenting of an occluded right coronary artery; intermittent 3rd degree AV block required the insertion of a temporary pacemaker. The patient has just completed a 72h period of targeted temperature management according to a treatment protocol [22]. As the patient is in stable conditions, sedation has been reduced to assess his neurological status and allow extubation, which is planned the same day.

Systems:

Central nervous system:	Sedation overhang with GCS6 (A3, M1, V2)
Cardiovascular:	External pacing with HR 80/min, BP 102/64
Pulmonary:	Intubated, spontaneous ventilator mode, RR 12/min, SpO2 98% with 40% inspiratory oxygen concentration
Renal / Hepatic:	Foley catheter in place, adequate diuresis, no hepatic problems
Endocrine:	No pathology
Heme/Coag:	Dual platelet aggregation

Current Medications and Allergies:

Medications: Dual platelet aggregation, sedation stopped, no vasoactive drugs

Allergies: None

Physical Examination:

General: Normal

Weight, Height: 80kg, 180cm

Vital Signs: HR 80/min (paced), BP 102/64, RR 12/min

Airway: Intubated, extubation planned for the same day

Lungs: Symmetrical bilateral breath sounds

Heart: Normal heart sounds

Laboratory, Radiology, and other relevant studies:

HCT: Normal laboratory values except for cardiac enzymes

CXR: No radiographs provided

EKG: Pacer ECG; HR 80/min with underlying 3rd degree AV block with HR 20/min

Baseline Simulator Patient State

The baseline simulator patient state refers to the patient state *after* the fall from bed, it includes the patient parameters set in the simulator as the responsible nurse enters the room.

Vitals: 3rd degree AV block with HR 20/min

Neuro**:** GCS 6 due to overhang in sedation

Respiratory**:** Patent airway with adequate spontaneous ventilation; respiratory rate of 16/min; oxygen saturation of 93% while breathing ambient air; oxygen saturation increases to 98% when oxygen is administered.

Cardiovascular**:** 3rd degree AV block with HR 20/min; blood pressure 75/35 mmHg with palpable pulses at all sites. Blood pressure increases to 120/70 mmHg with external pacing.

Gastrointestinal**:** None

Genitourinary**:** None

Metabolic**:** None

Environmental**:** None

RESULTS

The simulation scenario is described in six distinct phases; Table 1 provides a detailed description of the phases of the simulation scenario, the learning objectives, the performance marker list, as well as descriptive results for performance based on a sample of 12 teams.

Performance was assessed for each simulation scenario phase. Results indicate excellent performance (M > 95%) for diagnosing bradycardia (min = 66.67%, max = 100). Performance was good (M > 85%) for the systematic first assessment (min = 50%, max = 100%), the correct technical handling of the external pacer (min = 75%, max = 100%) and for coordination while lifting the patient back to the bedside (min = 50%, max = 100%). Team performance was mediocre (M > 75%) for establishing a shared mental model of the diagnosis (min = 33.3%, max = 100%) and unsatisfactory (M < 75%) for the handover to the incoming physician (min = 25%, max = 100%) and for the correct use of the scoop stretcher (min = 0%, max = 100%).

Average performance over all phases was mediocre for this sample of 12 groups of experienced nurses and physicians (min = 59.18%, max = 94.39%). As indicated by substantial standard deviations, there is quite some variation in performance between the groups. Similarly, performance differs considerably between the six scenario phases; average performance ranges from M = 58.33% (handover to incoming physician) to M = 97.22% (diagnosing bradycardia). In one performance measure (correct use of scoop stretcher), one team performed none of the desired behavioural responses resulting in 0% team performance.

< Table 1: The simulation scenario, learning objectives, performance marker checklist, and descriptive results for performance based on 12 teams >

CONCLUSION

Learning activities in Simulation Based training should reflect the clinical reality of trainees as closely as possible and thus involve more than only one set of skills. Rather, multiple skill sets comprising cognitive skills (e.g. complex decision making, problem solving, adequate medical reasoning) and technical skills (e.g. handling of a defibrillator in its pacer mode)[23] as well as non-technical skills (e.g. handovers, leadership, coordination) should be trained together, particularly if the trainees are experienced specialists. Developing such scenarios for experienced teams is rather challenging. The scenario has to depict a situation that is unusual (i.e., not routine) but at the same time realistic, combining medical, technical, and coordination tasks that challenge the team. One goal of the current study therefore was to conceptualize and test a simulation scenario suited to ad-hoc teams of advanced ICU nurses and physicians in a medical task that requires diagnostic, technical and teamwork proficiency simultaneously.

In-vivo assessment of team performance is still challenging and requires reliable observational checklists. Existing instruments to assess non-technical skills do not include task-related performance and technical aspects, which are important for training. The performance assessment checklist is a good basis for the debriefing. It allows immediate and accurate feedback by identifying specific gaps on all relevant performance aspects. Although such checklists have to be developed specifically for each training scenario, this greater effort pays off in terms of better measurement quality and training[16].

The feasibility of the scenario and the performance marker checklist was tested with 12 groups of experienced ICU nurses and physicians. Performance marker rating was feasible for trained raters, and the interrater comparison showed sufficient reliability. The checklist can be used for training and/or research purposes.

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Appendix

< Table 2: Performance marker checklist assessing Medical Technical and Teamwork Skills >

< Table 3: Optional further performance assessments (results not reported) >

Tables & Figures

Table 1. The simulation scenario, learning objectives, performance marker checklist, and descriptive results for performance based on 12 teams

Scenario stage	Patient status / Physical examination finding	Desired learner actions & ACGME based learning objectives	Operator intervention, simulation restrictions and triggers to move to next stage	Performance markers for observers	Performance results (N = 12) M (%)	SD
0. Patient handover	Patient is handed over to responsible nurse			NA	NA	
1. Entry	The responsible nurse enters the room and sees the motionless patient lying on the floor; one leg hanging on the edge of the bedside	*Desired learner action:* The responsible nurse is expected to request help; two fellow nurses enter upon this request. *Learning objective – ICS:* Demonstrate the ability - to form an initial, newly assembled (ad-hoc) nursing team to start cooperating - to call/ask for help in a potentially life threatening medical situation	*Operator Intervention:* If the responsible nurse does not request help, the two additional nurses are sent to the room by a confederate after 2 minutes. If the nurse(s) request(s) help from a physician, they are informed that the physician on call is occupied with another emergency but will come as soon as possible. The entry of the physician is delayed until the nursing team has decided to externally pace the patient.	NA	NA	
2. Systematic first assessment of the patient	The patient has a patent airway, adequate spontaneous breathing, oxygen saturation of 98%, and presence of circulation (bradycardia; heart rate 20/min), no obvious external bleeding; patient reacts with moaning to verbal commands.	*Desired learner action:* Systematic first assessment of the patient (Check responsiveness, pulse, saturation; call for help) Recognize that the pulse oximeter is disconnected due to the fall, but if reconnected, sufficient oxygen saturation is displayed on the monitor. *Learning objective - PC:* Demonstrate the ability - to make a targeted anamnesis and conduct an emergency medical examination - to provide initial medical assessment of the patient in an uncommon medical situation *Learning objective – PBLI* - Apply adequate approach to assessing and treating the patient		*Adequate systematic first assessment* *(Medical skills)* - Checked responsiveness - Checked pulse - Called for help - Checked saturation	85.42	16.71

Scenario stage	Patient status / Physical examination finding	Desired learner actions & ACGME based learning objectives	Operator intervention, simulation restrictions and triggers to move to next stage	Performance markers for observers	Performance results (N = 12)	
					M (%)	SD
3. Diagnosing bradycardia	Bradycardia (20/min) persists. Despite his very low heart rate, the patient has a cardiac output with a low, but marginally sufficient organ perfusion. Cardiac output is indicated by the patient's reacting to verbal commands (moaning) and the arterial pressure curve on the monitor. Applying external pacing is appropriate since the patient / bradycardia is unresponsive to vasoactive drugs.	*Desired learner action 1:* Diagnose the bradycardia and decide to apply external pacing. The bradycardia can be diagnosed by palpating the pulse, visually by the arterial pressure curve on the monitor and, if reconnected, visually by the ECG on the monitor. *Learning objectives – MK:* Diagnose severe bradycardia - Recognize symptoms and signs of a 3rd degree AV block (bradycardia) - Recognize that resuscitation is inappropriate - Recognize indication for external pacing	*Operator Intervention*: If the team decides to apply cardiopulmonary resuscitation, which is inappropriate, the patient responds with loud moaning of pain. If the team decides to apply vasoactive drugs, patient shows no improvement. *Trigger:* Defibrillator with pacing function used in real patients is available	*Diagnosing bradycardia (Medical skills)* - Verbalized slow pulse frequency and low blood pressure - Realized the disconnected pacer - Realized the disconnected ventilation tube - Realized the disconnected cable of the vital signs monitor - Oxygen administered by mask - Decided to treat bradycardia with vasoactive drugs and external pacemaker	97.22	9.62
		Desired learner action 2: Before applying the external pacemaker, the team is required to establish a shared understanding of the current situation and the next steps to take. *Learning objectives – ICS:* - Demonstrate the ability to establish a shared mental model of the diagnosis and treatment plan by communicating with team members		*Establish a shared mental model of the diagnosis (teamwork skills)* • Stated diagnosis • Communicated disconnection of pacer within the team • Communicated disconnection of ventilation tube within the team	77.78	21.71

Scenario stage	Patient status / Physical examination finding	Desired learner actions & ACGME based learning objectives	Operator intervention, simulation restrictions and triggers to move to next stage	Performance markers for observers	Performance results (N = 12)	
					M (%)	**SD**
4. External pacing	Bradycardia (20/min) persists, all patient status aspects as in stage 3. If the patient is correctly paced, impulse energy of 70mA is necessary to induce contraction.	*Desired learner action:* Correctly pace the patient externally. The simulator mannequin reacts to external pacing like real patients: electrical impulses produced by the pacer are visible on the monitor; however, capture (i.e. the transformation of an electrical impulse into an effective mechanical contraction of the heart) will only occur if sufficient electrical energy is applied. *Learning objectives – PC* Demonstrate the ability - to handle the defibrillator machine in external pacing mode (≠ default mode) - to find efficient energy level for pacing - to assess a paced patient - to manage the pathway	*Simulation restrictions:* An impulse energy of 70mA was set as capture threshold (range of the device from 30mA to 100mA). Monitor displays pacer rhythm if capture threshold is set to 70mA or higher. BD increases to 120/70 after external pacing.	*Correct technical handling of external pacer (technical skills)* • Turned on external pacemaker • Adjusted pace maker frequency • Adjusted amperage of external pacemaker • Regularly checked the functioning of the external pacemaker	91.67	12.31
5. Physician joins the group	Patient is successfully paced. Displayed rhythm on monitor corresponds to pacer rhythm chosen by the team, BP is 120/70. Patient reacts with moaning to talk, and pain.	*Desired learner action:* The nurses are faced with the task of informing the incoming physician about the patient's condition and the measures taken so far (handover). The physician should reassess the patient, establish and/or assure external pacing. *Learning objectives – ICS* Demonstrate the ability - to integrate a new team member - to hand-over (nurses), resp. takeover (physician) the leadership role - to re-evaluate and appraise the patient's condition and assure external pacing (new team leader)	*Simulation restrictions:* Once the nurses made the decision to apply external pacing, the physician is sent to the room. *Trigger*: Physician enters the room	*Handover (teamwork skills)* • Correct / complete handover to physician • Physician applied ABCD protocol • Physician communicated diagnosis • Physician assumed the leadership role	58.33	30.77

Scenario stage	Patient status / Physical examination finding	Desired learner actions & ACGME based learning objectives	Operator intervention, simulation restrictions and triggers to move to next stage	Performance markers for observers	Performance results (N = 12) M (%)	SD
6. Safe transfer of the patient to the bedside	Paced patient remains stable if pacer is correctly branched.	*Desired learner action 1:* As the fall might have resulted in fractures of the vertebral spine, the patient has to be protected from potential neurological injury: a cervical collar has to be applied, and the patient has to be immobilised on a scoop stretcher before being lifted back to the bed. *Learning objectives – PC* Demonstrate the ability - to evaluate the risk of lifting the patient back to bed - to take patient safety precautions	*Trigger:* The patient is now stable. A scoop stretcher and cervical collar are available.	*Correct use of scoop stretcher and cervical collar* *(teamwork skills)* • Put on cervical collar • Dismantled the scoop stretcher (start) • Stabilised the head • Patient turned on one side • Patient turned on other side • Put together the scoop stretcher • Dismantle scoop stretcher	59.52	37.47
		Desired learner action 2: Lift the patient as a team in a coordinated way without disconnecting the external pacer while lifting. Once the patient has been mobilised on the scoop stretcher he can be lifted to his bed. *Learning objectives – PC* - Demonstrate the coordination ability when lifting the patient to bed with the scoop stretcher		*Coordination while lifting* *(teamwork skills)* • Lift coordinated • Protect cables and lines	87.50	22.61
		Desired learner action 3: There is, however, no time pressure for lifting the patient to the bed. Team members can express concerns and own limitations (e.g. back problems, pregnancy). *Learning objectives – ICS* - Demonstrate the ability to protect oneself from harm during task execution		None developed		

Note. PC = Patient Care, MK = Medical Knowledge, ICS = Interpersonal and Communication Skills, PBL = Practice-based learning

Table 2. Performance marker checklist assessing Medical Technical and Teamwork Skills

Phase	Performance markers	Operationalization	Assessment
Patient handover	NA	-	-
Entry	NA	-	-
		Patient assessment (medical skill)	
Systematic first assessment of the patient	- Checked responsiveness	- Addressing the patient and/or giving pain stimulus	☐ Yes ☐ No
	- Checked pulse	- Checking pulse manually on wrist, groin and/or vital signs monitor	☐ Yes ☐ No
	- Called for help	- Calling for help via phone (e.g. giving heart alarm)	☐ Yes ☐ No
	- Checked saturation	- Checking saturation on vital signs monitor	☐ Yes ☐ No
		Diagnosis of bradycardia (medical skill)	
Diagnosing bradycardia	- Verbalized slow pulse frequency and low blood pressure	- Saying the patient is hypotonic / bradycardic and/or saying patient has a slow pulse frequency and blood pressure	☐ Yes ☐ No
	- Realized the disconnected pacer	- Saying that pacer is disconnected and/or picking up the disconnected cable of pacer; and/or pointing finger at the disconnected cable	☐ Yes ☐ No
	- Realized the disconnected ventilation tube	- Saying that ventilation tube is disconnected and/or picking up the disconnected ventilation tube and/or pointing finger at the disconnected ventilation tube	☐ Yes ☐ No
	- Realized the disconnected cable of the vital signs monitor	- Saying that cable of the vital signs monitor is disconnected and/or picking up the disconnected cable and/or pointing finger at the disconnected cable	☐ Yes ☐ No
	- Positioned ventilation mask on patient's face	- Positioning ventilation mask on patient's face	☐ Yes ☐ No
	- Made decision to treat arrhythmia with external pacer	- Gets / asks for external pace maker; code does not apply if only defibrillator is requested / applied	☐ Yes ☐ No
		Establishment of a shared mental model (teamwork skill)	
	- Stated diagnosis	- Saying "third-degree AV block"; if named before naming the bradycardia, the code "realized slow pulse frequency and low blood pressure" is coded as well since the AV block slows down (not always but in this scenario) the pulse	☐ Yes ☐ No
	- Communicated disconnection of pacer to the team	- Speaking out loudly that pacer is disconnected	☐ Yes ☐ No
	- Communicated disconnection of ventilation tube to the team	- Speaking out loudly that ventilation tube is disconnected	☐ Yes ☐ No

	Correct technical use of external pacer (technical skill)		
External pacing	- Turned on external pacer	- Changing the mode from defibrillating to pacing; code does not apply if the device was switched on (power) only	☐ Yes ☐ No
	- Adjusted pace maker frequency	- Adjusting frequency between 50-100/min.	☐ Yes ☐ No
	- Adjusted amperage of external pacer	- A clear ventricular excitation / pacer rhythm is visible on the vital signs monitor	☐ Yes ☐ No
	- Regularly checked the functioning of the external pacer	- Checking if pacer is still working properly	☐ Yes ☐ No
	Complete handover (teamwork skill)		
Physician joins the group	- Correct / complete handover to physician	- Providing information about patients' clinical history, initial situation when entering the room/scenario, actions taken so far, what is planned next	☐ Yes ☐ No
	- Physician applied ABCD protocol	- Checking patient's responsiveness, pulse and saturation by him-/herself and/or instructs the nurses to do so, respectively, to give the relevant information	☐ Yes ☐ No
	- Physician communicated diagnosis	- Saying "third-degree AV block"	☐ Yes ☐ No
	- Physician assumed the leadership role	- Giving clear instructions; allocating tasks; ensuring a clear division of responsibilities	☐ Yes ☐ No
	Correct use of scoop stretcher and cervical collar (medical and teamwork skills)		
Safe transfer to the bed	- Put on cervical collar	- Cervical collar put on patient before lifting back to the bedside	☐ Yes ☐ No
	- Dismantle the scoop stretcher (start)	- Dismantle the scoop stretcher (start)	☐ Yes ☐ No
	- Stabilized the head	- Stabilized the head	☐ Yes ☐ No
	- Patient turned on one side	- Patient turned on one side	☐ Yes ☐ No
	- Patient turned on other side	- Patient turned on other side	☐ Yes ☐ No
	- Put together the scoop stretcher	- Put together the scoop stretcher	☐ Yes ☐ No
	- Dismantle scoop stretcher (end)	- Dismantle scoop stretcher (end)	☐ Yes ☐ No
	Coordination while lifting (teamwork skills)		
	- Lift coordinated	- Team members are on both sides of the patient or other surfaces; counting up/down and synchronizing the lift; smooth, coordinated motion	☐ Yes ☐ No
	- Protect cables and lines	- Arranging cables before lifting; cables are not disconnected after the lift	☐ Yes ☐ No

Table 3. *Optional further performance assessments (results not reported)*

Phase	Performance markers	Operationalization	Assessment
		Correct drug administration (medical skill)	
External pacing	- Administered medication for circulatory support	- Administering Atropine and/or Adrenalin	□ Yes □ No medication administered; dispensing errors
	- Administered a sedative	- Administering Dormicum, Fetanyl and/or Propofol	
	- Discussed administration of the sedative	- Discussing the administration of the sedative in the team (e.g. potential risks)	□ Yes □ No
		Situation monitoring (teamwork skill)	
Situation monitoring *(in all phases)*	- Regularly checked patient's state / condition	- Addressing the patient regularly	□ Yes □ No
	- Regularly checked pulse, blood pressure, saturation	- Checking pulse manually on wrist, groin and/or vital signs monitor, blood pressure and saturation on vital sign monitor and naming it	□ Yes □ No
		Efficient use of location	
	- Created space to work	- Moving obstructions out of the way to work (e.g. moving the bedside)	□ Yes □ No

5. General Discussion

Teamwork, especially in the health care sector where mistakes can have serious consequences, is important. Good teamwork requires effective coordination. And it requires training, especially in case of ad hoc teams, which are common in health care, and in emergency situations. Understanding these coordination processes and making the knowledge available for training is therefore essential. The goal of this dissertation was threefold. First, to better understand a specific coordination mechanism that is considered particularly beneficial in teams studied in this dissertation, acute care teams. In this regard, we on the one hand reviewed relevant literature in Article 1 and developed the interpretability model of implicit and explicit coordination. On the other hand, we addressed the role of verbal communication in greater detail in Article 2, examining implicit coordination over time in two consecutive task executions. Second, to show how coordination processes can be measured by behavioral observation (Article 3). And third, how knowledge from research can be used and made available for training purposes. In this regard we presented a simulation scenario for effective simulation-based training of ad hoc formed, experienced and multidisciplinary teams in Article 4.

5.1.1 Understanding coordination processes (Article 1 & 2)

The review (Article 1) has shown that it is not always clear whether, how and under what circumstances teams benefit from implicit coordination. The root of this fact, we assumed among other things in the many different operationalizations and analysis procedures of implicit coordination in the studies included in the review (cf. article 1, Table 2). The first key finding in this regard was that the operationalization of implicitness has so far been strongly related to decreasing verbal communication and increasing anticipatory behavior such as offering information or offering help without being asked (Grote et al., 2010; Grote et al., 2004; Kolbe, Künzle, Zala-Mezö, et al., 2009; Riethmuller et al., 2012; Shah & Breazeal, 2010; St.Pierre et al., 2011; Zala-Mezo et al., 2009). The second key finding referred to the fact that task characteristics and their requirements have been predominantly neglected, not so much on the theoretical level (e.g. Espinosa et al., 2004; Wittenbaum et al., 1998) though, but on the practical level in the actual analysis of the coordination mechanism. In this respect we have pointed out the risk of misleading conclusions (cf. Article 1, p. 56), especially when verbal communication is analyzed, since coordination-related communication is related to actions, respectively the (sub-)tasks. This gave rise to the claim that tasks as the object of coordination and the point of reference require more attention in the analysis of (implicit) coordination. Based on these key findings regarding the definition, operationalization, and analysis of implicit coordination we discussed some conceptual aspects that may be important to consider for future research. In doing so, we have taken into account essential principles of the Action Regulation Theory (Hacker, 2014, cf. Section 2.2.2.1) and explanations from psycholinguistics (e.g. Clark, 1996, cf. Section 2.2.2.3), in particular the notion of action-triggering signals as information that indicate the need for action. We concluded with the presentation of the interpretability model of explicit and implicit coordination.

The interpretability model of explicit and implicit coordination broadens the concept of implicitness in coordination processes i.e., by considering communication ambiguity as a criterion for implicitness. From our perspective, it offers great value to group researchers interested in coordination processes by extending previous conceptualizations of implicit coordination. Extensions were primarily made in two places: the process of anticipation, which is a cornerstone of implicit coordination, and the manifestation of implicit coordination during the coordination process (i.e., shortening of communication). The anticipatory process has previously been addressed in more detail by Wittenbaum (1996) (cf. Section 2.2.2.3), though with a different focus. While discussing the *preconditions* of anticipation (i.e., member's expectations before interaction, task assessment, and resource allocation), we looked at the process itself from the perspective of team communication and, in terms of action regulation, focused on the fact that teams, unlike individuals, coordinate their actions via communication. Nevertheless, we based our explanations on established assumptions regarding anticipation, specifically that anticipation is a matter of monitoring (Kolbe et al., 2013). Going into this in a little more detail, we stated that monitoring is a matter of cues which need to be perceived while performing the task. Based on explanations of Clark (1996) and Gersick and Hackman (1990, cf. Section 2.2.2.3) we claimed that such cues can be of different kinds (e.g., verbal, or non-verbal, explicit, or implicit). Other basic and established assumptions, such as that implicit coordination is based on team knowledge structures (e.g., SMM) have been incorporated into the model too. For example, the model assumes that the degree to which a communication may be ambiguous for outsiders yet be interpretable for insiders increases with the amount of shared knowledge. Overall, the model fits well with previous theoretical considerations and can be used to expand the conceptualization of what "implicit" means in group coordination and possibly find new, alternative ways of operationalizing it.

Building on the two findings from Article 1, in Article 2 we examined how the process of decreasing verbal communication evolves over time in groups that are repeatedly confronted with the same task. First, we considered different task demands that we assumed would moderate the evolution from explicit to implicit coordination. Second, we measured not only quantitative communication indicators (e.g., the number of words), but also communication ambiguity. This qualitative indicator of the grounding/chunking process served to show that the linguistic representation of a message also changes as coordination proceeds, highlighting the importance of qualitative indicators in studying the shift from explicit to implicit coordination.

First, the claim we have made that verbal communication should decrease in groups that repeatedly coordinate the same task is simple and undisputed. Thus, examining indicators such as word count may seem relatively straightforward. However, studies of implicit coordination have rarely examined in detail this defining aspect of reduced verbal communication, namely the amount of communication itself (see the review in Article 2, p. 11 ff.). Mainly because task demands could not be held constant (Entin & Serfaty, 1999; Grote et al., 2003; Grote et al., 2004). This is because it is also undisputed that the task itself, or the task demands, influence how much teams communicate (Kerr, 2017). And this is independent of the (non-)existence of mental models. For example, Entin and Serfaty (1999) examined the over-all communication rate but found that it was too strongly influenced by task demands to be interpretable. So, even though the results of Article 2 were largely within expectations and generally very consistent with the basic claims of explicit and implicit team coordination theories, it is still important to provide detailed empirical support for such generally plausible claims.

Second, the emphasis on qualitative changes in communication is in line with Serfaty et al. (1993) who pointed out early on that communication itself may be changed during the process from explicit to implicit coordination. Yet, they referred primarily to the tendency of team members to pass on more information without being asked, suggesting more efficient verbal communication by anticipating the task intentions of others. Concepts from the field of psycholinguistics were, at least not directly, discussed. One of the few studies from small group research that investigated team coordination explicitly using linguistic concepts is the study by Grote et al. (2004). They showed that behavioral problems during coordination can be related back to unsuccessful coordination on the linguistic level. They showed that behavioral problems in coordination can be attributed to failed coordination at the linguistic level. The linguistic level as a coordination behavior was investigated based on the analysis of discourse activities under the premise of the Quaestio model of dialogue production (Von Stutterheim & Klein, 1989). That is, the coherence of the discourse was qualitatively assessed and thus whether coordination at the linguistic level succeeded or failed. This was done by determining who initiated discourse activities, how complex the emerging sequences were, and whether they were jointly constructed and closed. Thus, the focus of the study was on overall linguistic coordination. Implicit and explicit coordination were, however, coded independently of this linguistic coordination analysis by categorizing all spoken utterances as either implicit (e.g., giving unsolicited information) or explicit (e.g., requesting information). Nevertheless, studies such as this support our view of the importance of psycholinguistic concepts in the study of (implicit) group coordination. In particular, in action teams.

5.1.2 Training coordination processes: Simulation training in multidisciplinary medical teams (Article 4)

Making knowledge from research on effective teams available for training is a main goal of our research. The question that team research has been asking for years is how to “create” effective teams via team training? If effectiveness is understood in terms of good team performance (i.e., goal achievement, safe patient care, treatment efficiency etc.), this implies on the one hand that certain contextual (e.g., nature of emergency), individual (e.g., technical, and non-technical skills) and team characteristics (e.g., communication structure) are met, and on the other hand, effective team processes (Salas et al., 1998). Examples of such processes include team leadership, problem solving, workload distribution, communication, or coordination. In Article 4, we developed a simulation scenario that addressed these factors. The scenario confronts medical professionals with an unusual and challenging, but realistic situation, where correctly resolving the task requires diagnostic, medical, technical, and teamwork/coordination skills, as well as integrating a new team-member and leadership skills. The competencies required in the scenario correspond to the individual knowledge, skill and attitude factors that Baker et al. (2007) consider important for working together as an effective team. Thus, in terms of content, the skills and competencies trained in the scenario could be described as "classic". Likewise, because they are also trained in other settings (e.g., military).

However, there are two issues that add value to the scenario presented in Article 4. First, the skills mentioned above can be trained simultaneously in a single training session. And second, the scenario was developed considering the fact that there are many scenarios designed for novices. Scenarios designed specifically for ad hoc formed health care teams with multidisciplinary, experienced professionals are, to our knowledge, rather rare. Taking such special characteristics of the working environment into account is important because health care is clearly different in some respects from other settings such as the military (e.g., in respect of team stability). Thus, caution should be taken when translating team training models from other domains. The goal in training healthcare professionals, compared to the military setting, for example, is to train individuals to work in a team context rather than to train a team as a unit (Murray & Foster, 2000).

That being said, it should not go unmentioned though that this is exactly what could be a major challenge in practice. The scheduling required to train multidisciplinary and ad hoc teams is a challenge and still a common obstacle to regular, full team training (Marshall & Flanagan, 2010). The use of confederates to fill not only a supporting but a full role on the team (e.g., the surgical team in anesthesia team training) could be seen as a way to compensate for such scheduling problems. However, this has also been a criticism of earlier simulation programs, particularly in anesthesia (Howard et al., 1992). Confederates in our scenario are therefore only intended to have a supporting function. A tempting argument for training without "real" multidisciplinary teams might be that the superior effectiveness of such training compared to training with monodisciplinary groups has not been proven (Salas, DiazGranados, et al., 2008, cf. Section 2.4.4). Nevertheless, multidisciplinarity is a reality and considering it in training takes into account its psychological fidelity (Salas, DiazGranados, et al., 2008). Psychological fidelity means that one must create a situation that teams could potentially encounter in their daily work.

Training real multidisciplinary teams might also be particularly important when considering that hierarchical thinking in medical collaboration still exists, and although it may be changing, it is a process that may take its time (Lancaster et al., 2015). Hierarchical differences are a known contributor to communication failures in medical settings (e.g., Joint Commission on Accreditation of Healthcare Organizations, 2005). For example, when members distort or withhold communication, especially if one person is concerned about appearing incompetent, does not want to offend others, or feels that others are not open to communicating (Sutcliffe et al., 2004). Issues such as openness, trust, and mutual respect play an important role in overcoming such hurdles in teamwork and building them is facilitated by training multidisciplinary teams. When this is not possible in planned simulation training, role-playing may be an option which can provide guided hands-on practice in addition to lecture-based classroom instruction. Simulation scenarios such as ours can be used to prepare such role plays well, so that participants can experience the targeted cognitive and behavioral processes that they will also use on the job. One advantage of role plays is that they can be conducted on-site.

5.1.3 Assessing coordination processes (Article 3)

Last but not least, we developed a feasible observational checklist in Article 4 to evaluate non-technical skills as well as task-related performance and technical aspects which can be used for research or for feedback purposes. The checklist includes process measures as recommended, for example, by Tschan, Semmer, Vetterli, et al. (2011a). Especially when the team's performance is to be assessed in-vivo, it is important to have an instrument at hand that contains aspects that are cognitively easy to evaluate. Checklists are therefore particularly suitable for such situations; they contain the most important actions for a particular medical treatment (in our case) and the observer only needs to keep track of whether these actions are performed during the process or not.

The process of developing coding schemes to capture team performance is similar to that of developing general observational coding schemes (cf. Article 3). In general, the development of reliable measurement tools is an important prerequisite for researchers and, in the case of team performance evaluation, for practitioners to be able to make reliable statements about coordination processes, including in training. We are not the only ones who have published a checklist for developing coding systems (see e.g., Schmutz et al., 2014). The value of Article 3, compared to other related work in the field, is twofold. On the one hand, in providing an in-depth insight into our work for both researchers and practitioners through many concrete examples. And second, the article not only outlines the “ideal” process, but also discusses challenges that many a researcher and practitioner is likely to face in the development process (ourselves included), and provides concrete support for decision-making. With this last remark, practical implications are indicated, which will be addressed in more detail in the following chapter.

5.2 Theoretical, Methodological and Practical Implications

This dissertation makes important contributions to research and practice for group research, and specifically for medical teams.

Article 1 focused on the state of the art of implicit coordination research through systematic review of the literature. The identification of conceptual aspects in the definition and measurement of the construct led to an expanded theoretical framework of the construct. We have shown how information-related ambiguity is related to team-based knowledge structures on the one hand, and how its degree influences the implicitness of verbal or non-verbal communication on the other hand. In this way, we have overcome the dichotomous classification of verbal to explicit and non-verbal to implicit coordination that often prevails in research. The development of the interpretability model of implicit and explicit coordination involved borrowing perspectives from other fields such as communication theory or linguistics.

Implicit coordination has been studied experimentally (e.g., Wittenbaum, 1996), using self-report measures, and via behavior observations (Rico et al., 2008). A challenge in the investigation of implicit coordination especially in behavioral studies has always been in the tacit nature of implicitness. This dissertation makes methodological contributions to the scientific study of implicit coordination, especially in observational studies. The extended conceptualization offered in the interpretability model of implicit and explicit coordination provides group researchers with the opportunity to enrich their conceptual models and find new ways to operationalize implicit coordination and possibly increase the validity of their predictions. Building on the findings of Article 1, we have shown in Article 2 what such an operationalization might actually look like and thereby suggested how the extended theoretical concept of implicit coordination can be practically implemented.

There are contributions for practitioners involved in team training. From a practical perspective it seems not only important to analyze and teach the need and usefulness of explicit versus implicit coordination but also the various ways to accomplish it, i.e., via verbal and/or non-verbal communication. Identifying verbal and/or non-verbal cues that have the potential to trigger certain actions or scripts in the daily work routine is important, especially for the kind of teams studied in this dissertation. For example, teaching teams “if-then” rules regarding potential action triggering cues. However, it seems equally important to reduce the risk of “over-implicitness”, which may occur because scripts that are triggered by minimal cues tend to be highly routinized. The benefit of such routines is efficiency, but there is a risk that these routines might not be adjusted once they are triggered. That includes also that healthcare workers and trainers to be aware of idiosyncratic cues that are likely to remain ambiguous even to experts and therefore to identify and possibly replace them. This is particularly important for experts who are familiar with the task but not with the team.

The comprehensive description of the training scenario in Article 4 enables educators of health care teams to adopt it directly for their training purposes. It offers them the opportunity to train even experienced medical personnel in medical, technical, and team-related skills that are important in everyday medical practice. This contribution is important in that previous scenarios were mainly developed for novices, often focused on technical aspects and are rarely multidisciplinary. The additional checklist we developed in Article 4 can be used by both instructors for the purpose of feedback and researchers to assess team performance for research purposes. It is designed to allow reliable in-vivo assessment. Finally, for users who wish to develop their own checklists or coding schemes we have provided a step by step guide with valuable tips in Article 3.

5.3 Limitations, Strengths and Future Directions

The articles included in this dissertation need to be interpreted in consideration of several limitations. The following comments are primarily related to either general methodological choices or the predominant topic of this dissertation, implicit coordination. The two other topics, which concern the prerequisite to understand coordination processes (i.e., coding scheme development) and training (i.e., developing simulation scenarios) on the other hand are, however, indirectly addressed.

Generalizability. First of all, the generalizability of the results in Article 2 on implicit coordination is limited by the rather small sample size. This is mainly due to the fact that we focused on the coordination process over time and the associated inclusion criteria, i.e., teams had to perform their task (i.e., defibrillation) at least twice in two executions. Compared to other observational studies in the field small sample sizes are however not uncommon. Particularly not in studies that, like ours, perform in-depth, resource-intensive team process analyses that require comparable cases performed by medical personnel with predefined experience in specific tasks.

Apparatus. Concerning methodological choices, the results of Article 2 must be seen in the light of the fact that the data was collected using a simulator. The importance of simulation in healthcare was highlighted in Section 2.4.1 and remains undisputed, especially because it is often impossible to train medical emergencies realistically. However, even if simulations are implemented in a realistic setup, it is still difficult to re-create real-life situations. The fact that mistakes have no real-world consequences is an often-cited advantage of simulation trainings (cf. Section 2.4.1). However, it can also be a disadvantage as it may lead to participants under performing and becoming less engaged in the training, thus leading to inaccurate results (Gray, 2002). The practice of learning content in everyday work is thus still very important. However, it is also possible to try to make simulation training more realistic by certain means. We had, for example, the possibility that our data could be collected in in-house trainings. Such in-situ simulation, which blends simulation and the real working environment, brings the advantage that training takes place where people work. In-situ training is associated with increased engagement of post-graduate medical professionals and possibly more time can be spent on, for example, debriefings (Sørensen et al., 2017). Simulation programs might also be enhanced by involving theater students, as practiced by the University of Alabama in Huntsville, for example. They may play family members whom the patients have at their bedside, helping the simulation participants to better empathize with unpleasant and stressful situations they may encounter in everyday work. For example, by asking questions about the patient or wanting to stay with the patient even though they should leave the room for treatment. However, when it comes to training interdisciplinary collaboration, it is not recommended that confederates perform a full role on the team (e.g., the surgical team in anesthesia team training) (cf. Chapter 5 General Discussion). The explanations in this section also addresses Article 4 on effective simulation-based training.

Study focus. One point regarding the study of implicit coordination concerns the inclusion criteria in the review on implicit coordination (Article 1). We included studies where human individuals jointly perform a task and are allowed to communicate during the coordination process. These criteria make sense, among other things because it is known that teams coordinate via communication (cf. Section 2.2.2.3). At the same time, studies whose theory, operationalizations, and research methods differ significantly from those included in the review and that perhaps offer new and interesting perspectives on the construct, remained unconsidered. Indeed, tacitly coordinated practices have been widely studied, for example in economics and/or game theory (Andersson & Holm, 2010; Guastello et al., 2005; Vollmer, 2019), social psychology (De Kwaadsteniet et al., 2012; van Dijk et al., 2009), music (Gaggioli et al., 2017; Sawyer, 2003, 2007), or biology (Grassé, 1959). Some of the studies address the role of verbalization, others refer to implicit cues (cf. Article 1) as the main component of implicit coordination.

Non-verbal communication is for example addressed by a study of Guastello et al. (2005). They studied how players coordinate their decisions (or learn coordination) in an iterated card game. The underlying assumptions are those of a (strictly cooperative) intersection game, in which drivers at a four-way stop traffic intersection have to figure out which rule to follow when turning and when to turn. Drivers achieve coordinated driving behavior as an implicit learning process; while the explicit goal is to figure out the correct action sequence that leads to success, implicitly, they learn to respond correctly to behaviors and non-verbal signals from others.

Musical bands also commonly coordinate using nonverbal signals to achieve a state of "group flow." Sawyer (2003), for example, studied jazz improvisations by observing and classifying participants' conversations, gestures, and body language. Gaggioli et al. (2017) studied bands in a rehearsal room, specifically whether group flow (i.e. “a collective state of mind”, Sawyer, 2007) is related to a specific pattern of interpersonal coordination / communication structure among band members. In addition to explicit coordination (operationalized via the exchange of verbal orders), implicit information flow was measured by exchanges of gazes between band members.

Finally, Vollmer (2019) has developed an understanding of tacit coordination in accounting. According to this understanding, tacit coordination between accounting practitioners takes place, for example, through the application of rules and accounting standards. While neither the activities (such as asking people for directions) nor, consequently, the people involved are silent in producing distinct outcomes such as financial statements, reposts, timesheets, or invoices, it is the process itself that remains unverbalized.

The role of implicit cues can be found in several studies which cover a wide range of topics such as market entry decisions, social dilemmas, or even nesting of insects.

When it comes to coordinating market entry decisions, communication between firms is not allowed. However, they have a mutual interest in coordinating on a particular strategy (i.e., pure Nash equilibrium, Nash, 1951). The reason is simple: When firms enter the same market, they make only normal profits, whereas when they enter different markets, each firm makes monopoly profits. Andersson and Holm (2010) allowed communication between firms in an experimental market entry game and studied how communication affects their market entry strategy (i.e., cooperation vs. domination). What is of special interest here is not the communication that was allowed, but that they considered asymmetric entry costs as a tacit coordination cue. It is assumed that certain locations give firms entry cost advantages in their respective home markets (e.g., when firm 1 is at the center of country A and firm 2 is at the center of country B), making the decision as to which firm enters the market of country A or country B more or less self-evident. Efficiency considerations may thus serve as a natural means of coordination (e.g., Schelling, 1960) that is completely tacit because no communication is required and thus no evidence of coordination intent is provided. Put in a nutshell, this, and other studies of this type (e.g., Schelling, 1980) are concerned with how people may use environmental information (i.e., information about features of the coordination situation itself) as so-called focal points for (tacit) coordination (i.e., coordination without communication).

Other research has shown that not only environmental information, but also social information, e.g. in social dilemmas, can provide useful cues for tacit coordination of decisions (see De Kwaadsteniet et al., 2012 for a comprehensive overview). Social dilemmas may include situational features that can be used as a basis for tacit coordination (e.g. van Dijk et al., 2009). In a resource dilemma, for example, where people must decide whether or not to limit consumption of scarce resources, people may focus on the amount that can be harvested collectively without depleting the resource and thereby jeopardizing the collective interest. Because focal points of coordination (e.g., the level of consumption) are defined on the collective level, people need additional means to determine how to coordinate it in the absence of communication. This coordination requirement is met by members basing their decisions according to social norms such as the equal division rule (i.e., calculating what an equal share of the prescribed level would be). A prerequisite for successful coordination is a common understanding (i.e., feeling that others will act alike and adhere to the equal division). If situations provide insufficient cues for tacit coordination (i.e., when a shared understanding is lacking) people base their decisions on their own social value orientations rather than adhering to the equal division rule.

Finally, even biology may offer some useful inputs, for example the concept of stigmergic coordination proposed by the French entomologist Pierre-Paul Grassé (Grassé, 1959). This coordination mechanism concerns, among other things, the question of how insects with very limited intelligence and without obvious communication manage to work together on complex projects, such as the construction of a nest (also known as coordination paradox, see e.g., Theraulaz & Bonabeau, 1999). Stigmergy is a mechanism of indirect coordination via the environment in which a trace left by one action in the environment stimulates subsequent actions enabling complex, coordinated activities without the need for planning, control, communication, direct interaction, or even mutual awareness (Heylighen, 2015).

In summary, a cross-disciplinary look and their respective definitions, operationalizations, and research methods could provide new inputs for developing a comprehensive multilevel under-standing of implicit coordination.

Measurement methods. With respect to the interpretability model of implicit and explicit coordination (cf. Article 1), we included communication ambiguity as a direct criterion for measuring implicit coordination, respectively an indicator for grounding processes, for the first time (cf. Article 2). Nevertheless, like many other studies before ours, we have so far focused primarily on verbal communication. Non-verbal communication was included only in terms of "no communication" (cf. methods section in Article 2). Future studies should also include explicit and implicit non-verbal cues (gestures, or condensed gestures), cues from the action process, or the environment (e.g., beeping monitor) and behavioral cues (e.g., colleague showing signs of stress).

Methods of analysis. Implicit coordination, also in this dissertation, has been analyzed mainly via rather quantitative methods (except for communication ambiguity as a qualitative indicator of grounding/chunking in Article 2). In future studies, however, it may be interesting and also necessary to examine (verbal) communication more qualitatively. This is because even if implicit coordination, for example, may be indicated by shorter rather than lesser communication per se, the communication content may still have an explicit character. In an interview-based study by Bogdanovic et al. (2015) physicians and nurses succeeded in narrating coordination mechanisms traditionally assigned to explicit coordination (e.g., planning or task distribution), whereas they had difficulty extracting implicit coordination structures or behaviors. However, interviewees generally reported that communication in unexpected or more complex situations tended to *decrease* and become more focused and *concise*. As an example of concise communication, Bogdanovic et al. (2015, p. 8) quote "…brief, concise commands" which traditionally would rather be classified as explicit coordination. The German dictionary Duden[6] points in the same direction, listing "unambiguous" among the synonyms of concise. In the course of this dissertation, however, it should have become clear that shortened communication may also rather be an indicator of implicitness. In short, it might be interesting for a future study to investigate how much ambiguity is inherent in the abbreviated verbal communication. In our study in Article 2, we measured communication ambiguity and the shortening of communication (i.e., mean words per communication units) independently of each other. That is, the ambiguity of the communication was analyzed on the basis of the entire communication related to

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a specific (sub-)task, not specifically based on the shortened parts of the communication. However, this would also potentially require new methods of measurement and analysis, likely based on a much more qualitative approach.

Study setting. Article 2 suggest that implicit coordination in acute care teams changes over time given different task demands, specifically with less implicit coordination during tightly coupled tasks. Yet, coordination requirements and patterns may differ in other clinical specialties. In the study by Manser et al. (2008), for example, it appeared that anesthesia teams heavily relied on implicit coordination strategies also during critical episodes of the surgery where both task interdependence and coordination demands were high. To address and better understand such differences in the use of implicit coordination, further studies are needed. Comparatively less explored regarding implicit coordination are, for example, surgical teams. Only one study on implicit coordination conducted in an experimental setting that met our inclusion criteria, and where teams of two performed a laparoscopic task, was included in Article 1 (Gjeraa et al., 2017). This medical field could provide interesting insights because performing surgery can also be highly dynamic and optimal task and team coordination is reached by adapting coordinating behaviors to different task and coordination requirements (e.g., Bogdanovic et al., 2015).

Overall evaluation. In conclusion, the dissertation is critically evaluated referring to the I-P-O models (McGrath, 1964) presented at the beginning (cf. Section 2.2.1). Although we developed a performance rating checklist in Article 4 to measure performance in a challenging scenario for experienced ICU nurses and physicians, this dissertation was mainly focused on effective team coordination processes (P) and omitted the two other parts of the I-P-O model, particularly in Article 2, namely inputs and output variables (e.g., performance). Investigating the influence of observed coordination patterns on performance data was in fact beyond the scope of this dissertation. One reason was clearly the rather small sample size as mentioned above. However, it seems important to include performance measures in future studies; while many studies have found a positive relationship of implicit coordination with various types of performance (De Jong & Fodor, 2017; Fisher et al., 2012; Marques-Quinteiro et al., 2013; Shah & Breazeal, 2010; Stachowski et al., 2009; Stout et al., 1999; Urban et al., 1995; Wang et al., 2018; Zhang et al., 2016), there is also some evidence of the benefit of explicit coordination in high performing groups (Grote et al., 2010; Grote et al., 2004; Xiao, 2001). And although (objective) task performance measures are often tied to the task at hand (e.g., number of shot down aircraft, Volpe et al., 1996), there are others that are not (e.g., error rate). And also, it does not necessarily apply to many measures related to teamwork. It would be desirable to include such teamwork related measures by default in the future, also to increase the comparability of studies. Section 2.4.3 of this dissertation provides useful inputs in developing performance measures. Potential input (I) variables could be, for example, the different knowledge structures such as the general (prior) knowledge of the study participants and the investigation of what it adds to effective coordination processes in repeated task performance. Team-based knowledge structures are a much-cited prerequisite for implicit coordination (see e.g., Rico et al., 2008). Finally, we adopted a multi-cycle view proposed in the IMOI model (Ilgen et al., 2005) by investigating implicit coordination over two consecutive task executions. Taking into account that teams change and develop over time (Arrow et al., 2004; Tschan & McGrath, 2008) is vital in understanding team coordination processes because effective teams tend to adapt their coordination behavior to specific situational factors (Riethmuller et al., 2012).

5.4 Conclusions

This dissertation contributes to small group research on a theoretical, methodological, and practical level. By focusing on health care teams, the overall aim of this dissertation was to gain a deeper understanding of the necessities for successful coordination processes, including the development of appropriate training and measurement methods.

The review on implicit coordination (Article 1) expands our understanding of implicit coordination by presenting the interpretability model of implicit and explicit coordination. Besides its importance for the theoretical interpretation, it has practical relevance for further investigations in the field of implicit coordination.

Article 2 generates challenging research inquiries regarding how implicit coordination unfolds over time, not only by differentiating different task demands in the analysis of implicit coordination but also by connecting linguistic concepts such as grounding/chunking processes or the concept of communication ambiguity to the measurement of implicit coordination.

With the practical guidelines for the development of coding schemes, Article 3 provides a broad methodological knowledge, summarized and directly usable for researchers of small group research, whose method of choice is behavioral observation.

Article 4 on the development of effective simulation scenarios presents a scenario for a specific and important group in the work context, which is often not in focus when it comes to training - *experienced* nurses and physicians. The scenario is specifically designed for training various skills that are necessary in the real health care environment to perform well as a team. With the performing marker checklist, this article in addition provides a tool that clinicians and researchers can use for research purposes or feedback in simulation training.

In conclusion, notwithstanding the limitations outlined in Section 5.3, the articles of this dissertation contribute to answering the overall research question and provide relevant avenues for future research and training. Ideally, the dissertation stimulates further theoretical discussions and possibly new ways to empirically study implicit coordination. And optimally, this should help to identify successful coordination strategies in acute care teams and lead to the (further) development and implementation of new training methods and curricula in (simulation-based) trainings from which both novices and experienced teams can benefit.

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