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Regularity and beyond: Impaired production and comprehension of inflectional morphology in semantic dementia

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A B S T R A C T

Studies on inflectional morphology in semantic dementia (SD) have focused on the contrast between the regular and the irregular English past-tense. These studies aimed to contrast the claims of single- and dual-mechanism theories. However, both theories can account for impaired production of irregular verbs observed in SD. According to the dual-mechanism theory, this impairment is related to word-retrieval difficulties, while according to single-mechanism theory it is the consequence of semantic impairment. However, authors suggest that it is time to envision a broader role for semantic memory in the produc-tion of semantically encoded aspects of inflectional morphology. This study reports the performance of 10 French-speaking patients with SD in three tasks of inflectional morphology. Their performances were compared to those of a group of 20 age-, gender- and education-matched adults without cognitive impairment. Results show that SD patients had difficulties producing tense and person inflection in verbs and pseudo-verbs, whether regular or pseudo-regular. In a second task in which participants were directly exposed to regularity manipulations, SD patients tended to choose a more typical or predictable alternative over a correctly inflected verb. Results of the third task show that their difficulties in produc-ing semantically encoded aspects of inflection, such as tense, are related to difficulties to understand the semantic content conveyed by inflectional morphemes. Overall, these results support the claim that semantic impairment can cause morphological deficits that do not only affect irregular verbs, but that also have impacts on the production and comprehension of semantic information conveyed by inflec-tional morphemes.

Keywords:
Inflectional morphology Semantic dementia Production Comprehension

1. Introduction

Semantic dementia (SD) (also known as the semantic variant of primary progressive aphasia (svPPA) (Gorno-Tempini et al., 2011) is characterised by a central impairment of semantic cognition caused by anterior temporal lobe (ATL) atrophy (Lambon Ralph, 2014; Neary et al., 1998; Patterson, Nestor, & Rodgers, 2007). This semantic impairment is multi-modal and affects all aspects of cognition, whether verbal (e.g., word-finding, reading, etc.) or non-verbal (e.g., object drawing, object use, etc.) (Lambon Ralph, 2014). Over the years, studies have shown that this central impairment has several consequences, including difficulties in language domains that are not traditionally considered to rely heavily on semantic cognition, such as inflectional morphology (Benedet, Patterson, Gomez-Pastor, & Garcia de la Rocha, 2006; Cortese, Balota, Sergent-Marshall, Buckner, & Gold, 2006; Jefferies, Rogers, Hopper, & Lambon Ralph, 2010; Lambon Ralph et al., 2011; Meteyard & Patterson, 2009; Meteyard, Quain, & Patterson, 2014; Murray, Koenig, Antani, McCawley, & Grossman, 2007; Patterson, Lambon Ralph, Hodges, & McClelland, 2001; Patterson et al., 2006; Rochon, Kavé, Cupit, Jokel, & Winocur, 2004; Sajjadi, Patterson, Tomek, & Nestor, 2012; Wilson et al., 2014; for a review, see Auclair-Ouellet, 2015). Support for the presence of morpholog-ical difficulties in SD comes in large part from studies that target the production of inflected verbs in controlled contexts (i.e., carrier

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phrases) (Benedet et al., 2006; Cortese et al., 2006; Jefferies et al., 2010; Patterson et al., 2001, 2006; Wilson et al., 2014). In these contexts, the performance of SD patients is characterised by difficulties to produce the past-tense of irregular verbs, especially those of low frequency, while the production of regular inflected verbs is largely preserved (Jefferies et al., 2010; Patterson et al., 2001, 2006; Wilson et al., 2014). A rTMS study with young partic-ipants without cognitive impairment also supported the involve-ment of ATL in irregular verb inflection (Holland & Lambon Ralph, 2010).

Several studies focusing on the production of the English past-tense were motivated by a debate opposing the dual-mechanism (e.g., Ullman, 2001; Ullman et al., 1997), to the single-mechanism theory (e.g., Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002). According to the dual-mechanism theory (e.g., declarative/procedural model: Ullman, 2001; Ullman et al., 1997), regular and irregular verb inflection are subtended by two completely independent mechanisms: the past-tense form of regular verbs is *generated* by a rule (subtended by procedural memory) while irregular verbs are *retrieved* in the lexicon. According to this theoretical proposition, patients that present lexical/semantic impairment are expected to have irregular verb-retrieval difficulties (Ullman, 2001; Ullman et al., 1997). The single-mechanism theory (e.g., connectionist models such as Parallel Distributed Processing (PDP) Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002), rather suggest that all words and morphemes are represented by distributed patterns of activation over phonological, orthographic and semantic units. Since the past-tense form of irregular verbs is less similar to other forms of the same verb and does not follow the most frequent and predictable pattern of inflection (adding "–ed"), irregular inflected verbs' representations depend more on semantic units. Therefore, irregular verbs, especially those of low frequency, are more vulnerable to semantic impairment.

In the case of SD, both theories can account for the presence of specific difficulties in producing the past-tense of irregular verbs, and most importantly, no specific result or aspect of the participants' performance can rule-out the claims made by either one of the theories (Patterson & Holland, 2014). In fact, it is difficult to imagine an experimental manipulation that would determine that morphological processing is based on rules or on probabilistic connections (McClelland & Patterson, 2002; Patterson & Holland, 2014). Moreover, the interpretation that difficulties with irregular, low-frequency verbs often reported in SD are truly morphological in nature is controversial. In the dual-mechanism account, difficulties with these verbs can be explained by lexical retrieval impairment rather than morphological processing deficits (Kavé, Heinik, & Biran, 2012). Also, because semantics and grammar are traditionally considered as two independent and non-interacting aspects of language, some authors have claimed that irregular verb inflection deficits in SD could not be attributed to semantic impairment caused by ATL atrophy. According to these authors, morphological deficits would rather be related to additional language impairments caused by the progressive atrophy of neighbouring language regions of the brain (Bright, Moss, Stamatakis, & Tyler, 2008; Tyler et al., 2004).

It appears that by focusing on regularity, studies of morphology in SD have narrowed their scope on a very specific aspect of morphological processing and might have overlooked other aspects (Bishop, Nation, & Patterson, 2014). In fact, these studies and the theories on which they are based have not addressed how morphology is used to translate semantic information from the broader context into a conventional and synthetic way, i.e. inflectional morphology. This aspect of morphology, however, is more fundamentally semantic and is therefore susceptible to impairment in the case of central semantic impairment caused by ATL atrophy. Studies on aphasia of vascular origin bring interesting insight regarding this matter.

Following dual-mechanism perspectives of inflectional morphology and the tradition of aphasiology, patients with agrammatism in Broca's aphasia are expected to show larger impairments in the production of regular compared to irregular inflected verbs (Faroqi-Shah, 2007). According to this view, regular verbs are generated by the concatenation of a root and an affix at the stage of phonological encoding (Levelt, 1989). The fact that regular verbs are produced by assembling two elements instead of retrieving only one (as is the case for irregular verbs) makes them more complex, and hence more vulnerable to difficulties at the stage of phonological encoding, which is considered as the locus of morphological difficulties in Broca's aphasia (Levelt, 1989). However, it seems that dissociations of performance in agrammatism are the exception rather than the rule. A meta-analysis (Faroqi-Shah, 2007) found that half of the data sets analysed did not report dis-sociation in performance between regular and irregular verbs and that some studies even reported the opposite pattern of dissocia-tion (larger impairment for irregular verbs compared with regular verbs).

Faroqi-Shah and Thompson (2003, 2004, 2007) proposed a hypothesis that could account for impairments found in both regular and irregular verb inflection in aphasia. According to the Diacritical Encoding and Retrieval hypothesis (DER), inflectional difficulties find their origin at the stage of diacritical features, which can be defined as parameters (such as tense and number) that must be specified in order to select the correctly inflected form of a verb. The authors suggest that diacritical feature impairments could take two forms: (1) difficulties in the activation of diacritical features based on the information provided by the context (e.g., time cues given by adverbs such as Yesterday, Tomorrow) and,(2) difficulties to retrieve the correct form of the verb based on diacritical feature activation. The first type of difficulties proposed by Faroqi-Shah and Thompson suggests an involvement of semantic (conceptual) nature in morphological impairments. For example, difficulties in semantic time processing could have impacts on the production of tense inflection in verbs. According to Faroqi-Shah and Thompson, the morphological difficulties of patients with agrammatism would be caused by impaired retrieval of an inflected form based on diacritical feature activation, the activation (or encoding) of diacritical features itself being well preserved. However, the two different forms of impairments found at the diacritical feature stage remain difficult to tease apart in practice, and since diacritical features are *syntactic* properties of the lemma (the lexical representation of a word) (Levelt, 1989), the question of how semantic/conceptual information is translated into diacritical features remains unclear.

Results suggesting that semantics would play a role in morphology were also found in studies on paragrammatism. Paragrammatism is an ensemble of language difficulties found in aphasia and characterised by impairments of syntax and morphology in an otherwise fluent language profile (Bastiaanse, 2011; Butterworth & Howard, 1987; Edwards, 2005). It has been far less studied than its pendant in non-fluent language profiles, agrammatism, yet sev-eral hypotheses were put forward to explain the origin of difficul-ties found in this language profile: lexical retrieval difficulties, syntactic and/or grammatical problems, or semantic/syntactic integration problems (Bastiaanse, 2011; Butterworth & Howard, 1987; Edwards, 2005). A recent study by Bastiaanse (2011) showed that in spontaneous language production, patients with paragrammatism produced as many verbs as normal control subjects and that the verbs they produced had normal diversity (as measured

by type/token ratio) as long as these verbs did not have to be inflected in the context (non-finite verbs). However, patients with paragrammatism produced few inflected verbs and they tended to reuse the same ones in a short language production sample. Bastiaanse concluded that these patients presented a semantic/syntactic integration problem. In fact, producing inflected verbs would be a challenge, not because they are more complex from a grammatical point of view but because they are more semantically complex. It is the production of several different pieces of information in a single word that would be difficult for patients with paragrammatism.

Up to now, models that adopt a single-mechanism perspective have focused on a rather specific aspect of semantic impairment in morphology, namely its importance in the representation of irregular verbs, but authors suggest that it is time to consider a broader role for semantic cognition (Bishop et al., 2014). In PDP models of morphology, semantic units are one of three types of units that subtend the representation of all words and morphemes (Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002). Contrary to lexical models and to localist connectionist models (e.g., Bates & Wulfeck, 1989), PDP does not represent morphemes as "fixed", independent language units. What are identified as morphemes on the surface are in fact the result of connections between form (phonological, orthographic) and meaning (semantic) units. These connections are established and reinforced through language use. Therefore, frequent form-to-meaning mappings are strongly reinforced and they gain a form of "saliency" in language. A study by Patterson and Holland in non-fluent post-stroke aphasia (2014) suggests that inflectional difficulties would be directly related to the comprehension of the notion of time and that this would impact on verb tense agreement, via an impairment of the form-to-meaning mapping at the basis of morphology.

As shown by these studies, taking into account the involvement of semantic processing, not only in the representation of irregular verbs, but also in the semantic representation of information that is transmitted by morphological marking (e.g. tense) opens up new perspectives. Also, up to now, most studies of inflectional morphology in SD have been conducted with English speaking patients and only a few studies (mostly case studies) have reported results in other languages (Benedet et al., 2006; Diesfeldt, 2004; Kavé et al., 2012; Lambon Ralph et al., 2011). English has a simple morphological system, with only a few different inflected forms for each verb; and unlike other languages, words are inflected for only one piece of information at a time (e.g., tense – "played" – or person – "plays" – not both). The goal of this study is to specify semantic cognition's involvement in structural aspects of morphology like morpheme assembly and regularity, but also in the production and comprehension of semantically encoded aspects of inflection, such as tense. This study was conducted in French, a language with a complex morphological system, which gives the opportunity to explore these aspects.

2. Methods

2.1. French morphology

In French, verbs are inflected for person, number, mood and tense (Grevisse, 1995). Some inflections are phonologically identical but differ in orthography (e.g., for the verb "jouer" (to play): "je joue" (first person singular), "tu joues" (second person singular), "ils jouent" (third person plural) are all pronounced /ʒu/). In general, person and number inflection are associated to three or four phonologically distinct endings for a specific mood or tense. For specific persons and numbers, differences between moods and tenses are also marked phonologically: "je joue" (/ʒu/) (I play); "je jouais" (/ʒuɛ/) (I played); "je jouerai" (/ʒuʁe/) (I will play); "je jouerais" (/ʒuʁɛ/) (I would play).

The majority of French verbs are subdivided in four conjugation classes based on their endings in the infinitive. The class of verbs that end in "-er" contains the majority of French verbs and is considered as the true regular conjugation class (Grevisse, 1995). Verbs ending in "-er" are formed by adding inflectional affixes to the root, which remains unchanged (at least phonologically) for all moods and tenses. Verbs ending in "-ir" represent around 330 verbs. They are the second most regular form of verbs in French, but they are subdivided in two conjugation patterns: verbs that follow the model of "finir" and have an allomorphic root with dou-ble "s" in some tenses and moods – "finir": "finissant" (finishing); and those that do not – "partir": "partant" (leaving). This allomor-phy confers some unpredictability to verbs ending in "-ir", which can be considered as "pseudo-regular". The third and fourth classes are composed of verbs ending in "-oir" and "-re", respectively. Together, these last two classes represent less than 150 verbs. They can also be considered "pseudo-regular". Finally, like English, French has irregular verbs with suppletive forms. These verbs are either highly frequent (e.g., "aller" (to go): "je vais" (I go); "nous allons" (we go); "j'irai" (I will go)) or slowly falling out of use.

In summary, irregularity results mostly from root variation in French. Except for verbs with suppletive forms, inflected verbs can be decomposed into their roots and endings, even when they are pseudo-regular. Also, endings associated to persons, numbers, moods and tenses remain mostly the same between conjugation classes. For example, the pseudo-regular verb "ils finissent" (they finish) has the same ending as the regular verb "ils chantent" (they sing). Instead of depending on the possibility to be formed with a specific ending, regularity in French depends mostly on the consistency of the root in all inflected forms.

2.2. Participants

The participants, all native speakers of Quebec French, completed standard evaluation of language and a neuropsychological test battery, as well as experimental tasks of morphology. The study was approved by the institutional ethics committee of the Centre Hospitalier Universitaire de Québec (CHUQ), of the Institut de Gériatrie de Montréal (IUGM) and of the Institut Universitaire en Santé Mentale de Québec (CRIUSMQ). All participants gave written informed consent for their participation.

Ten SD patients were recruited at the CHUQ and the IUGM. The SD diagnosis was based on criteria proposed by Neary et al. (1998): presence of significant loss of word meaning, demonstrated by impaired single word comprehension and word-finding difficulties and was made by a neurologist. MRI showed anterior temporal lobe atrophy in all patients. Five patients had more severe atrophy in the left hemisphere, two patients had more severe atrophy in the right hemisphere and three patients had bilateral atrophy. For each SD patient, two age, gender and education matched adults with normal cognition (MoCA; Nasreddine et al., 2005) were recruited to form the control group. The experimental and the con-trol groups were well matched for age, gender and education ($p > .05$). Exclusion criteria for both groups were: history of psychi-atric disorder, history of brain damage of traumatic or vascular ori-gin, history of drug or alcohol abuse, uncorrected vision or hearing problems, six years of education or less. Demographic characteristics, and results in language and neuropsychological tests are provided in Table 1. The SD group was similar to other groups reported thus far in the literature in terms of age, education and gender balance. The results show preserved performance in some spheres of cognition such as attention and working memory. Language tasks show impairments coherent with the portrait of SD.

Table 1
Socio-demographic profile, neuropsychological tests and language tests.

		SD (n = 10)		Control (n = 20)	
		Mean	s.d.	Mean	s.d.
Age		66.2	7.55	66.55	7.39
Gender		3 F: 7 M		6 F: 14 M	
Education		15.3	4.3	15.65	2.85
MoCA		18.4[ab]	3.27	27.05	2.09
ROCF	Copy (36)	31.60	2.14	33.18	2.32
	Recall – 3 min (36)	10.20[a]	7.44	19.30	6.89
	Recall – 20 min (36)	12.67[b]	8.36	19.53	6.91
BORB	Line length judgment (30)	26.00	2.05	26.95	1.54
	Object judgment – List A (32)	20.10[ab]	3.63	25.45	2.95
	Object judgment – List B (32)	22.86[ab]	5.43	29.90	2.13
DS-LS	Forward	6.10	0.74	6.80	1.01
	Backward	4.50	1.18	4.80	1.32
TMT	A – Simple	55.10	22.05	38.58	11.03
	B – Alternate	128.10[a]	65.35	70.26	21.28
PENO – Praxis	Meaningless gestures (35)	29.4[b]	2.91	31.00	2.70
	Pantomimes (35)	21.90[ab]	10.19	34.20	1.47
TDQ-60 (60)		25.30[ab]	13.28	57.70	1.81
Verb video naming (100)		47.60[a]	21.29	95.70	4.28
MEC – Fluency	Unconstrained	24.20[ab]	11.33	66.70	14.08
	Letter p (2 min)	8.30[ab]	3.37	29.50	10.45
	Items of clothing (2 min)	6.50[ab]	5.17	26.05	5.86
PPTT	Image-image condition (52)	31.80[ab]	10.59	50.22	1.70
KDT	Image-image condition (52)	37.40[ab]	6.70	48.00	2.90
Semantic written word matching (40)		26.30[a]	9.42	39.05	0.94
Reading	Words (24)	21.00[a]	3.56	24.00	0.00
	Pseudo-words (15)	9.90[a]	1.73	12.05	2.16

Abbreviations
ROCF: Rey-Osterrieth Complex Figure; PENO: Protocole d'Évaluation Neuropsychologique Optimal; BORB: Birmingham Object Recognition Battery; DS-LS: Digit Span, Longest Span; TMT: Trail Making Test; TDQ-60: Test de Dénomination de Québec, 60 items; MEC: Protocole Montréal d'Évaluation de la Communication; PPTT: Pyramids and Palm Trees' Test; KDT: Kissing and Dancing Test; BECLA: Batterie d'Évaluation Cognitive du Langage.
[a] Signals an impaired performance compared with this study's control group (n = 20) (Mann–Whitney, $\alpha = p < .05$, two-tailed).
[b] Signals an impaired performance according to published norms (below the point of alert or two standard deviations below the reference mean).

2.3. Procedure

The participants completed three experimental tasks: production of inflected verbs and pseudo-verbs, inflected form selection, and inflected verb and pseudo-verb to time cue matching. Detailed methods, results and a discussion for each task will be presented in the following sections.

Stimuli were presented in a semi-random order using DMDX (Forster & Forster, 2003). The software automatically generated a file detailing RTs and the type of answer (correct or error) for each item. Written words were presented on a laptop computer screen in Times New Roman, 16 points, black characters over a white background. As they saw the stimuli, participants also heard their recording through headphones. Stimuli were recorded in a sound-proof room by the main experimenter. Minimal volume intensity was the same for all participants but it was raised at their demand to a level judged comfortable. Simultaneous written and oral presentation was done with the aims of controlling for the potential presence of reading difficulties in SD.

Before each task, the experimenter read the instructions with the participant and made sure he or she understood the task. The participants completed practice items before each task and were not given feedback during the completion of experimental items. Depending on the task, they produced their response orally or by pressing on a button. At the onset of the carrier phrase or of answer choices, the participants had eight seconds to produce an answer. Reaction times (RT) were collected in forced-choice format tasks but not in the production task because of potential problems related to false starts, repetition of the carrier-phrase, etc.

2.4. Data analysis

Once the errors were removed, RTs of the two forced-choice format tasks were screened for the presence of outliers. Results were stratified according to variable of interests. RTs that fell above or below two standard deviations from their reference mean were considered as outliers and removed from the analysis (Baayen & Milin, 2010). No more than 5% of each group's observations were removed in this process. Corresponding behavioural data were also removed from the analysis.

The difference between groups and the effect of variables of interest was analysed using linear mixed-effects models in R (R core team, 2004) with the "lme4" package (Bates, Maechler, Bolker, & Walker, 2014). Statistical significance of effects was obtained using likelihood ratio tests.

3. Inflected verb and pseudo-verb production task

This task's goal was to specify the role of semantic cognition in the processes responsible for morpheme assembly and their relation with regularity. This task manipulates verb regularity in a way that is more representative of French morphology, that is by contrasting regular and pseudo-regular verbs. This task also addresses the role of semantic cognition in the transmission of different pieces of information (tense, person) required in the production of inflectional marking. French verbs need to be inflected for several pieces of information at a time, which gives the opportunity to study the impact of semantic impairment in complex inflectional marking.

3.1. Material

A verb or pseudo-verb and a short carrier phrase were presented to the participants. They were asked to complete the carrier phrase by producing an inflected verb that respected its requirements regarding tense (future) and person (second or third plural). An example of a real verb item was "verse/Demain, ils" (pour/Tomorrow, they). The corresponding pseudo-verb item was "*-tirse/Demain, ils". Tense (future) and number (plural) were held constant but grammatical person (second or third) varied between items. The choice to vary only one aspect was done in order to limit demands in terms of mental flexibility. Also, the second and third person plural forms of the future tense are well contrasted phonologically, which is not the case for all inflected forms in French.

Regularity was manipulated by contrasting regular verbs (infinitive form ending in "-er") and pseudo-regular verbs (infinitive form ending in "-ir"). Irregular verbs with suppletive forms (e.g., "aller" – to go) were not used because they are either highly frequent (which explains why they were not regularised and are still in use), or slowly falling out of use (Grevisse, 1995).

The experimental list comprised 36 real-verbs and 36 pseudo-verbs (half regular, half pseudo-regular) with a length of 1–3 syllables. The inclusion of a pseudo-verb condition had the purpose to control for lexical support in inflectional morphology production. Verbs were controlled for spoken token frequency (between 3.95 and 39) using the Lexique database (New, Pallier, Ferrand, & Matos, 2001). Average token frequency was not different between the regular (mean: 13.88; s.d.: 9.45) and pseudo-regular verbs (mean: 9.21; s.d.: 6.47) ($t(34) = 1.731$, $p = .093$). No verb was exclu-sively pronominal or intransitive. Each pseudo-verb ($n = 36$) was constructed by substituting the two or three first phonemes of its corresponding verb. Each pseudo-verb was similar to real verbs in terms of syllable complexity.

In English, verbs given as starting point in production tasks are usually presented in the present-tense form. English has the particularity to have no overt marking of inflection for certain conjugations, which means that these verbs are identical to their citation form and their root. In French, no verb form is uninflected, even the infinitive. Choosing an inflected form that was as similar as possible to the verb's root was done with the purpose of limiting the cues to the expected inflected form (e.g. presence of "r" in the future-tense form). Therefore, to this respect, regular verbs were presented in the first/third person singular of the indicative present tense (e.g., "profite" (benefit/benefits)) and pseudo-regular verbs were presented in the singular, masculine past participle (e.g., "fourni" (provided)).

3.2. Results

Two SD patients did not complete the pseudo-verb condition because of important difficulties to understand task instructions. All the responses, transcribed by the first author, were categorised as a correct answer or an error, and were stratified according to lexicality status (verb or pseudo-verb), regularity (regular or pseudo-regular) and person (second or third person plural).

The results were not normally distributed and analyses had to be conducted on transformed data (substraction of each score from a constant and inversion of the result). Fig. 1 gives mean raw scores for participants of both groups.

Results were fitted and analysed with a linear mixed-effect model. Fixed effects included group, lexicality, and regularity as predictors and person as a control variable. A random intercept effect for participants and random slope effects for lexicality and regularity by participants were also included in the model.

The analysis revealed significant effects of group, with lower performance for the SD group on average ($Chi^2(1) = 19.833$, $p < .001$). The effect of lexicality was also significant ($Chi^2(1) = 14.172$, $p < .001$). The effect of regularity was not significant ($Chi^2(1) = 1.7325$, $p = 0.19$). The simple interaction effect between lexicality and regularity was significant ($Chi^2(1) = 4.3323$, $p < .05$) and the difference between the two levels of regularity was less marked for real verbs. None of the other interaction effects were significant.

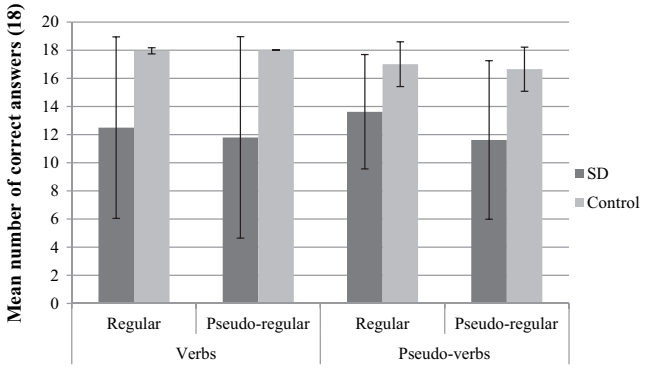


Fig. 1. Average score in the verb and pseudo-verb production task.

Errors were for the most part close to the expected target. Non-responses were rare overall, except for the SD patient who had the most severe semantic impairment. Regularisation errors (i.e., inflecting pseudo-regular verbs as if they were regular verbs ending in "–er": "ils *réunireront" instead of "ils réuniront" (they will reunite)) were rare and were produced in the real verb condition only. Of the 117 errors produced by SD patients in this condition, only 13 could be described as regularisation errors and 12 were produced by the same participant. In fact, most errors in the real verb and the pseudo-verb conditions consisted in tense and person errors.

A more detailed analysis of errors was conducted to compare the proportion of errors produced on the root (e.g., lexicalisation of a pseudo-verb) or on the inflectional part of the items (e.g. tense and/or person agreement errors) in both groups. Each error (203 in the SD group and 47 in the control group) was analysed according to the successful production of three types of information: root, tense agreement and person agreement. This analysis revealed that in the control group, errors were mostly caused by a misproduction of the root (e.g. phonological error, lexicalisation). In fact, in the 47 errors made by participants of the control group, the root was cor-rect only 6.38% of the time. In contrast, inflection for tense and inflection for person was correct 91.49% and 95.74% of the time, respectively. The pattern is different in the SD group. In the 203 errors made by the participants of this group, the root was correctly produced 60.1% of the time. Most importantly, inflection for tense was correct 51.72% of the time and, inflection for person only 31.51% of the time. The repartition of these proportions of correctly produced information for root, tense, and person inflection was different between the two groups ($Chi^2(2) = 51.12$, $p < .001$).

3.3. Intermediate discussion

Results show that SD patients had significant inflectional morphology difficulties compared with the control group. The significant lexicality effect seems to be driven mostly by the better performance of control participants for real verbs. The lexical status of items supported the performance, at least in the control group. However, the results did not reveal any significant regularity effect. More interestingly, the absence of interaction effect between group and regularity suggests that SD patients did not have more difficulties for pseudo-regular than for regular verbs.

In the current study, regularity was manipulated by comparing regular to pseudo-regular verbs. While this comparison may be more representative of French morphology as a whole, it is not as strong as the comparison of regular and irregular verbs in English. This result does not run contrary to those observed in English but is related to the graded nature of regularity and more complex morphology of French.

Regularisation errors were rare in the SD group. Because they required root modification, it was probably less likely to observe this type of error compared to English in which "–ed" tends to be added systematically. The detailed analysis of errors shows that in the SD group, errors mostly concern the inflectional part of items and not their root. This error pattern supports the conclusion that their difficulties are really morphological in nature rather than paraphasias that affect the verbs' roots.

Our results are in line with more recent perspectives on morphology that suggest that morphological difficulties may affect both regular and irregular (or in this case pseudo-regular) verbs (Faroqi-Shah & Thompson, 2003, 2004, 2007) and that errors can be caused by the challenges related to the production of semantic information (e.g., tense, person, etc.) in inflectional morphemes (Bastiaanse, 2011; Bishop et al., 2014). Central semantic impairment would have an impact over the representation of these types of information or would impair their integration in the form of inflected verbs.

Even though the regularity effect did not reach significance, patients with SD were slightly more impaired with the pseudo-regular than with the regular verbs. Due to the design of the carrier phrases and word-cues, the participants were not directly exposed to what causes verbs to be pseudo-regular in French (i.e., root allomorphy between different inflected forms of the same verb) but it was assumed that this factor could still exert an influence over performance because of the competition between the dominant, regular "–er" pattern, and the pseudo-regular pattern. The results of a second task addressing the influence of regularity over the performance of SD patients are presented below.

4. Inflected form selection task

This task explored the role of semantic cognition in the processing of more idiosyncratic, pseudo-regular verb forms. According to connectionist models, these verbs' representations rely more on semantic units than regular verbs' representations because they overlap less in phonology and orthography with the other forms of the same verb (Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002). In this task, participants were directly exposed to manipulations in terms of regularity and had to choose the correctly inflected form of a verb. The task had the purpose to test the influence of phonological and orthographic typicality and predictability over performance in SD.

4.1. Material

Participants saw a sentence ("Demain, ils…" – Tomorrow they) with a regular verb ending in "-er" (e.g. "filmeront": (they) will film) or a pseudo-regular verb ending in "-ir" or "-re"(e.g. "éteind ront": (they) will turn off) inflected in the future tense, followed by the beginning of another sentence comprising a present tense cue (i.e., time adverb "Aujourd'hui" which means "Today"). They were then presented with two inflected verbs and were asked to choose the one that completed the sentence correctly. In half of the items, the distractor was a verb inflected for the wrong person (second person plural instead of third person plural; e.g. "filmez" instead of "filment"). In the other half, the distractor focused on regularity and was either a "regularised" or "irregularised" version of an inflected verb.

Distractors that manipulated regularity were constructed differently for the regular and the pseudo-regular verbs. For regular verbs, regularity distractors were "irregularised" pseudo-verbs. These items were formed using an inflection pattern that is less frequent and less regular than the completely regular "–er" pattern. More precisely, the distractors were constructed by adding the ending of verbs in "–ir" with a double "s" allomorph such as "finir" (to end) to the root of a regular verb (e.g., instead of "ils filment" (they film): "ils *filmissent"). For pseudo-regular verbs, regularity distractors were constructed by keeping the future tense root (which also corresponds to the infinitive root) and adding the ending of present tense regular verbs (e.g., instead of "ils éteignent" (they turn off): "ils *éteindent"). The task included 48 items, divided in four types: 12 regular verbs with a "wrong person" distractor, 12 regular verbs with an "irregularised" distractor, 12 pseudo-regular verbs with a "wrong person" distractor and 12 pseudo-regular verbs with a "regularised" distractor.

Regular verbs are from the most regular conjugation in French (verb in "–er"). Pseudo-regular verbs have an allomorphy of the root between the present and the future tense form (e.g., "ils rejoindront" (they will reach), "ils rejoignent" (they reach)). Verbs in the future form were controlled for token frequency (New et al., 2001). Mean token frequency was not statistically different between verb types (regular and pseudo-regular: Chi^2 (1) = 3.154, p = 0.08) or conditions ("wrong person" distractor and "regularity" distractor: Chi^2 (1) = 0.41, p = 0.84). Verbs in the future tense had between two and four syllables. Response choices (verbs and pseudo-verbs in the present tense) had between one and three syllables.

4.2. Results

The majority of errors were caused by the choice of the distractor and not by the expiry of answer delay. Items were stratified for regularity (regular or pseudo-regular verb) and for the type of distractor ("wrong person" or "regularised/irregularised" alternative). Crossing these two factors gave four subscores. One item had to be eliminated because of a problem in the recording of the stimuli. The score for this subcategory of items was weighted to make it equivalent to scores from other categories. Fig. 2 presents behavioural and RT results for both groups.

Analyses were conducted using a linear mixed-effect model. Fixed effects comprised group, regularity and distractor type. A random intercept effect for participants and random slope effects for regularity by participants were also included in the model. When a random effect of distractor type by participants was included, the model did not converge so this effect was omitted from the final model.

Analysis of behavioural data showed a main effect of group, with SD patients producing fewer correct responses on average (Chi^2 (1) = 11.327, p < .001). There was no main effect of regularity (Chi^2 (1) = 1.3771, p = 0.24) or distractor type (Chi^2 (1) = 1.8474, p = 0.17). The three simple interaction effects were statistically sig-nificant (group by regularity: Chi^2 (1) = 4.9569, p < .05; group by distractor type: Chi^2 (1) = 6.1472, p < .05; regularity by distractor type: Chi^2 (1) = 5.913, p < .05). The multiple interaction effect between group, regularity and distractor type was also significant (Chi^2 (4) = 38.085, p < .001). Overall, these results show that SD patients had significant difficulties for pseudo-regular verbs, but only when they were presented with a regularised alternative.

The same model was used to fit and analyse RT data. Results show a main effect of group (Chi^2 (1) = 5.685, p < .05). SD patients were slower to produce their responses overall. The effect of

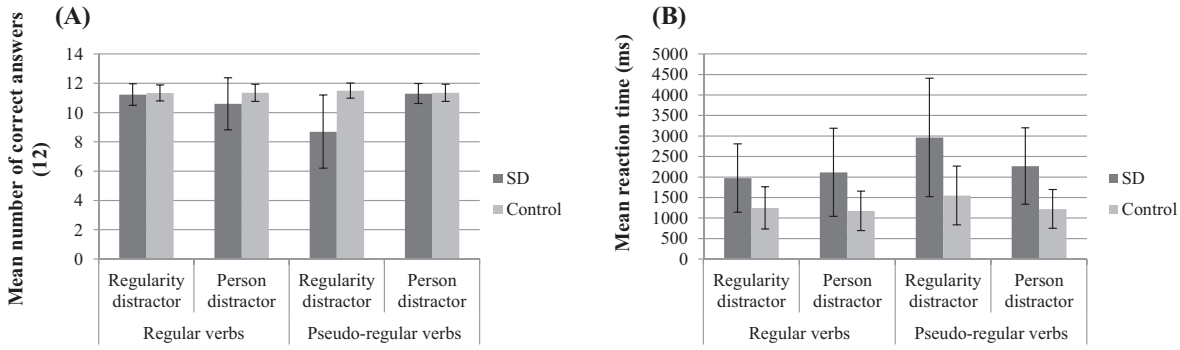


Fig. 2. Correctly inflected verb choice between two alternatives.

regularity (Chi^2 (1) = 14.41, $p < .001$) was also significant and showed slower responses for pseudo-regular verbs compared to regular verbs in all the participants. Responses were also slower in all the participants for items that were presented with a regularised alternative, as shown by the significant distractor type effect (Chi^2 (1) = 12.597, $p < .001$). Regarding simple interaction effects, group by regularity (Chi^2 (1) = 7.493, $p < .01$) and regularity by distractor type (Chi^2 (1) = 15.194, $p < .001$) were significant, but not group by distractor type (Chi^2 (1) = 0.3857, $p = 0.53$). The mul-tiple interaction effect between group, regularity and distractor type was also significant (Chi^2 (4) = 30.477, $p < .001$). The multiple interaction effect is coherent with behavioural results and shows that SD patients had significantly slower RTs for pseudo-regular verbs, but only when they were presented with a regularised alternative.

4.3. Intermediate discussion

The analysis of behavioural data shows that SD patients had specific difficulties to choose the correctly inflected form of a pseudo-regular verb, but only when it was presented with a regularised alternative.

RT analysis revealed a similar significant three-way interaction showing that SD patients had longer response latencies for pseudo-regular verbs presented with a regularised alternative compared with the control group. However, contrary to the analysis of behavioural results, RT analysis showed main effects of regularity and distractor type, but no interaction of group by distractor type. These results show that items in which a pseudo-regular verb was presented with a regularised alternative were associated with longer response latencies in both groups. Participants from the control group managed to choose the correct verb more often than SD patients, but still took longer to do it for these items.

The results suggest that processing pseudo-regular verbs, i.e. verbs that are more idiosyncratic, comes with a processing cost. Control participants took more time to choose the correctly inflected form of a verb but in the end, their intact semantic representations outweighed orthographic and phonological information that were more compatible with the regularised alternative. SD patients, on the other hand, could not benefit from normal semantic representations and were in a state of "imbalance". In other words, their preference was tilted in favour of phonological and orthographic consistency between verb forms and they chose the regularised alternative more often than the control participants. "Irregularised" alternatives were less likely than the correct answer, and did not represent a difficulty. Similarly, the possible interference caused by the "wrong person" alternative was not sufficient to rule-out the correct answer.

These results are compatible with the general tendency of SD patients to favour more "typical" answers, i.e. answers that follow the most frequent pattern of a given domain of language or cognition (Patterson et al., 2006, 2007). They also show that in normal performance, the most frequent pattern of answer is counterbalanced by information coming from an intact semantic system. These results suggest that difficulties of SD patients with irregular items would be related to reduced semantic input in morphological processing, not general lexical retrieval difficulties that would prevent them from retrieving the inflected form from the lexicon. However, other studies are needed to confirm this result.

5. Inflected verb and pseudo-verb to time cue matching

The verb and pseudo-verb production task showed that SD patients have difficulties to produce tense and person marking in morphological inflection. However, whether these difficulties derive from impairments in the comprehension of morphological requirements presented in the carrier phrase remains unclear. This question is specifically addressed in the third task of the present study.

This task's goal was to specify semantic cognition involvement in the capacity to understand temporal semantic information included in inflectional morphemes. This capacity was assessed with a task requiring the selection of an inflected verb based on a time-cue given by an adverb. Contrary to other tasks, this task did not aim to assess morpheme assembly. For this reason, regular-ity, number and person were held constant, and only tense was manipulated.

5.1. Material

In this task, participants saw a verb or a pseudo-verb in the infinitive form, followed by a short carrier-phrase composed of a time adverb ("Aujourd'hui" (Today), "Hier" (Yesterday) or "Demain" (Tomorrow)) and of the pronoun "il" (he). They were then asked to select, from amongst three different choices, the inflected form of the same verb or pseudo-verb that completed the sentence correctly. Distractors consisted in verbs or pseudo-verbs inflected for the wrong tense (e.g. verbs in their future and past-tense forms for a target in the present tense). The inclusion of a pseudo-verb condition had the goal to test for the presence of a lexicality effect on the processing of inflectional morphemes' meaning and to control for the lexical support provided by roots and whole words in the real verb condition.

This task included 36 verbs and 36 pseudo-verbs. The verb list included no ditransitive verbs and no exclusively intransitive or pronominal verbs. It comprised regular verbs ending in "–er" of two (18 verbs) or three (18 verbs) syllables length. Verbs in the infinitive form were controlled for spoken type frequency (comprised between 30 and 100) (New et al., 2001). The verbs

were presented in carrier phrases that targeted three tenses (12 verbs per target tense): past (imperfect), present and future. All verb tenses were formed by inflectional marking and not by the use of an auxiliary. In each trial, the correct answer was the verb form correctly inflected for tense and the two distractors were forms of the same verb inflected for the two other tenses included in the task. For example, the verb "signer" (to sign) was followed by the carrier phrase "Demain il" (Tomorrow he) and the partici-pants had to choose which inflected verb completed the sentence correctly between "signe" (signs), "signait" (signed) and "signera" (will sign).

The 36 pseudo-verbs were constructed based on real verbs by changing the first two or three phonemes (e.g. "former" (to form): "*pirmer"). Each pseudo-verb had the same number of syllables and respected the syllable structure of its associated real verb (e.g., consonant groups).

5.2. Results

The majority of errors were caused by the choice of the distractor and not by the expiry of answer delay. Items were stratified according to lexicality status (verb or pseudo-verb) and target time (past, present, future). Fig. 3 presents behavioural and RT results for both groups.

Analyses were conducted using a linear mixed-effect model. Group and lexicality were entered as predictors. Target time was included among fixed effects as a control variable. A random intercept effect for participants and random slope effect for lexicality by participants were also included in the model.

The analysis revealed a significant effect of group (Chi^2 (1) = 5.5531, $p < .05$), with participants of the SD group committing more errors on average than participants of the control group. The effect of lexicality was not significant (Chi^2 (1) = 1.7412, p = 0.19). Interaction between group and lexicality was not signif-icant (Chi^2 (1) = 1.8276, $p < 0.18$).

The same model was used to fit and analyse RT data. Results are in line with behavioural data and show a significant effect of group (Chi^2 (1) = 13.093, $p < .05$) that indicates longer response latencies in the SD group. The effect of lexicality was not significant (Chi^2 (1) = 0.4525, p = 0.5). Interaction between the two factors was not significant (Chi^2 (1) = 1.3528, p = 0.24).

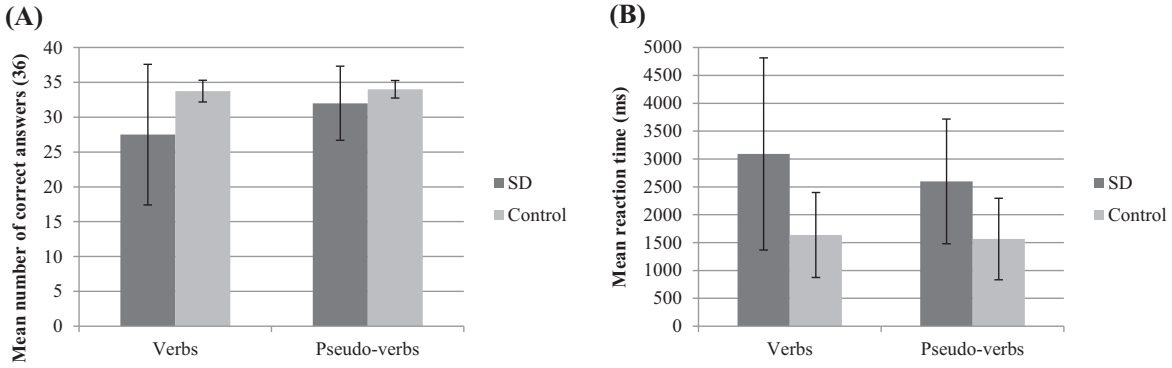
This analysis considered that there was only one correct answer for each item. However, in everyday language, it is not uncommon to encounter "Today" followed by the future tense (e.g., to refer to an event that will happen later in the same day), or "Tomorrow" followed by the present tense (e.g., to refer to an event in the close future that is very likely to happen). To account for the possibility that this might have influenced the results, a second analysis was conducted for items targeting the past tense only. In French, "Hier" (Yesterday) cannot be followed by the present or the future, making the past the only possible correct answer and avoiding any potential ambiguity.

The model included group and lexicality as predictors and a random intercept effect for participants. The results replicate those obtained when all three target times are considered. For the number of correct answers, the analysis reveals a significant effect of group (Chi^2 (1) = 8.937, $p < .01$), no effect of lexicality (Chi^2 (1) = 1.404, p = .24), and no interaction between the predictors (Chi^2 (1) = 3.611, p = .06). For RT, the analysis shows a significant effect of group (Chi^2 (1) = 11.604, $p < .001$), no effect of lexicality (Chi^2 (1) = 2.739, p = .10), and no interaction between the predictors (Chi^2 (1) = 0.967, p = .33).

5.3. Intermediate discussion

Both behavioural and RT results show that on average, participants of the SD group had more difficulties to choose the correctly inflected form of a verb based on a time cue provided by an adverb. This conclusion is supported by the global analysis and an analysis that considered only unambiguous responses targeting the past tense. The main effect of lexicality and the group/lexicality interaction were not significant, showing that real verbs did not provide additional support to the performance. In fact, since the verbs' root did not add relevant information to choose the correct answer, it was possible to ignore it in both conditions and to focus on inflectional morphemes to perform the task.

Difficulties of SD patients in this task are another of the many consequences of the central semantic impairment that characterises this disease. In fact, semantic impairment would affect semantically encoded aspects of inflectional morphology, such as tense. This interpretation is compatible with several models that suggest that semantic cognition would play a role in inflectional morphology. This role could be rather indirect as in the DER of Faroqi-Shah and Thompson (2003, 2004, 2007) in which conceptual requirements of the sentence would set a number of parameters named "diacritical traits", which would guide the selection of the correctly inflected form of a verb. According to other models such as PDP, semantic cognition plays a central role in inflectional morphology since it is directly involved in the representation of morphemes in the form of distributed patterns of activation (Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002). Recent studies have started to shift the focus of semantic involvement in irregular verb representation to consider its broader role in form-meaning association (Patterson & Holland, 2014; Bishop



A. Behavioural data: mean number of correct answers
B. RT: mean RT

Fig. 3. Inflected verb to time-cue matching.

et al., 2014). This newer approach still needs to be developed further but it could account for the presence of impaired tense inflection processing in the context of central semantic impairment.

No hypothesis was made regarding a possible processing difference between the three target times. Studies on people with agrammatism following stroke suggest that verbs in the past tense would be harder to process than other verbs because they require discourse linking, which would not be the case for verbs in the present and future tense (Bastiaanse, 2013). However, results show that verbs in the present and future tense are not completely spared. A careful examination of semantic and pragmatic properties of verb tenses but also verb stems could bring relevant information regarding this matter in future studies.

6. Relation of semantic composite score and inflectional morphology

Results reported in this study support the presence of morphological difficulties in SD. However, when similar results have been reported in the past, some studies questioned the semantic origin of the difficulties observed in SD (Bright et al., 2008; Kavé et al., 2012; Tyler et al., 2004). This last section aims to quantify the role played by semantic cognition in the performance of participants of the SD group.

6.1. Methods

To further quantify semantic cognition's influence on performance, a semantic composite score (SCS) was derived from the performance on five standardised semantic tasks: object picture naming (TDQ-60 Macoir, Beaudoin, & Bluteau, 2008), verb video naming (Routhier, 2014), semantic object picture matching (Pyramids and Palm Trees Test (PPTT), Howard & Patterson, 1992), semantic verb picture matching (Kissing and Dancing Test (KDT), Bak & Hodges, 2003) and written word semantic matching (Macoir, 2009).

The distribution of results from these tests was examined to detect departures from linearity or normality. The score from the PPTT had to be transformed by substracting each participant's score from the maximum possible score (52) and then extracting the square root of the result obtained. As some of these tasks are not yet normalised and validated for the Quebec French popula-tion, the scores from the control group were used to derive *Z* scores. The semantic composite score represents the average of *Z* scores (or inverse *Z* scores, so that high positive scores represent good performances) from these five tasks.

The score for some tasks of the battery was missing for three control participants. It was judged better not to implement these missing data and not to compute a composite score based on fewer raw scores. The composite score was computed for 17 participants of the control group.

Regression analyses (R core team, 2004) were run with the SCS as predictor of performance for the tasks of inflectional morphology. Total scores were entered as the dependant variable. Word and pseudo-word conditions were considered separately.

6.2. Results

SCS of participants of the control group is homogeneous (range: −0.94 to 0.92; mean = 0.11; s.d. = 0.56). In the SD group, SCSs show impairments that range from moderate to severe (range: −18.78 to −5.98; mean = −11.02; s.d. = 4.82).

The SCS was a significant predictor of performance in all experimental tasks of inflectional morphology. In the verb production task, the SCS predicted the performance ($F(1, 25) = 65.503$, $p < .001$) and explained around 70% of the variance ($R^2 = 0.724$; adjusted = 0.713). Results are similar for the pseudo-verb production condition ($F(1, 23) = 58.254$, $p < .001$; $R^2 = 0.717$; adjusted = 0.705). The SCS was also a significant predictor in the selection of an inflected verb task ($F(1, 25) = 50.088$, $p < .001$). It explained 65% of the variance in this task ($R^2 = 0.667$; adjusted = 0.654). Finally, the SCS was a significant predictor of performance in the time-cue matching task, both in the verb ($F(1, 25) = 29.180$, $p < .001$) and the pseudo-verb condition ($F(1, 23) = 9.903$, $p < .01$). It explains a larger proportion of variance in the verb ($R^2 = 0.539$; adjusted = 0.520) than in the pseudo-verb condi-tion ($R^2 = 0.301$; adjusted = 0.271).

As can be expected in SD, there was some individual variability in the group. Not all patients had difficulties in every task. In general, difficulties were more present in patients that had a moderate-to-severe or severe semantic impairment, and in the production task. A figure illustrating variability in individual per-formances with percentile scores can be found in supplementary online material.

6.3. Intermediate discussion

Regression analyses show that semantic cognition, as assessed by an array of tasks, is a significant predictor of performance on morphological tasks in SD. Interestingly, it is a significant predictor of performance in the pseudo-verb conditions of the production and of the time-cue matching tasks, although it explains a smaller percentage of variance than in the associated real-verb conditions. Because semantic cognition is not associated with the processing of the root in pseudo-verb conditions, these results suggest that it is involved in producing and selecting the appropriate mor-phemes to convey information such as time.

These results should be interpreted with caution. First, none of the tasks used to derive the SCS (and none of the tasks used in the assessment of semantic cognition in general) are "pure", in the sense that they target semantic processing exclusively. The inclusion of tasks with different forms of input and output material and their common requirement in terms of semantic processing gives some confidence regarding the validity of the SCS as an indi-cator of semantic performance. Second, due to the limited number of participants included in this study, only one factor was entered as predictor of performance in the analyses. The contribution of other factors that could potentially have an influence over perfor-mance cannot be appraised.

The progression of SD from a central and relatively isolated impairment of semantic cognition to a more general cognitive impairment is an important but understudied question. The progression of the disease is associated with more severe atrophy in the anterior temporal lobe, but also with the spread of atrophy to adjacent brain areas. The atrophy of other brain regions, some of which also play a role in language, has been interpreted as the cause of morphological impairment seen in SD by some authors (Bright et al., 2008). This interpretation is the consequence of the authors' position regarding the separation of semantic and morphological processing. The result of the current study and some others do not support this separation, but more studies are necessary to characterise SD's evolution in time, and to better delineate the boundaries of semantic cognition, both from a functional and an anatomical point of view.

7. General discussion and conclusion

In our study, we have shown that French-speaking SD patients had difficulties producing tense and person inflection in verbs and pseudo-verbs, whether regular or pseudo-regular. However, when

they were directly exposed to manipulations in terms of regularity, they tended to choose a more typical or predictable alternative over a correctly inflected verb. Their difficulties in producing semantically encoded aspects of inflection, such as tense, are related to difficulties to understand the semantic content conveyed by inflectional morphemes. In sum, central semantic impairment can cause morphological deficits that do not only affect irregular verbs, but that also have impacts on the production and comprehension of semantic information conveyed by inflectional morphemes.

The great majority of studies published on inflectional morphology in SD up to now have focused on the production of verbs in the past-tense in English, a morphologically simple language in which verbs have only a few different inflected forms. These forms are also simple because they are marked for a single piece of grammatical information at a time. The contrast between regular and irregular verbs has received a lot of attention and served as theoretical background for several studies conducted in languages other than English (e.g. Colombo, Fonti, & Stracciari, 2009; Macoir et al., 2013; Penke, Janssen, Indefrey, & Seitz, 2005), even if this type of contrast is not best suited to characterise their morphological systems. It is also worth noting that some authors argue that regularity is a graded phenomenon, even in English (Albright & Hayes, 2003; Embick & Noyer, 2007; Halle & Marantz, 1993). However, the influence of the regular/irregular contrast is such, that even studies on SD that adopt a connectionist framework (which would allow them to accommodate graded regularity effects) still emphasise the contrast between regular and irregular verbs (Patterson et al., 2001, 2006). Given the simplicity of English inflectional morphology, the possibility to detect differences is maximised by contrasting regular, high-frequency forms to irregular, low-frequency ones. The results of the present study also show effects of regularity in French. This factor remains without a doubt central to the study of morphology. It is interesting to note that the effect of regularity observed in the inflected verb selection task was found with frequency-matched verbs, and that the participants of the control group were also influenced by regularity. In fact, they had longer response latencies when they had to choose between a regularised alternative and a correct but more idiosyncratic form of a verb. However, only the SD patients committed more errors when confronted with these items, because their impaired semantic input was not sufficient to counter phonological and orthographic information that was more compatible with the regularised alternative.

The originality of this study lies in the fact that it reports results that are not limited to regularity effects. In fact, it reports results that show the difficulties of SD patients to produce and understand semantic information such as tense in the form of inflectional morphemes. SD patients had difficulties to produce the inflection for tense and the inflection for person in regular and pseudo-regular verbs, but also in pseudo-verbs. They also had difficulties to choose which inflected form of a verb corresponded to a time cue given by an adverb.

These results underline the importance of taking semantically-related aspects of inflectional morphology into consideration in models, but also in the assessment of language disorders. More precisely, the results of the present study are an illustration of difficulties that arise when the integration of different pieces of semantic information into inflectional morphemes is compromised by central semantic impairment. Several researchers have put forward hypotheses compatible with this idea (Bastiaanse, 2011; Bishop et al., 2014; Faroqi-Shah & Thompson, 2003, 2004, 2007; Patterson & Holland, 2014). These models all describe a form of semantic involvement in morphology, though it is sometimes rather indirect as in the DER (Faroqi-Shah & Thompson, 2003, 2004, 2007). More studies are needed to specify how semantic requirements are translated into inflectional morphemes. As expressed by Bishop et al. (2014), if this direction is to be taken further, one of the challenges that models of morphology will face will be to identify the semantic, grammatical, and we could add pragmatic (contextual) conditions that specify the production of inflectional morphemes.

Models of semantic cognition have started to address the question of the representation of very abstract concepts such as those that are usually conveyed by inflectional morphology (Meteyard, Rodriguez Cuadrado, Bahrami, & Vigliocco, 2012). Efforts in modelling the production and comprehension of morphology should also aim to address this question.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.bandl.2016.02.002.

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