Published in Aphasiology, 2016
which should be used for any reference to this work

Conception or *conceivation? The processing of derivational morphology in semantic dementia

Noémie Auclair-Ouellet[a,b,c], Marion Fossard[c], Robert Laforce Jr.[d], Nathalie Bier[e] and Joël Macoir[a,b]

[a]Faculté de médecine, Université Laval, Québec, Canada; [b]Axe de recherche Neurosciences cliniques et cognitives, Centre de recherche de l'Institut universitaire en santé mentale de Québec, Québec, Canada; [c]Institut des sciences du langage et de la communication, Université de Neuchâtel, Neuchâtel, Switzerland; [d]Clinique interdisciplinaire de mémoire, Centre hospitalier universitaire de Québec, Québec, Canada; [e]Centre de recherche de l'Institut universitaire de gériatrie, Montréal, Canada

ABSTRACT

Background: Only a few studies have focused on derivational morphology in semantic dementia (SD). The productive and componential nature of derivational morphology as well as recent findings in psycholinguistics suggest that semantic cognition would be involved in the production and comprehension of derivational morphemes and derived words. Therefore, participants with SD might present impairment in derivational morphology.

Aims: This study aims to specify semantic cognition's involvement in the production and comprehension of derivational morphemes and morphologically complex words in SD participants. This involvement was considered in relation to the production of morphologically complex words, the comprehension of the meaning conveyed by morphemes, and the capacity to distinguish between words with a real vs. an apparent morphological structure.

Methods and Procedures: Ten French-speaking SD participants completed three tasks of derivational morphology. Their performances were compared to those of a group of 20 age-, gender- and education-matched adults without cognitive impairment.

Outcomes and Results: Compared with participants of the control group, SD participants had more difficulty producing nouns derived from verbs that follow less-frequent patterns of root allomorphy, while their performance was less affected when they could rely on basic morphological decomposition/composition abilities. Participants with SD also had more difficulties to match derived words and pseudo-words to a definition and to distinguish between pairs of real morphological antonyms and pseudo-morphological non-antonyms.

Conclusions: These results support the involvement of semantic cognition in the validation of morpheme combinations and in derivational morpheme representation. Difficulties in the production and comprehension of derived words and derivational morphemes are another of the many consequences of central semantic impairment that characterises SD. More studies are needed to develop tests and further characterise the involvement of semantic cognition in derivational morphology.

KEYWORDS

Derivational morphology; production; comprehension; semantic dementia

Introduction

Semantic dementia (SD) (also known as the semantic variant of primary progressive aphasia, Gorno-Tempini et al., 2011) is a degenerative impairment of semantic cognition. Semantic cognition refers to the cognitive mechanisms that are involved in all behaviours that require conceptual knowledge (e.g., generating a message, understanding a word, recognising an object or drawing it from memory) (Lambon Ralph, 2014). From a clinical point of view, SD is mainly characterised by word-retrieval and single-word comprehension difficulties (Hodges, Patterson, Oxbury, & Funnell, 1992; Neary et al., 1998). Over the past 15 years, several studies focused on other aspects of language and cognition that are not usually considered to require a semantic contribution (e.g., lexical decision, object decision and delayed copy drawing: Caine, Breen, & Patterson, 2009; Patterson et al., 2006; Rogers, Lambon Ralph, Hodges, & Patterson, 2004). Many of these studies focused on inflectional morphology (for a review, see Auclair-Ouellet, 2015). Inflectional morphology concerns the transmission of grammatical information (e.g., for verbs: tense, person, number) by the addition of inflectional morphemes to a stem. Morphology can be subdivided in different domains, including derivational morphology. Derivational morphology concerns the creation of new words by the addition of a prefix or a suffix to a base word (Booij, 2013; Lieber, 2010).

Up to now, only a handful of studies investigated derivational morphology in SD (Auclair-Ouellet, Fossard, Houde, Laforce, & Macoir, 2016; Benedet, Patterson, Gomez-Pastor, & Garcia de la Rocha, 2006; Kavé, Heinik, & Biran, 2012; Meteyard & Patterson, 2009). This is surprising considering that derivational morphology plays a very important role in lexical enrichment and grammatical category transposition (Bauer, 2008). Unlike inflected words, which can be described as grammatical variants of their stem, derived words constitute different lexical entries from their base word (Booij, 2013; Lieber, 2010). In fact, derivational morphology can change a word's grammatical category or create a new word with a related, though different meaning (Bauer, 2008; Booij, 2013; Lieber, 2010).

From a linguistic point of view, derivational morphology is based on the addition of affixes (prefixes and suffixes) to a base. However, some psycholinguistic models do not put componential properties of derivational morphology forward. According to Levelt's model of language production (Levelt, 1989), derived words are not produced "on-line" by adding a prefix or a suffix to a base, but are rather retrieved in their complete form in the lexicon. This means that words that are derived from the same base do not share a common lemma (the lemma is the lexical representation of a word, or its lexical form, as opposed to the lexeme, which is its material or phonological form). The fact that derived words are represented in their complete form in the lexicon is justified by the inconsistency of derivational morphology in terms of the possibility to form words (e.g., arrive: arrival; derive: *derival) and the meaning that morphemes convey (e.g., a singer is a person who sings; a crusher is not a person who crushes but an object that crushes) (Janssen, Roelofs, & Levelt, 2002; Levelt, 1989). Dissociation in the performance of participants with aphasia that showed relatively good preservation of derivational morphology but impaired inflectional morphology is also taken as support for this claim (Faroqi-Shah & Thompson, 2007; Miceli & Caramazza, 1988).

However, some derivational morphemes are "productive". There is no consensus on what exactly is meant by productivity, but briefly put, productive morphemes are those that are the most likely to be used by native speakers to create new words (Bauer, 2001; Lieber, 2010). Lists of new words (such as the one compiled by the Oxford English Dictionary online) are replete with derived words formed with productive morphemes (e.g., declutter, photobomber, etc.). In order to be productive, morphemes must be salient and readily available to native speakers, but they also need to convey a relatively consistent and predictable meaning to produce the expected effect when they are added to a base (Lieber, 2010). To account for the fact that speakers regularly coin new words, a latter version of Levelt's model (Levelt, Roelofs, & Meyer, 1999) suggests that productive derivational morphemes have their own lexical representation, which would be selected from the conceptual level. In fact, morphological productivity has two implications: (1) that derivational morphology functions in a componential way and (2) that derivational morphemes have a form of semantic representation.

Other models can account for the componential nature of derivational morphology and for the claim that derivational morphemes need to be semantically represented in order to be productive. Local connectionist models such as the one proposed by Bates and Wulfeck (1989) support the representation of both open and closed class morphemes, including derivational *and* inflectional morphemes, which all have a form of semantic representation. Distributed connectionist models go a step further and suggest that there is no level of morphological representation as such (Gonnerman, Seidenberg, & Andersen, 2007; Plaut & Gonnerman, 2000; Seidenberg & Gonnerman, 2000). What is perceived as a morpheme on the surface would be in fact a frequent form-to-meaning mapping, represented by a pattern of activation distributed over phonological, orthographic and semantic units (Gonnerman et al., 2007; Plaut & Gonnerman, 2000; Seidenberg & Gonnerman, 2000). If a form is repeatedly activated in association with a specific meaning, it progressively gains a componential representation and relative independence from its specific instances. Conversely, the more a word presents unique features that are not shared by other words, the less componential its representation is (Plaut & Gonnerman, 2000). Distributed connectionist models are well suited to account for the consistent and less consistent aspects of derivational morphology.

In the few studies on derivational morphology in SD, researchers found difficulties in structured tasks of derived word production and comprehension (Benedet et al., 2006), errors of derivational morphology in connected speech production (Meteyard & Patterson, 2009) and good preservation of basic morphological abilities (decomposition/composition) but production of morphological paraphasias and morphologically complex neologisms (Auclair-Ouellet et al., 2016; Kavé et al., 2012).

The single-case study of Kavé et al. (2012) reports the result of a participant with SD, S.H.S., in different tasks of morphology. In a derivational morphology production task, S.H.S. produced several errors that were characterised by the authors as "regularisation errors". In fact, when he was asked to retrieve words that could not be produced by morphological decomposition/composition, S.H.S. used a word presented in the definition and added one of the agentive suffixes of Hebrew, which resulted in the production of morphological paraphasias (e.g., "someone who repairs pipes: piper", instead of plumber). According to the authors, these errors suggest the preservation of morphological abilities such as decomposition and composition of morphologically complex words. However, their interpretation does not account for the production of regularisation errors by S.H.S.

A previous study (Auclair-Ouellet et al., 2016), reported the performance of N.G., a French-speaking participant with SD. N.G. completed a task of verb production starting from an inducing noun. She had no difficulty producing verbs that had a transparent morphological relation to the inducing nouns (e.g., "chanter" (to sing) starting from "chanteur" (singer)). However, she had significant difficulties compared with the control group when morphological support was reduced because of root allomorphy between the inducing noun and the verb (e.g., "rédacteur" (writer), "rédiger" (to write)), or when morphological support was non-existent because there was no attested morphologically related verb (e.g., there is no attested morphologically related verb to the noun "sénateur" (senator)). Similar to results reported by Kavé et al. (2012), in response to these items, N.G. tended to produce morphologically complex pseudo-words: morphological paraphasias such as "*rédacter" instead of "rédiger", starting from "rédacteur" and unattested forms such as "*sénater" starting from "sénateur".

Based on well-documented effects of more errors and longer response times for morphologically complex pseudo-words in lexical decision (Burani, Dovetto, Thornton, & Laudanna, 1997; Taft & Forster, 1975; for a review, see Amenta & Crepaldi, 2012), these errors could be related to difficulties validating morpheme combinations. N.G.'s errors presented a striking morphological structure and were composed of valid "building blocks" of language. Her difficulties emerged when the combination of these building blocks did not result in an existing word. In fact, her impaired semantic representations did not allow her to prevent the production of morphological paraphasias and unattested forms. This interpretation was supported by the results of a complementary lexical decision task in which N.G. had to judge her own errors, other morphologically complex pseudo-verbs and real verbs. Results showed that, compared to the control group, she tended to accept morphologically complex pseudo-verbs as real verbs. These results also align with several studies that have shown that the validation of a root/affix combination involves semantic processing (Bölte, Schulz, & Dobel, 2010; Burani, Dovetto, Spuntarelli, & Thornton, 1999; Fruchter & Marantz, 2015; Lavric, Elchlepp, & Rastle, 2012; Levy, Hagoort, & Démonet, 2014; Whiting, Marslen-Wilson, & Shtyrov, 2013; Wurm, 2000). From a neuroanatomical point of view, the study conducted by Whiting et al. (2013) suggests that the semantic validation of morpheme combinations in auditory word processing would activate the anterior temporal lobes, which is the locus of maximal brain atrophy consistently reported in SD (Gorno-Tempini et al., 2011; Patterson, Nestor, & Rogers, 2007).

Aims and hypotheses

A previous study (Auclair-Ouellet et al., 2016) reported the case of one participant with SD, showing moderate semantic impairment. The current study reports the results of 10 individuals with SD in a similar task of morphologically derived word production. Also, this study expands on the exploration of semantic cognition's involvement in derivational morphology by focusing not only on semantic cognition's role in sanctioning morpheme decomposition/composition, but also on its role in underlying morphemes' semantic representations. As explained above, morphological productivity and connectionist models of derivational morphology support the existence of semantic representations for morphemes (or their underlying pattern of activation) (Bates & Wulfeck, 1989; Gonnerman et al., 2007; Plaut & Gonnerman, 2000; Seidenberg & Gonnerman, 2000). Therefore, it is logical to suppose that central semantic impairment alters the semantic representation of derivational morphemes and causes difficulties to understand their meaning.

The purpose of this study is to specify semantic cognition's involvement in the production and comprehension of derivational morphemes and morphologically complex words. It aims to investigate the role of semantic cognition in the production of morphologically complex words that vary in terms of transparency, in the comprehension of the meaning conveyed by morphemes, and in the capacity to distinguish between words with a real vs. an apparent morphological structure. To achieve these aims, derivational morphology was studied in three experiments.

In Experiment 1, participants completed a noun production task that contrasted the production of nouns starting from two different types of verbs: verbs that have the same transparent root as a morphologically related noun, and verbs that are also related to a derived noun but with an allomorphic root. Because less transparent words (such as those with allomorphic roots) require more semantic support (Plaut & Gonnerman, 2000), it was expected that SD participants would have more difficulties producing nouns starting from verbs that have allomorphic roots.

In Experiment 2, participants performed a words- and pseudo-words-to-definition matching task that consisted in choosing which of three derived words of pseudo-words matched a definition based on morphemes' meaning. Different models support the existence of a form of semantic representation for morphemes (Bates & Wulfeck, 1989; Gonnerman et al., 2007; Plaut & Gonnerman, 2000; Seidenberg & Gonnerman, 2000). If this were the case, derivational morphemes should be vulnerable to semantic impairment and SD participants should have difficulties to choose which derived word or pseudo-word corresponds to a definition by relying on a prefix or suffix's semantic content.

In Experiment 3, participants completed an antonymy judgment task that explored semantic cognition's role in differentiating words with a real morphological and a pseudo-morphological structure. It contrasted different types of verb pairs, some that are antonyms and some that are not. More specifically, it included antonyms that are formed with the prefix "dé–" and non-antonyms that seem to be formed with "dé–". Like non-antonyms that are formed with "dé–", there are several words that seem to have a morphological structure but do not (e.g., "corner"). Interpreting pseudo-morphological words based on their morphological structure (e.g., "a corner is a person who corns") would be incorrect. Recent findings show that semantic cognition plays an important role in preventing such an interpretation (Fruchter & Marantz, 2015). SD participants were expected to be impaired at discriminating between real antonym and pseudo-antonym verb pairs.

Methods

Participants

The participants, all native speakers of Quebec French, completed a 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 individuals with SD, all right handed, 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 participants. Some participants had atrophy that extended to other brain regions (e.g., posterior temporal and parietal lobe). Five participants had more severe atrophy in the left hemisphere, two participants had more severe atrophy in the right hemisphere, and three participants had bilateral atrophy. Right temporal lobe atrophy has been associated with more severe object recognition deficits but better word processing in SD (Neary et al., 1998). Of the two participants with more severe atrophy in the right hemisphere, none showed a clear advantage for words over pictures. For each SD participant, two age, gender and education matched adults with normal cognition, assessed with a global cognition test (Montreal Cognitive Assessment (MoCA), Nasreddine et al., 2005) were recruited to form the control group. The experimental and the control groups were well matched for age, gender and education ($p > .05$). Exclusion criteria for both groups were: history of psychiatric disorder, history of brain damage of traumatic or vascular origin, history of drug or alcohol abuse, uncorrected vision or hearing problems and 6 years of education or less. Exclusion criteria were verified by the neurologist before referral. Demographic characteristics, and results in language and neuropsychological tests are provided in Table 1.

The SD group was similar to other groups reported in the literature in terms of age, education and gender balance (Hodges et al., 2010; Johnson et al., 2005). The results showed preserved performance in some domains of cognition such as attention and working memory. However, object recognition (BORB—Object judgment: Riddoch & Humphreys, 1993) and execution of gestures from imitation and verbal command were impaired (PENO: Joanette et al., 1995). Language tasks showed impairments consistent with the portrait of SD. Participants had significant word-retrieval difficulties as shown by their performance in object picture naming (TDQ-60: Macoir, Beaudoin, & Bluteau, 2008) verb video naming (5-s videos showing humans performing actions in a simplified environment; e.g., "to cut") (Routhier, Bier, & Macoir, 2015) and word generation (Verbal fluency, MEC: Joanette, Ska, & Côté, 2004). They were also impaired on three semantic matching tasks: object picture matching (choosing which of two object pictures could best be matched to a stimulus; e.g., "wood": "saw" vs. "hammer") (PPTT: Howard & Patterson, 1992); action picture matching (choosing which of two action pictures could best be matched to a stimulus; e.g., "kissing": "dancing" vs. "running") (KDT: Bak & Hodges, 2003); Concrete and abstract written word matching (choosing which of two written words could best be matched to a stimulus; e.g., "rabbit": "hare" vs. "beaver"; "authorization": "permission" vs. "instruction") (Macoir, 2009). To characterise the variability of semantic impairments within the group of SD participants, a composite score was computed. This score represents the average of standardised (Z) scores (computed using the control group's average and standard deviation) in five different tasks: (1) Object naming (TDQ-60) (2) Verb video naming; (3) Object picture matching (PPTT); (4) Action picture matching (KDT); (5)

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

		SD (n = 10)		Control (n = 20)	
		Mean	SD	Mean	SD
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*†	3.27	27.05	2.09
ROCF	Copy (36)	31.60	2.14	33.18	2.32
	Recall—3 min (36)	10.20*	7.44	19.30	6.89
	Recall—20 min (36)	12.67†	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*†	3.63	25.45	2.95
	Object judgment—List B (32)	22.86*†	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*	65.35	70.26	21.28
PENO—Praxis	Meaningless gestures (35)	29.4†	2.91	31.00	2.70
	Pantomimes (35)	21.90*†	10.19	34.20	1.47
TDQ-60 (60)		25.30*†	13.28	57.70	1.81
Verb video naming (100)		47.60*	21.29	95.70	4.28
MEC—Fluency	Unconstrained	24.20*†	11.33	66.70	14.08
	Letter *p* (2 min)	8.30*†	3.37	29.50	10.45
	Items of clothing (2 min)	6.50*†	5.17	26.05	5.86
PPTT	Image-image condition (52)	31.80*†	10.59	50.22	1.70
KDT	Image-image condition (52)	37.40*†	6.70	48.00	2.90
Semantic written word matching (40)		26.30*	9.42	39.05	0.94
BECLA—Reading	Words (24)	21.00*	3.56	24.00	0.00
	Pseudo-words (15)	9.90*	1.73	12.05	2.16

*: Signals an impaired performance compared with this study's control group (n = 20) (Mann–Whitney, α = p < .05, two-tailed).

†: Signals an impaired performance according to published norms (below the point of alert or two standard deviations below the reference mean).

Abbreviations: MoCA, Montreal Cognitive Assessment; 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.

Concrete and abstract written word matching. Table 2 gives the age, number of years of education, lateralisation of brain atrophy, and semantic score of each participant, ranked from the least to the most severely impaired. Age and education were not correlated with the semantic score (age: r (8) = . 05, p = .89; education: r (8) = .34, p = .34). Within the group, the severity of semantic impairment ranged from moderate to severe.

Experiment 1—noun production

This task targets the production of morphologically complex words by asking participants to produce a noun starting from an inducing verb. Verbs either shared a transparent or an allomorphic root with their target noun. Producing nouns starting from verbs that have allomorphic roots was expected to be more difficult for SD participants because these words require more semantic support (Plaut & Gonnerman, 2000). Material and procedure are presented in the following sections.

Table 2. Age, education, lateralisation of brain atrophy and semantic composite score.

Participant	Age	Education	Atrophy	Composite score
OI	78	16	B	−5.98
NG	72	12	L > R	−6.84
MU	68	18	R > L	−7.6
LD	68	17	L > R	−7.99
NI	61	24	L > R	−8.07
ND	53	13	L > R	−9.65
LS	59	10	R > L	−11.48
NIT	61	19	B	−15.41
AS	73	12	L > R	−18.43
MN	69	12	B	−18.78

B, Bilateral atrophy; L > R, Left hemisphere more atrophied than right hemisphere; R > L, Right hemisphere more atrophied than left hemisphere.

Material

The task included 60 verbs that were morphologically related to a noun in a semantically transparent way. There was one correct morphological answer that was expected for every verb given as starting point and the morphological link between the starting verb and the expected answer was clearly stated to the participants in the instructions. All the target nouns ended in "–tion", "–ation" or "–ition". Half of the verbs (30) had a transparent phonological relation to the noun (e.g., "adapter" (to adapt)—"adaptation" (adaptation)). The other half (30) had an allomorphic root (e.g., "percevoir" (to perceive)—"perception" (perception)). Accessing the root of an allomorphic verb can help the production of the corresponding noun by giving access to the noun's root (Burani & Laudanna, 1992; Marslen-Wilson & Zhou, 1999). However, if the verb's surface root is used as the starting point for noun production, it would result in the production of a morphological paraphasia (e.g., "concevoir" (to conceive): "*concevation" instead of "conception").

The verb length was two or three syllables. Each verb from the first list was matched in frequency to a verb with an allomorphic root, t (58) = .316, p = .75 (New, Pallier, Ferrand, & Matos, 2001). Expected target nouns were also matched for frequency, t (58) = −1.180, p = .29.

Verbs were presented in the infinitive form and were followed by a short carrier phrase to cue noun production (e.g., "Translate. To do a"… expected response: "translation"). All carrier phrases were of the form "To have/do a/the".

Procedure

Stimuli were presented in a semi-random order (no more than three consecutive verbs of the same type) using DMDX (Forster & Forster, 2003). 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 soundproof 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 the task, the experimenter read the instructions with participants and made sure they understood the task. The participants completed practice items and were not given feedback during the completion of experimental items. At the onset of the carrier phrase, the participants had 8 s to produce an answer orally. The response was noted by the experimenter on a response sheet.

Data analysis

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

Results

Accuracy

All the responses were compiled by the main experimenter and were categorised as correct answers or errors. Once data collection was completed, results were reviewed to make sure that they were categorised uniformly. Since the instruction was to produce a noun that was morphologically related to the verb, other derived words than the expected answer in "–(a/i)tion" were accepted as correct answers. These responses were rare in both groups.

The rate of correct answers and errors was also calculated to make sure that no item was systematically failed. This analysis showed that a subset of verbs with allomorphic roots was associated with better performance in the SD group, as shown by a bimodal distribution. Seven verbs were answered correctly by only four SD participants out of ten, but eight verbs were answered correctly by eight SD participants out of ten. The distribution was normal in the control group. In order to explain this lack of uniformity of responses for stimuli with allomorphic roots, a phonological analysis of target words ending in "–(a/i) tion" was done. This analysis had the aims of uncovering a pattern of word formation that would apply to several items. This pattern could constitute an intermediate level of transparency that was not considered when stimuli were initially selected.

The phonological analysis showed that in half of the allomorphic nouns, the ending morpheme was preceded by the consonant /k/ (for example in "réduction" and "élection" but not in "promotion" and "perception"). Lexique database (New et al., 2001) lists 167 words ending in /ksjɔ̃/ and only 36 words ending in /psjɔ̃/, the second most frequent pattern in stimuli. Therefore, words ending in /ksjɔ̃/ could constitute an intermediate level of transparency or predictability that was not considered in the initial selection of items. Studies show that the performance of participants with SD is influenced by regularity and frequency or "typicality" of items (Patterson et al., 2006, 2007; Wilson et al., 2014). Therefore, it was possible to expect that SD participants would have intermediate performances for items ending in /ksjɔ̃/, that is, less good than for transparent words, but better than for allomorphic verb-noun pairs that correspond to another pattern.

The results were analysed according to the original subdivision of items in two types (transparent and allomorphic) and according to an exploratory subdivision in three types (transparent, formed with /ksjɔ̃/, and formed with other patterns). Nouns formed with /ksjɔ̃/ constituted half of the 30 allomorphic verbs (15/30). The total for transparent items was divided by two, giving three scores with a possible maximum of 15.

Both analyses were conducted using a mixed linear model. Group and verb type were entered as fixed effects. A random intercept effect for participants was also included. The inclusion of a random slope effect for verb type according to participants prevented the model from converging and was omitted from the final model. Figure 1 shows the percentage of correct answers for the different types of verbs in both groups. Figure 1A gives the results for the subdivision in two types and Figure 1B gives the results for the subdivision in three types.

For the subdivision of items in two types, overall, SD participants had more difficulties than participants of the control group, as shown by the significant main effect of group, χ^2 (1): 20.22; $p < .001$. The significant main effect of verb type shows that verbs with allomorphic roots were associated with more errors than verbs with transparent roots, χ^2 (1): 12.12; $p < .001$. The significant interaction between group and verb type shows that, compared to participants of the control group, SD participants had more difficulties for verbs with an allomorphic root, χ^2 (1): 34.92; $p < .001$.

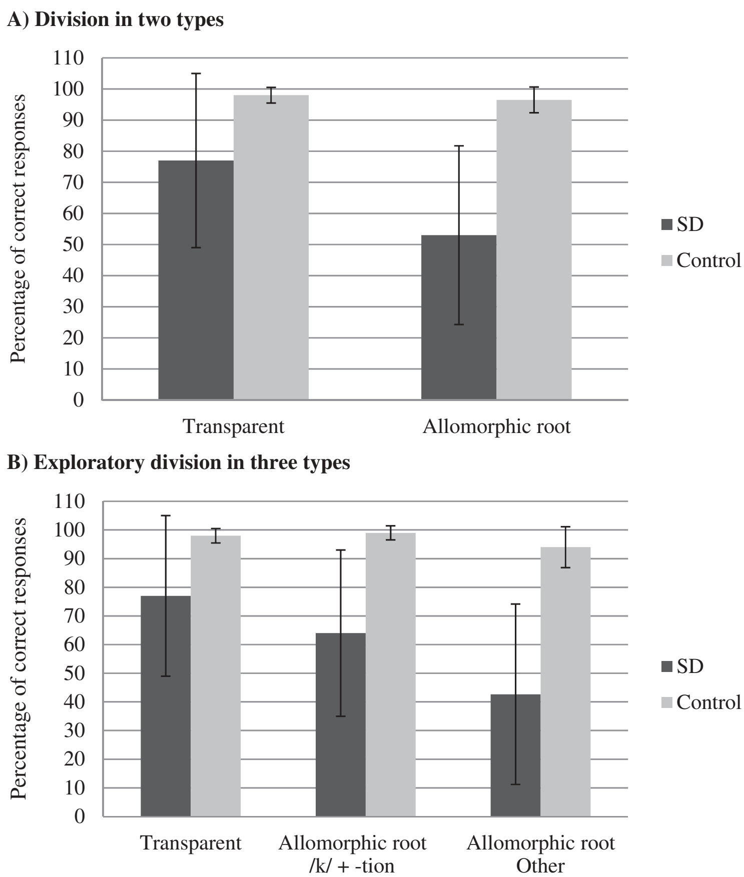

Figure 1. Percentage of correct responses in the noun production task.

For the subdivision in three types, overall, SD participants had more difficulties than participants of the control group, as shown by the significant main effect of group, χ^2 (1): 23.27; $p < .001$. The effect of verb type was significant, χ^2 (1): 23.62; $p < .001$. The interaction effect between group and verb type was also significant, χ^2 (1): 41.04; $p < .001$.

Post-hoc analyses of the significant verb type by group interaction effect was conducted with Tukey's Honest Significant Difference (HSD) test in R (R Core Team, 2014) with the "multcomp" package (Hothorn, Bretz, & Westfall, 2008).

In the SD group, pairwise comparisons of verb types show that transparent words were associated with better performances than allomorphic words with a "/k/ + –tion" pattern, z = 4.19, $p < .001$, and other allomorphic words, $z = 11.07$, $p < .001$. Allomorphic words with a "/k/ + –tion" pattern were associated with better performances than allomorphic items that did not follow this pattern, $z = 6.88$, $p < .001$. This gradation of performance was found specifically in the SD group. None of the differences were significant in the control group, all $p > .05$.

Type of answers

SD participants produced 209 errors which constitutes more than a third of the responses produced in this group. Errors, in large part, constituted morphologically complex pseudo-words (102/209, 49%) that presented similarities with the expected target. In fact, the majority of these morphological paraphasias (84/102, 82%) ended in "–tion". They were formed with a "pseudo-root", which, in 52% of occurrences (53/102), also presented a form of transformation compared with the starting verb (e.g., concevoir (to conceive): "*concerviction").

In addition to morphological paraphasias, SD participants also produced real words that were incorrect in the context (mostly repeating the inducing verb) (75/209, 36%). The remainder of errors were non-responses or aborted responses (32/209, 15%). Real word and non-responses were summed so that all expected values were superior or equal to 5. The proportion of errors of each type is statistically different between the two groups, χ^2 (1): 6.93; $p < .01$.

Correlation with the semantic score

A correlational analysis between the semantic score and the total noun production score was performed. The analysis included all participants because an analysis including only the SD group would have been underpowered due to the small number of participants. The semantic score was not computed for three control participants because some semantic test results were missing. The correlation between the semantic score and the total noun production score was significant, r (25) = .86, $p < .001$.

Group and semantic scores were significantly correlated, r (25) = .89, $p < .001$. However, group could account for differences between SD and control participants that were not captured by the semantic score. When controlling for group, the correlation between the semantic score and the total noun production score remained significant, r (22) = .64, $p = .001$.

Discussion

On average, SD participants had a fairly good performance for transparent verbs, that is, when they were able to produce nouns by relying on a frequent and productive pattern of word formation. However, they had more difficulties producing morphologically derived nouns from verbs with allomorphic roots. An exploratory analysis has shown that not all allomorphic verbs caused equal difficulty. A subset of them, following the same pattern (/k/ + /sjɔ̃/), was associated with more errors than completely transparent verbs, but with fewer errors than other verbs with allomorphic roots. Errors consisted in great part of morphological paraphasias, the majority of which were formed with "–tion", the expected suffix. Non-responses and aborted responses were rare and participants attempted to produce answers by relying on morphological operations most of the time. The noun production score is correlated with the semantic score, even when controlling for group. This supports the involvement of semantic cognition in the production of derived words.

This noun production task explored semantic involvement in complex word formation, that is, decomposition and composition. However, according to connectionist models (Bates & Wulfeck, 1989; Gonnerman et al., 2007; Plaut & Gonnerman, 2000; Seidenberg & Gonnerman, 2000) semantic cognition is also involved in derivational morphology because it underlies morphemes' semantic representation. The next experiment explores the preservation of derivational morphemes' semantic representation in SD participants.

Experiment 2—definition matching

This task evaluates the comprehension of derivational morphemes in words and pseudo-words that are formed with the same root. According to some researchers (Bates & Wulfeck, 1989; Gonnerman et al., 2007; Plaut & Gonnerman, 2000; Seidenberg & Gonnerman, 2000) derivational morphemes have a form of semantic representation. This representation could be altered by the central semantic impairment found in SD.

Material

In this task, participants saw a complete sentence that included a target word or pseudo-word. This sentence provided the definition of the target word (e.g., "Que l'on peut laver": "That one can wash") or pseudo-word (e.g., "Que l'on peut *miver"). In the case of pseudo-words, participants were asked to treat the definition as if the target word was a real word. Then, participants had to choose which of three words (e.g., "lavable" ("washable") (the correct answer), "laveur" ("washer"), "relaver" ("rewash")) or pseudo-words (e.g., "*mivable", "*miveur", "*remiver") corresponded to the definition. All response choices were formed with the same root and were semantically transparent derivations, but only one corresponded to the definition.

Morphemes used in this task are all productive and their semantic content can easily be summarised in a definition format that applies to several words formed with the same morpheme. There were six definition formats (X represents the target word or pseudo-word): three for prefixed words and pseudo-words ("re–" ("re–"): "To X again.";

"in–/ir–" ("in–/un–"): "That is not X"; "dé–" ("de–/un–"): "The opposite of X") and three for suffixed words and pseudo-words ("–able" ("–able"): "That one can X"; "–eur" ("–er"): "Person who does the action of X"; "–ment" ("–ly"): "In a X way"). There were six items for each definition format (72 in total). Target word token frequency in prefixed and suffixed word definitions was equivalent, t (29.93) = 1.96, p = .06 (New et al., 2001). Response choices (correct answer and two distractors) were matched for frequency, F (2, 105) = 3.41, p = .71.

Procedure

Stimuli were presented in a semi-random order (no more than two consecutive items with the same definition format) using DMDX (Forster & Forster, 2003). The presentation of stimuli followed the same procedure as the noun production task.

Before the task, the experimenter read the instructions with the participants and made sure they understood the task. The participants completed practice items before the task and were not given feedback during the completion of experimental items. At the onset of answer choices, the participants had 8 s to produce an answer by pressing on a button.

Data analysis

The difference between groups and the effect of variables of interest was analysed using linear mixed effects models in R (R Core Team, 2014) with the "lme4" package (Bates et al., 2014). Statistical significance of effects was obtained using likelihood ratio tests.

Results

Two participants (MN and LS) did not complete the pseudo-word condition because of difficulties understanding the instructions. Overall, most errors were caused by selecting a distractor and not because of the expiration of answer delay.

Figure 2 shows the percentage of correct answers for words and pseudo-words.

Results were analysed using a linear mixed model. Group and lexical status (word or pseudo-word) were entered as fixed effects. Morpheme type (prefix or suffix) was entered as a control fixed effect. Random effects included a random intercept effect for participants and definition formats. Random slope effects for lexical status and morpheme type in function of participants and definition format prevented the model from converging (whether included alone or in combination) and they were not included in the final model.

Results show that overall, SD participants had more difficulties than participants of the control group, χ^2 (1): 19.69; $p < .001$. Performance was similar for words and pseudo-words, χ^2 (1): 2.06; $p = 0.15$. However, the interaction between group and lexical status was significant, χ^2 (1): 10.04, $p < .01$, showing that SD participants had slightly more difficulties with pseudo-words.

The correlation between the semantic score and the total score was significant for words, r (25) = .81, $p < .001$, and pseudo-words, r (23) = .79, $p < .001$. When controlling for group, the correlation between the semantic score and the total score was no longer

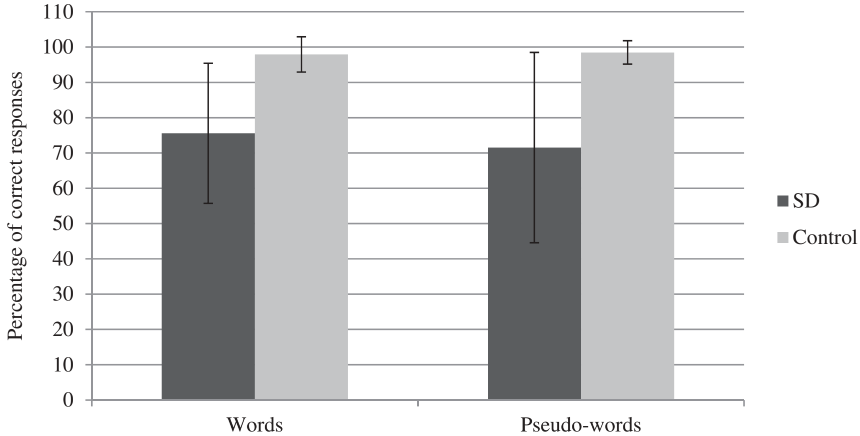

Figure 2. Percentage of correct responses in the word- and pseudo-word-to-definition matching task.

significant for words, r (22) = .37, p = .08, but remained significant for pseudo-words, r (22) = 0.58, p = .003.

Discussion

Compared to participants of the control group, SD participants had more difficulties to choose which word or pseudo-word corresponded to a definition, a result suggesting that the comprehension of derivational morphemes is impaired in SD. This conclusion cannot be made based on the real-word condition alone because it could be performed based on whole-word meaning, which is also expected to be impaired in SD. However, the pseudo-word condition had to be performed by relying only on derivational morphemes because these items did not have a meaning as a whole. Correlational analyses showed significant correlations between the semantic score and the total score for words and pseudo-words. However, when the analysis was controlled for group, only the correlation between the semantic score and the total score for pseudo-words remained significant. Overall, the results suggest that semantic cognition is associated with the comprehension of morphemes and that it is especially important when no support is provided by whole-word meaning or familiarity.

This task included only words (and pseudo-words) that have a morphologically transparent relation to their root. However, there are several words that seem to have a morphological structure but do not. The last task explored the role of semantic cognition in preventing interpretations based on morphological structure when these are not appropriate.

Experiment 3—antonymy judgment

This task consisted in asking participants to decide if two verbs are antonyms or not (if they mean the opposite of one another). More precisely, it contrasted antonyms that are formed with the prefix “dé–” and non-antonyms that seem to be formed with “dé–”.

Non-antonyms start with the same first syllable as prefixed antonyms, but in this case, it is not a morpheme and it is not associated with antonymy. Because semantic cognition is necessary to prevent morphological interpretations when they are not appropriate, it was expected that participants with SD would have difficulties discriminating between antonyms and non-antonyms formed with “dé–”.

Material

The task included four different types of verb pairs (20 stimuli for each type, 80 in total): (1) antonyms with “dé–” (“un–”) (e.g., “coller” (stick) and “décoller” (unstick)); (2) non-antonyms with “dé–” (e.g., “fendre” (split) and “défendre” (defend)); (3) semantic antonyms without “dé–” (e.g., “flotter” (float) and “couler” (sink)); (4) non-antonyms with “re–” (e.g., “coudre” (sew) and “recoudre” (sew again)). Pairs with “re–” were included as a control because they are morphologically complex but the morpheme “re–” is not associated with antonymy. Therefore, half of the expected responses were positive (verbs are antonyms) and half were negative (verbs are not antonyms).

Verbs were controlled for spoken frequency (comprised between 0 and 100) (New et al., 2001). Verb pairs were controlled between antonyms and non-antonyms for the average difference in token frequency between the two verbs of a pair, $t(78) = -1.49$, $p = .14$.

Procedure

Stimuli were presented in a semi-random order (no more than two consecutive items from the same experimental list and no more than three consecutive pairs of antonyms or non-antonyms) using DMDX (Forster & Forster, 2003). The presentation of stimuli and instruction phase followed the same procedure as the two other tasks.

Data analysis

Data analysis procedure was the same as for the definition matching task. Comparisons of verb pairs between groups were done using independent-sample *t*-tests with a Bonferroni-corrected level of significance, $\alpha = .0125$.

Results

One participant (MN) did not complete the task because of difficulties understanding the instructions. The majority of errors was caused by choosing the distractor and not because the delay of answer had expired. Figure 3 shows the percentage of correct answers for the four types of verb pairs in both groups.

Results were analysed using a mixed linear model. Fixed effects were group and type of verb pair. A random intercept effect for participants was also included.

Overall, SD participants had more difficulties than participants of the control group, as shown by the significant main effect of group, χ^2 (1): 28.91; $p < .001$. The type of verb pair was significant, χ^2 (1): 17.8; $p < .001$. The interaction between group and type of verb pair was also significant, χ^2 (1): 5.61; $p = .02$.

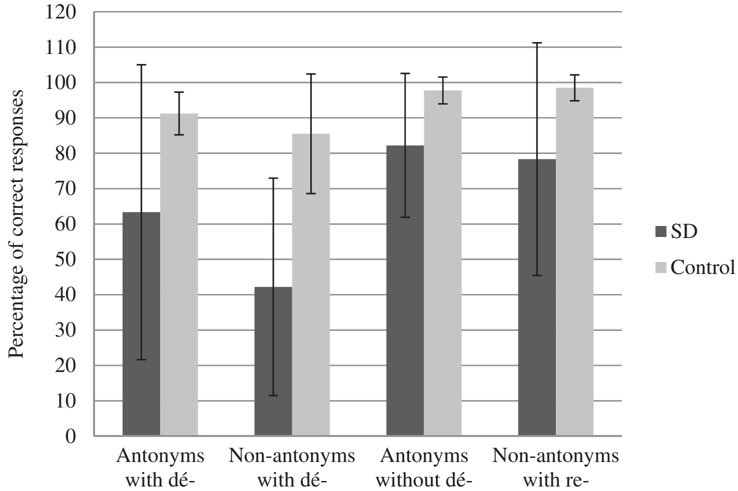

Figure 3. Percentage of correct responses in the antonymy judgment task.

Pairwise comparisons of verb types between groups showed that non-antonyms with "dé–" were associated with poorer performance in the SD group than in the control group, t (27) = −4.914, $p < .001$. The difference between groups for the other three types of verb pairs was not significant (t corrected for unequal variance between groups, $\alpha = .0125$): antonyms with "dé–", t (8.15) = −2, $p = .08$; semantic antonyms without "dé–", t (8.25) = −2.25, $p = .052$; non-antonyms with "re–", t (8.09) = −1.84, $p = .1$.

The correlation between the semantic score and the total score was significant, r (24) = 0.82, $p < .001$. When controlling for group, the correlation was marginally significant, r (22) = 0.4, $p = .054$.

Discussion

SD participants had difficulties discriminating between pairs of real morphological antonyms, and pairs of pseudo-morphological, non-antonym verbs. In the SD group, results show a tendency to wrongly accept non-antonyms with "dé–" as real antonyms. In fact, on average, they perform below chance level for these items. However, SD participants also wrongly rejected real antonym pairs. The performance of the control group was not at ceiling for every type of verb pairs. However, as already mentioned, words tend to be spontaneously decomposed into morphemes, whether this morphological structure is real or not (Amenta & Crepaldi, 2012). In this task, the interpretation based on morphological structure was correct for half of the items starting with "dé–" and incorrect for the other half. So, the morphological interpretation was reinforced by half of these items and had to be inhibited for the other half. Considering that this task was done under a time-limit constraint, some errors were expected.

Correlational analyses showed that the total score was correlated with the semantic score. When controlling for group, the correlation was marginally significant. Overall, results suggest that semantic cognition is required to determine that an interpretation based on morphological structure ("déX" is the antonym of "X") is appropriate or not.

General discussion

This study aimed to investigate the different roles played by semantic cognition in derivational morphology. According to connectionist models, semantic cognition is involved in the representation of less transparent and less predictable words (Plaut & Gonnerman, 2000). SD participants were expected to make more mistakes when they had to produce a noun starting from a verb with an allomorphic root than from a verb with a transparent root. The results showed that SD participants had indeed more difficulties for verbs with allomorphic roots and that their performance followed a graded pattern. Semantic cognition would also be involved in the representation of semantic information conveyed by derivational morphemes, allowing them to be productive (Bates & Wulfeck, 1989; Gonnerman et al., 2007; Plaut & Gonnerman, 2000; Seidenberg & Gonnerman, 2000). Consequently, central semantic impairment should alter morphemes' semantic representation. As predicted, results showed that SD participants had difficulties associating derived words and pseudo-words to a definition based on the semantic information conveyed by morphemes. Lastly, many words present similarities to morphologically complex words but are not morphologically complex themselves. Semantic cognition would play an essential role in preventing erroneous interpretations based on a seemingly morphological structure (Fruchter & Marantz, 2015). Results show that SD participants had difficulties discriminating between real morphological antonyms and pseudo-morphological non-antonyms. This study's main findings are discussed in more details below.

SD participants are able to produce transparent morphologically complex words. However, they have difficulties when operations of morphology are made less reliable by allomorphy and their performance follows a graded pattern. Studies on inflectional morphology in SD show that participants have difficulties producing the past tense of irregular verbs, especially those of low frequency (Patterson et al., 2006; Wilson et al., 2014; for a review, see Auclair-Ouellet, 2015). As in inflectional morphology, semantic cognition would play an important role in the representation of less predictable words and in encoding the links between these words and those that are formed with the same base. Semantic cognition would also intervene to inhibit the production of non-words constituted of two valid morphemes that do not form a word together. In the absence of normal semantic input, pseudo-words that are formed by applying productive operations of morphology are more likely to be produced.

These results are in line with other studies on derivational morphology (Auclair-Ouellet et al., 2016; Kavé et al., 2012) that also reported the production of morphological paraphasias by participants with SD. The production of these errors shows that participants are still able to form words by applying productive morphological operations (Kavé et al., 2012). These errors are also a manifestation of central semantic impairment, a conclusion recently made in a single-case study (Auclair-Ouellet et al., 2016).

Because of their semantic impairment, SD participants had to rely on morphology more than the participants of the control group. Morphology could support the production of words with allomorphic roots, although less than for completely transparent words. Lexical access to words with allomorphic roots would give access to the other forms of their root, either because each allomorphic root has a representation that is linked to the others (Burani & Laudanna, 1992) or because they share a common, abstract representation (Marslen-Wilson & Zhou, 1999). It is possible that people with SD could not correctly access verbs' lexical representations and that they could not access their allomorphic roots. However, problems accessing allomorphic roots are likely to affect all words with allomorphic roots equally. The presence of a graded pattern of performance for words with a common pattern of allomorphy suggests another interpretation.

Results show that SD participants had a better performance for words with a frequent form of allomorphy, which could be described as a "sub-transparency". Distributed connectionist models are able to account for these patterns. More a sound-to-meaning mapping is encountered and the more it is present in several different words, the more likely it is for this pattern to gain an independent representation, and to become salient and able to generalise to different words (Plaut & Gonnerman, 2000). It is interesting to note that, in this study, many of SD participants' errors presented root transformations (although incorrect ones) that were akin to allomorphy.

Only a small proportion of SD participants' errors are non-responses or aborted responses. In fact, they produced more than three times as many morphological paraphasias. In a single-case study (Auclair-Ouellet et al., 2016), similar errors made by a woman with SD (N.G.) were interpreted as difficulties determining that a combination of morphemes form a real word or not. In other words, the building blocks of language (i.e., morphemes) were still well preserved, but her semantic impairment prevented her from inhibiting the production of responses that are composed of morphemes that do not form real words when they are put together. Several studies show that morphologically complex pseudo-words are associated with more errors and longer response latencies in lexical decision (Burani et al., 1997; Taft & Forster, 1975; for a review, see Amenta & Crepaldi, 2012). Studies that support the automatic decomposition of morphologically complex words in lexical access recently showed that lexical access ends with a final stage in which the initial segmentation is validated (Fruchter & Marantz, 2015; Lavric et al., 2012; Levy et al., 2014; Whiting et al., 2013). This final stage would be necessary to confirm that the two automatically segmented units form a word when they are put together and that an interpretation based on segmentation is appropriate (Fruchter & Marantz, 2015). This final stage requires semantic cognition and is associated with the activation of the anterior temporal lobes (Whiting et al., 2013). While more studies on derived word production are needed, this study shows that participants with SD are able to produce morphologically complex words, that their performance is influenced by transparency in a graded manner and that their semantic impairment prevents them from inhibiting the production of morphological paraphasias.

In addition to having difficulties of morphologically complex word formation, which are similar to difficulties found in inflectional morphology, SD participants have difficulties understanding the meaning of morphemes. A productive morpheme is a morpheme that is likely to be used to coin new words. In fact, the pseudo-word condition of the definition matching task is not completely foreign to "real-life" word creation based on morphological productivity. In order to play their role in new word creation and to be productive, morphemes (or their corresponding form-to-meaning patterns of activation) must have a form of semantic representation. This claim is supported by different models, such as a latter account of Levelt's language production model (Levelt et al., 1999), localist connectionist models (Bates & Wulfeck, 1989) and distributed connectionist models (Gonnerman et al., 2007; Plaut & Gonnerman, 2000; Seidenberg & Gonnerman, 2000). As any form of semantic representation, the one that is included in derivational morphemes is vulnerable to central semantic impairment found in SD.

Last, semantic cognition would also be involved when judging if interpreting a word based on its morphological structure is appropriate. The presence of morpheme-like units in words is sometimes coincidental, but many studies show that these units are automatically segmented and that they influence word processing (Rastle, Davis, Marslen-Wilson, & Tyler, 2000; Rastle, Davis, & New, 2004). When faced with a pseudo-morphological word, semantic cognition would be essential to counterbalance the misleading form-based information and prevent a morphological interpretation (Fruchter & Marantz, 2015; Lavric et al., 2012; Levy et al., 2014; Whiting et al., 2013). In other words, semantic cognition is necessary to override erroneous interpretations based on apparent morphological structure. Recent studies have focused on suffixed words and visual word processing. While results for prefixed words are less consistent, there are studies that show pseudo-prefix priming, which indicates that prefixes are subject to blind segmentation, just like suffixes (Amenta & Crepaldi, 2012).

Conclusion

Through three experiments, this study showed that semantic cognition is involved in supporting the production of less transparent or less predictable derived words, in supporting the representation derivational morphemes' meaning, and in preventing interpretations based on morphological structure when they are not appropriate.

This study has some limitations. First, SD is a rare form of cognitive impairment. For this reason, it was not possible to recruit more SD participants in this study. However, the group reported in the present study is one of the largest groups of French-speaking participants reported up to now and its characteristics are similar to those reported in the literature (Hodges et al., 2010; Johnson et al., 2005).

Second, the antonymy judgment task might be criticised because it focused on morphological/semantic relations and because it might be considered difficult for SD participants. However, results show that they obtained relatively good scores for semantic antonyms without "dé–" and non-antonyms with "re–" compared to non-antonyms with "dé–". In fact, they did not have significant difficulties for these word pairs compared to the control group. Also, a study by Crutch, Williams, Ridgway, and Borgenicht (2012) showed that participants with global aphasia following stroke had better performances for antonyms than synonyms and other associates (e.g., good fun). The authors suggest that a relation of antonymy between two words can be determined based on polarity (i.e., the degree to which the concept is positive or negative). Synonyms and other associates would require more fine-grained processing over a range of conceptual properties (e.g., reference to time, space, quantity, etc.). Although Crutch et al. (2012) did not use morphologically complex words, their study shows that antonymy is a robust form of semantic relation. Because it does not require in depth processing, it is more likely to remain better preserved in aphasia. In sum, it is interesting to note that on average, participants were not impaired overall but that it is the presence of non-systematic form-to-meaning mappings that caused difficulties.

Only a few studies of SD participants focused on derivational morphology up to now (Auclair-Ouellet et al., 2016; Benedet et al., 2006; Kavé et al., 2012; Meteyard & Patterson, 2009). Derivational morphology is not routinely assessed in the clinic, and tests are rare. However, these results and those of recent psycholinguistic studies show that tests of derivational morphology have the potential to contribute valuable information to assessment, not only in SD, but in other forms of language impairment. For example, assessing the comprehension of derivational morphemes could provide information on an individual's capacity to use them as cues to understand new or unfamiliar words, both in the oral and written modalities. Most psycholinguistic studies published up to now used sophisticated masked priming paradigms which are not best suited to test participants with complex language impairments. More studies are needed to develop adapted tests.

Morphology provides structure to language. However, when this structure is not informed by semantic input, it can become misleading. Other language impairments such as surface dyslexia and surface dysgraphia (Brambati, Ogar, Neuhaus, Miller, & Gorno-Tempini, 2009; Gorno-Tempini et al., 2011; Henry, Beeson, Alexander, & Rapcsak, 2012; Woollams, Lambon Ralph, Plaut, & Patterson, 2007) are a demonstration of the imbalance between form and meaning that is characteristic of SD. Semantic cognition's essential role in counterbalancing formal information explains why the manifestations of central semantic impairment are so numerous and diverse.

Acknowledgements

The first author was supported by a Joseph-Armand Bombardier Canada Graduate Scholarship from the Social Sciences and Humanities Research Council of Canada [grant number 767-2011-2215]. We would like to thank all the participants that have kindly taken part in this study.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

The first author was supported by a Joseph-Armand Bombardier Canada Graduate Scholarship from the Social Sciences and Humanities Research Council of Canada [grant number 767-2011-2215]. N. A. O., R. L, M. F. and J.M. were supported by a research grant from the Social Sciences and Humanities Research Council of Canada [grant number 435-2014-0509].

References

Amenta, S., & Crepaldi, D. (2012). Morphological processing as we know it: An analytical review of morphological effects in visual word identification. *Frontiers in Psychology*, *3*, 1–12. doi:10.3389/fpsyg.2012.00232

Auclair-Ouellet, N. (2015). Inflectional morphology in primary progressive aphasia and Alzheimer's disease: A systematic review. *Journal of Neurolinguistics*, *34*, 41–64. doi:10.1016/j.jneuroling.2014.12.002

Auclair-Ouellet, N., Fossard, M., Houde, M., Laforce, R., & Macoir, J. (2016). Production of morphologically derived words in the semantic variant of primary progressive aphasia: Preserved decomposition and composition but impaired validation. *Neurocase*, *22*, 170–178. doi:10.1080/13554794.2015.1081391

Bak, T. H., & Hodges, J. R. (2003). Kissing and dancing—A test to distinguish the lexical and conceptual contributions to noun/verb and action/object dissociation. Preliminary results in patients with frontotemporal dementia. *Journal of Neurolinguistics*, *16*, 169–181. doi:10.1016/S0911-6044(02)00011-8

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2014). lme4: Linear mixed-effects models using Eigen and S4. R package version 1.1-6. Retrieved from http://CRAN.R-project.org/package=lme4

Bates, E., & Wulfeck, B. (1989). Crosslinguistic studies of aphasia. In B. MacWhinney & E. Bates (Eds.), *The crosslinguistic study of sentence processing* (pp. 328–371). Cambridge: University Press.

Bauer, L. (2001). *Morphological productivity*. Cambridge: Cambridge University Press.

Bauer, L. (2008). Derivational morphology. *Language and Linguistics Compass*, *2*, 196–210. doi:10.1111/j.1749-818x.2007.00045.x

Benedet, M., Patterson, K., Gomez-Pastor, I., & Garcia de la Rocha, M. L. (2006). "Non-semantic" aspects of language in semantic dementia: As normal as they're said to be? *Neurocase*, *12*, 15–26. doi:10.1080/13554790500446868

Bölte, J., Schulz, C., & Dobel, C. (2010). Processing of existing, synonymous, and anomalous German derived adjectives: An MEG study. *Neuroscience Letters*, *469*, 107–111. doi:10.1016/j.neulet.2009.11.054

Booij, G. (2013). *The grammar of words – An introduction to linguistic morphology*. Oxford: University Press.

Brambati, S. M., Ogar, J., Neuhaus, J., Miller, B. L., & Gorno-Tempini, M. L. (2009). Reading disorders in primary progressive aphasia: A behavioral and neuroimaging study. *Neuropsychologia*, *47*, 1893–1900. doi:10.1016/j.neuropsychologia.2009.02.033

Burani, C., Dovetto, F. M., Spuntarelli, A., & Thornton, A. M. (1999). Morpholexical access and naming: The semantic interpretability of new root–suffix combinations. *Brain and Language*, *68*, 333–339. doi:10.1006/brln.1999.2073

Burani, C., Dovetto, F. M., Thornton, A. M., & Laudanna, A. (1997). Accessing and naming affixed pseudo-words. In G. Booij & J. von Marle (Eds.), *Yearbook of morphology 1996* (pp. 55–72). Dordrecht: Kluwer Academic.

Burani, C., & Laudanna, A. (1992). Units of representation of derived words in the lexicon. In R. Frost & L. Katz (Eds.), *Orthography, phonology, morphology, and meaning* (pp. 361–376). Amsterdam: Elsevier.

Caine, D., Breen, N., & Patterson, K. (2009). Emergence and progression of 'non-semantic' deficits in semantic dementia. *Cortex*, *45*, 483–494. doi:10.1016/j.cortex.2007.07.005

Crutch, S. J., Williams, P., Ridgway, G. R., & Borgenicht, L. (2012). The role of polarity in antonym and synonym conceptual knowledge: Evidence from stroke aphasia and multidimensional ratings of abstract words. *Neuropsychologia*, *50*, 2636–2644. doi:10.1016/j.neuropsychologia.2012.07.015

Faroqi-Shah, Y., & Thompson, C. K. (2007). Verb inflections in agrammatic aphasia: Encoding of tense features. *Journal of Memory and Language*, *56*, 129–151. doi:10.1016/j.jml.2006.09.005

Forster, K. I., & Forster, J. C. (2003). DMDX: A Windows display program with millisecond accuracy. *Behavior Research Methods, Instruments, & Computers*, *35*, 116–124. doi:10.3758/BF03195503

Fruchter, J., & Marantz, A. (2015). Decomposition, lookup, and recombination: MEG evidence for the Full Decomposition model of complex visual word recognition. *Brain & Language*, *143*, 81–96. doi:10.1016/j.bandl.2015.03.001

Gonnerman, L. M., Seidenberg, M. S., & Andersen, E. S. (2007). Graded semantic and phonological similarity effects in priming: Evidence for a distributed connectionist approach to morphology. *Journal of Experimental Psychology: General*, *136*, 323–345. doi:10.1037/0096-3445.136.2.323

Gorno-Tempini, M. L., Hillis, A. E., Weintraub, S., Kertesz, A., Mendez, M., Cappa, S. F., … Grossman, M. (2011). Classification of primary progressive aphasia and its variants. *Neurology*, *76*, 1006–1014. doi:10.1212/WNL.0b013e31821103e6

Henry, M. L., Beeson, P. M., Alexander, G. E., & Rapcsak, S. Z. (2012). Written language impairments in primary progressive aphasia: A reflection of damage to central semantic and phonological processes. *Journal of Cognitive Neuroscience*, *24*, 261–275. doi:10.1162/jocn_a_00153

Hodges, J. R., Mitchell, J., Dawson, K., Spillantini, M. G., Xuereb, J. H., McMonagle, P., … Patterson, K. (2010). Semantic dementia: Demography, familial factors and survival in a consecutive series of 100 cases. *Brain*, *133*, 300–306. doi:10.1093/brain/awp248

Hodges, J. R., Patterson, K., Oxbury, S., & Funnell, E. (1992). Semantic dementia – Progressive fluent aphasia with temporal lobe atrophy. *Brain*, *115*, 1783–1806. doi:10.1093/brain/115.6.1783

Hothorn, T., Bretz, F., & Westfall, P. (2008). Simultaneous inference in general parametric models. *Biometrical Journal*, *50*, 346–363. doi:10.1002/bimj.200810425.

Howard, D., & Patterson, K. (1992). *The Pyramids and Palm Trees Test: A test for semantic access from words and pictures*. Bury St. Edmunds: Thames Valley Test Company.

Janssen, D. P., Roelofs, A., & Levelt, W. J. M. (2002). Inflectional frames in language production. *Language and Cognitive Processes*, *17*, 209–236. doi:10.1080/01690960143000182

Joanette, Y., Ska, B., Belleville, S., Lecours, A. R., Peretz, I., & Poissant, A. (1995). Évaluation neuropsychologique dans la démence de type Alzheimer: Un compromise optimal. *L'année Gérontologique*, *3*, 69–83. Retrieved from http://www.serdi-fr.com/publications/lannee-gerontologique

Joanette, Y., Ska, B., & Côté, H. (2004). *Protocole Montréal d'évaluation de la communication (MEC)*. Isbergues: Ortho Édition.

Johnson, J. K., Diehl, J., Mendez, M. F., Neuhaus, J., Shapira, J. S., Forman, M., … Miller, B. L. (2005). Frontotemporal lobar degeneration – Demographic characteristics of 353 patients. *Archives of Neurology*, *62*, 935–930. doi:10.1001/archneur.62.6.925

Kavé, G., Heinik, J., & Biran, I. (2012). Preserved morphological processing in semantic dementia. *Cognitive Neuropsychology*, *29*, 550–568. doi:10.1080/02643294.2012.759097

Lambon Ralph, M. A. (2014). Neurocognitive insights on conceptual knowledge and its breakdown. *Philosophical Transactions of the Royal Society B*, *369*, 1–11. doi:10.1098/rstb.2012.0392

Lavric, A., Elchlepp, H., & Rastle, K. (2012). Tracking hierarchical processing in morphological decomposition with brain potentials. *Journal of Experimental Psychology: Human Perception and Performance*, *38*, 811–816. doi:10.1037/a0028960

Levelt, W. J. M. (1989). *Speaking: From intention to articulation*. Cambridge: University Press.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, *22*, 1–75. doi:10.1017/S0140525X99001776

Levy, J., Hagoort, P., & Démonet, J.-F. (2014). A neuronal gamma oscillatory signature during morphological unification in the left occipitotemporal junction. *Human Brain Mapping*, *35*, 5847–5860. doi:10.1002/hbm.22589

Lieber, R. (2010). *Introducing morphology*. Cambridge: Cambridge University Press.

Macoir, J. (2009). Is a plum a memory problem? Longitudinal study of the reversal of concreteness effect in a patient with semantic dementia. *Neuropsychologia*, *47*, 518–535. doi:10.1016/j.neuropsychologia.2008.10.006

Macoir, J., Beaudoin, C., & Bluteau, J. (2008). *Le test de dénomination d'images de Québec: TDQ-60*. Québec: Université Laval.

Marslen-Wilson, W., & Zhou, X. (1999). Abstractness, allomorphy, and lexical architecture. *Language and Cognitive Processes*, *14*, 321–352. doi:10.1080/016909699386257

Meteyard, L., & Patterson, K. (2009). The relation between content and structure in language production: An analysis of speech errors in semantic dementia. *Brain and Language*, *110*, 121–134. doi:10.1016/j.bandl.2009.03.007

Miceli, G., & Caramazza, A. (1988). Dissociation of inflectional and derivational morphology. *Brain and Language*, *35*, 24–65. doi:10.1016/0093-934X(88)90100-9

Nasreddine, Z. S., Phillips, N. A., Bédirian, V., Charbonneau, S., Whitehead, V., Collin, I., … Chertkow, H. (2005). The Montreal Cognitive Assessment, MoCA: A brief screening tool for mild cognitive impairment. *Journal of the American Geriatrics Society*, *53*, 695–699. doi:10.1111/j.1532-5415.2005.53221.x

Neary, D., Snowden, J. S., Gustafson, L., Passant, U., Stuss, D., Black, S., … Benson, D. F. (1998). Frontotemporal lobar degeneration: A consensus on clinical diagnostic criteria. *Neurology*, *51*, 1546–1554. doi:10.1212/WNL.51.6.1546

New, B., Pallier, C., Ferrand, L., & Matos, R. (2001). Une base de données lexicales du français contemporain sur internet: LEXIQUE. *L'Année Psychologique*, *101*, 447–462. doi:10.3406/psy.2001.1341

Patterson, K., Lambon Ralph, M. A., Jefferies, E., Woollams, A., Jones, R., Hodges, J. R., & Rogers, T. T. (2006). "Presemantic" cognition in semantic dementia: Six deficits in search of an explanation. *Journal of Cognitive Neuroscience*, *18*, 169–183. doi:10.1162/jocn.2006.18.2.169

Patterson, K., Nestor, P. J., & Rogers, T. T. (2007). Where do you know what you know? The representation of semantic knowledge in the human brain. *Nature Reviews Neuroscience*, *8*, 976–987. doi:10.1038/nrn2277

Plaut, D. C., & Gonnerman, L. M. (2000). Are non-semantic morphological effects incompatible with a distributed connectionist approach to lexical processing? *Language and Cognitive Processes*, *15*, 445–485. doi:10.1080/01690960050119661

R Core Team. (2014). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Retrieved from http://www.r-project.org/

Rastle, K., Davis, M. H., Marslen-Wilson, W. D., & Tyler, L. K. (2000). Morphological and semantic effects in visual word recognition: A time-course study. *Language and Cognitive Processes*, *15*, 507–537. doi:10.1080/01690960050119689

Rastle, K., Davis, M. H., & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review*, *11*, 1090–1098. doi:10.3758/BF03196742

Riddoch, M. J., & Humphreys, G. W. (1993). *The Birmingham object recognition battery (BORB)*. London: Erlbaum.

Rogers, T. T., Lambon Ralph, M. A., Hodges, J. R., & Patterson, K. (2004). Natural selection: The impact of semantic impairment on lexical and object decision. *Cognitive Neuropsychology*, *21*, 331–352. doi:10.1080/02643290342000366

Routhier, S., Bier, N., & Macoir, J. (2015). The contrast between cueing and/or observation in therapy for verb retrieval in post-stroke aphasia. *Journal of Communication Disorders*, *54*, 43–55. doi:10.1016/j.jcomdis.2015.01.003

Seidenberg, M. S., & Gonnerman, L. M. (2000). Explaining derivational morphology as the convergence of codes. *Trends in Cognitive Sciences*, *4*, 353–361. doi:10.1016/S1364-6613(00)01515-1

Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior*, *14*, 638–647. doi:10.1016/S0022-5371(75)80051-X

Whiting, C. M., Marslen-Wilson, W. D., & Shtyrov, Y. (2013). Neural dynamics of inflectional and derivational processing in spoken word comprehension: Laterality and automaticity. *Frontiers in Human Neuroscience*, *7*, 1–15. doi:10.3389/fnhum.2013.00759

Wilson, S. M., Brandt, T. H., Henry, M. L., Babiak, M., Ogar, J. M., Salli, C., … Gorno-Tempini, M. L. (2014). Inflectional morphology in primary progressive aphasia: An elicited production study. *Brain & Language*, *136*, 58–68. doi:10.1016/j.bandl.2014.07.001

Woollams, A. M., Lambon Ralph, M. A., Plaut, D. C., & Patterson, K. (2007). SD-Squared: On the association between semantic dementia and surface dyslexia. *Psychological Review*, *114*, 316–339. doi:10.1037/0033-295X.114.2.316

Wurm, L. H. (2000). Auditory processing of polymorphemic pseudowords. *Journal of Memory and Language*, *42*, 255–271. doi:10.1006/jmla.1999.2678