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Neural correlates of unconventional verb extensions reveal preschoolers' analogical abilities

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Abstract

In the current event-related potential (ERP) study, we assessed whether 4-year-olds' unconventional verb extensions are driven by abstract relational similarities or superficial object-based similarities. Participants were presented with images of action (e.g., peeling an orange) while hearing sentences containing a conventional verb (e.g., *peeling*), an unconventional verb sharing either an abstract relation (i.e., an approximate verb, e.g., *undressing*) or an object (i.e., superficially related verb, e.g., *pressing*) with the action, or a pseudoverb (e.g., *kebraying*). The amplitude of the N400 gradually increased as a function of verb type: from conventional verbs, to approximate verbs, to superficially related verbs to pseudoverbs. These findings suggest that processing of unconventional verb extensions based on abstract relations requires less cognitive effort than integrating those based on objects. Our results illustrate that measuring brain signals in response to unconventional word extensions provides a useful tool to investigate preschoolers' analogical abilities.

Keywords: analogy; semantic approximation; metaphor; overextension; relational similarity; relational category; verbs; preschoolers

1. Introduction

When young children say “Go on Mum, turn on your eyes”, “I undress the orange” or “He breaks the book”, what does it tell us about how they think (Duvignau et al., 2007)? Such semantic approximations denote a fundamental feature of the human mind, referring to an ability to draw analogies from previous experiences to make sense of new situations (Day & Goldstone, 2012; Hofstadter & Sander, 2013). These

unconventional verb extensions provide an insightful tool to study lexical development since they illustrate preschoolers' ability to apply words (e.g., *undress*) to new referents (e.g., a peeling action) on the basis of abstract relational similarities (e.g., *taking off an envelope*). In the current paper, we aimed at providing a better understanding of cognitive and neural processes underlying semantic approximations. To do so, we measured the event-related potentials (ERPs) associated with the comprehension of different types of unconventional verb extensions by preschoolers.

1.1. Early unconventional word extensions: analogical or superficial?

A great deal of research has highlighted preschoolers' ability to interpret new situations by analogy with more familiar concepts (Gentner, 1977; Hatano & Inagaki, 1987; Vosniadou, 1989; Goswami & Brown, 1990). In recent years, studies have documented the processes allowing young children to extract abstract relational representations that can be readily generalized (Gentner et al., 2011; Goddu, Lombrozo & Gopnick, 2020). Notably, analogical comparisons between several analog exemplars labeled in the same way allows young children to learn relational categories (e.g., *cutter for*) and to generalize them across superficially different examples (e.g., from *knife: watermelon* to *scissors: paper*) (Gentner et al., 2011; Thibaut & Witt, 2015, see also Childers, 2011). These findings may suggest that preschoolers are able to learn abstract concepts through repeated analog experiences and extend them in flexible ways (Naigles et al., 2009; Hofstadter & Sander, 2013).

Research documenting early word productions has highlighted that after a period of conservative use of newly learned words, young children frequently overextend words to a broader range of referents than conventionally accepted (Clarks, 1973; Rescorla, 1980; Bowerman, 1982). This literature on early word production extends developmental research on analogy in interesting ways. Whereas the latter has

focused on the ability to map two concepts presented simultaneously, the former informs how young children produce their own analogies to deal with new situations. Unconventional word extensions based on abstract relations are particularly demonstrative of young children's analogical abilities. Bowerman (1978, 2005) analyzed data from a diary study and reported frequent cases where children as young as 2 to 4 years of age interchanged related relational terms (e.g., saying *open* instead of *switch on*), reflecting that abstract semantic similarities between concepts are understood from an early age. Such overextensions have also been attested in more controlled naming tasks (Pye et al., 1996; Duvignau et al., 2007; Gentner & Bowerman, 2009; Bowerman, 2012) and categorization tasks (Schaefer, 1979), which notably revealed that preschoolers often use unconventional verbs for events involving material destruction or some types of separation (e.g., *breaking* for *tearing*, or *undressing* for *peeling*). Duvignau and colleagues coined the terms *semantic approximations* to refer to children's substitution errors involving concepts sharing an analogical similarity (Gaume et al., 2002).

Yet, another line of research has put forward that young children would initially focus on superficial features before attending to more abstract relations, suggesting that they initially understand words narrowly (Gallivan, 1988; Gentner, 1988, 2006; Gentner & Hoyos, 2017). In a study led by Seston et al., (2009), 6-year-olds were poor at explaining the meaning of novel extensions of familiar verbs (e.g., *she swept it away with her feet*). This result would illustrate their difficulty in focusing on the relevant relations involved in an action event. It was also proposed that children struggle with dissociating the verb's core components from the object in a scene when applying a familiar verb (Saji et al., 2011). The authors studied Chinese-speaking children's use of 13 *carry/hold* verbs distinguishing actions according to the manner of holding the object (e.g., *duan*, carry with two hands with caution, *ding*, carry on head). Interestingly, they found that children tended to apply a similar verb to different manners of holding as long as they were typically associated with the same object (e.g., *duan* and *ding* typically apply to bowls).

Thus, young children would have relied on the (irrelevant) type of objects being held rather than on the manner of holding when categorizing actions.

In summary, it appears that there are still some inconsistencies regarding whether preschoolers focus on objects or abstract relations when extending familiar words to novel situations. These inconsistencies may be at least partly due to the paradigms used in the experiments. Notably, production tasks (e.g., Seston et al., 2009) where children have to paraphrase metaphors may underestimate their metaphoric abilities (Pouscoulous, 2011). Indeed, these tasks test children's ability to express metaphoric meanings in an explicit manner rather than their understanding per se. Comprehension tasks have the advantage of reducing the demands on productive abilities, but they do not allow a direct measure of comprehension processes, since behavioral responses may also be affected by post-comprehension processes involved in interpreting and answering a specific question (e.g., judging if a metaphor is smart or silly, Zhu et al., 2020).

The ERP technique offers the possibility to provide a new insight on the role of similarities at the level of objects or abstract relations in unconventional verb extensions. Since the ERP technique does not require an overt response from the participant, it allows us to capture comprehension processes in real-time, prior to those involved in the production of a behavioral response. Furthermore, the ERPs have proved to be effective in measuring processing efforts associated with the interpretation of non-literal language (Kutas & Federmeier, 2011).

1.2. ERPs

One of the most documented ERP components is the N400, which is associated with the semantic processing of linguistic and non-linguistic inputs (Kutas & Federmeier, 2011). More specifically, the N400 may index the retrieval of lexical information from the LTM (Kutas & Federmeier, 2000) and/or

the post-lexical integration of a word meaning into the representation of the preceding context (Hagoort et al., 2009). This negative waveform is typically found around 400 ms over the centro-parietal recording sites (Kutas & Federmeier, 2011). Neural processes indexed by the N400 are shown to be mature at early age, and it has been used to study the organization of the developing lexical-semantic system (Friederici, 2005). The N400 component has been found in different experimental paradigms in young children (e.g., Friedrich & Friederici, 2005; Rämä et al., 2013). Using a picture-word matching task, Torkildsen and colleagues (2006) found a graded N400 response which was minimal for an expected word (e.g., *cat*, if the picture illustrates a cat), intermediate for a within category violation (e.g., *dog*), and maximal for a between category violations (e.g., *car*). The fact that the within-category effect was reduced compared to the between-category violation shows that young children have organized their lexical-semantic system by taxonomic categories (see also Rämä et al., 2013; Hendrickson et al., 2015). Hence, the ERPs have been used to gain insight on the type of semantic similarities that young children attend to.

The ability to establish similarities at the level of abstract relations between concepts in metaphor comprehension has been widely investigated in adult populations. These studies have generally sought to assess the ease of accessing non-literal meanings by comparing the amplitudes of the N400 elicited by metaphors (e.g., *The orchestra filled the concert hall with sunshine*), literal statements (e.g., *The orchestra filled the concert hall with music*), or anomalous statements (e.g., *The orchestra filled the concert hall with hail*) (Tartter et al., 2002). A more pronounced N400 for metaphors than for literal statements is generally assumed to reflect an early detection of a semantic anomaly (Pynte et al., 1996), a greater effort to retrieve concepts from long-term memory (Arzouan et al., 2007), or an additional cost of establishing a mapping between distant concepts (Coulson & VanPetten, 2002; Lai et al., 2009), whereas a smaller N400 for metaphors than for anomalous statements suggests the integration of the non-literal meaning (Tartter et al., 2002; Arzouan et al., 2007). Most notably, Arzouan et al. (2007) found a graded N400 amplitude, starting with a small negativity for literal statements, and increasing for conventional

metaphors, novel metaphors and finally the largest for anomalous statements. This graded pattern was interpreted as reflecting the implementation of a similar mapping process with increasing cognitive demand from literal sentences to conventional metaphors to novel metaphors (see also Coulson & VanPetten, 2002 and Rutter et al., 2012 for related findings and interpretation). Thus, the N400 amplitudes can be used as an index of the ease with which two concepts are mapped.

Metaphors also elicit specific components in later time windows, although the results have not been as consistent as for the N400. Notably, some studies found that metaphors elicit a greater P600 component than alternative types of statements, whereas others reported that metaphors evoke a Late Negative Component (LNC). The P600 is a positive response typically elicited by a syntactic error and which may index sentence level integration including repair and reanalysis of the initial structure (Friederici, et al. 1996). Larger P600s for metaphors than for literal and unrelated statements has been interpreted as reflecting a greater effort to retrieve information from semantic memory to achieve a sentence-level interpretation (Coulson & VanPetten, 2002). The LNC is thought to index secondary semantic integration processes (Friederici, et al., 1999). In the context of metaphor comprehension, the LNC is interpreted as reflecting further attempts to integrate the non-literal meaning, which is more effortful when a novel meaning has to be formed (Arzouan et al., 2007; Zucker & Mudrick, 2019). Studying how metaphorical extensions of verbs are processed, Rutter and colleagues (2012) found that both the N400 and the LNC followed a gradual increase from literal statements to metaphors and finally anomalous statements. A similar pattern of increase for both components suggests that the sustained negativity is a continuation of the effects observed in the earlier window. However, the fact that the difference between metaphorical and anomalous statements was significant in the late but not in the earlier temporal window is consistent with the existence of two distinguishable effects. Namely, a sustained negativity may index the ongoing difficulty of integrating two concepts, whereas a reduced LNC may reflect the successful reinterpretation of the verb in a metaphorical sense.





Another component of interest is the N300, which, in contrast to the N400, is modality specific and typically appears during the semantic processing of visual stimuli over the frontal and the occipital-parietal regions (Hamm et al., 2002; Balconi & Amenta, 2010; Ma et al., 2016). Hamm et al. (2002) reported that the N300 was observed in response to between-category but not within category violations, demonstrating that it is less sensitive than the N400 to semantic relatedness. Of a particular interest for our study, Maguire and colleagues (2013) found that while adult participants displayed both an N300 and an N400 in response to pictures of objects or actions mismatching a noun or a verb, respectively, 8- to 9-year-olds showed an N300 and an N400 congruity effect for objects, but only an N400 effect for incongruous actions. Considering the N300 as an index of rapid matching of a visual input to a stored semantic representation, the authors attributed its absence in children to a lack of abstraction and flexibility of their representations. Thus, the N300 component appears to be another relevant ERP component to study children's verb representations. Moreover, several studies on metaphor comprehension have reported N300 effects in addition to the typical N400 component, especially during the processing of cross-modal metaphors (e.g., where the source is a word and the target is a picture), suggesting that N300 indexes image-based processings preceding mapping (Balconi & Amenta, 2010; Ma et al., 2016).

1.3. The present study

In the current experiment, we used a picture-sentence matching task in which four types of spoken sentences were presented simultaneously with pictures describing actions (e.g., repairing a car). Sentences contained either a conventional verb (e.g., *he is repairing the car*), an approximate verb (e.g., *he is healing the car*), a superficially related verb (e.g., *he is driving the car*), or a pseudoverb (e.g., *he is troyding the car*, see Table 1). This design allowed us to test whether preschoolers' unconventional verb extensions

are mainly based on abstract relations or on objects, by assessing whether approximate verbs or superficially related verbs require more cognitive efforts to be mapped to the action.

Table 1: Examples of stimuli (translated from French).

Images	Verb types
	<p>He is [repairing / healing / driving / troyding] the car</p>
	<p>She is [peeling / undressing / pressing / kebraying] the orange</p>
	<p>The house has been [destroyed / killed / built / vedried]</p>
	<p>He is [tearing / breaking / reading / bideling] the book</p>

Note: the first verb in each sentence is the conventional verb, the second one is the approximate verb, the third one is the superficially related verb, and the last one is the Pseudoverb

Based on previous literature documenting semantic approximations, we propose the *relational focus hypothesis*, according to which preschoolers mainly focus on abstract relations and only secondarily on objects when extending verbs. Thus, the cost of mapping should be lowest for verbs sharing both the abstract relation and the object of the action (i.e. conventional verbs), slightly greater for verbs preserving

only the abstract relation (i.e. approximate verbs), more important for verbs sharing only the object (i.e. superficially related verbs), and maximal for verbs which are unknown (i.e. pseudoverbs). The implementation of a similar mapping process with increasing cognitive demand should be reflected by a graded N400 response that would be increasing from conventional verbs, to approximate verbs, to superficially related verbs, and finally to pseudoverbs. Alternatively, if young children mainly base their verb extension on objects, the amplitude of the N400 should be minimal for conventional verbs, slightly greater for superficially related verbs, more important for approximate verbs, and the greatest for pseudoverbs. Thus, the crucial predictions for differentiating between the two hypotheses regards the hierarchy of amplitudes of the N400 between superficially related and approximate verbs, the amplitude of the latter being inferior to the one of the first if the relational focus hypothesis is supported.

2. Methods

2.1. Participants

Thirty-five 4 years old children ($M = 4.0$ years, $SD = 1.8$ months, 18 girls and 17 boys) from monolingual French-speaking families took part in the study. Thirty other children were tested but their data were rejected due to noisy electroencephalogram recording (less than ten accepted trials in one experimental condition; $n = 23$), an early interruption of the experiment following the child's request ($n = 6$) or refusal to put on the cap ($n = 1$). All the children were born full-term and none of them suffered from hearing or language impairments. They were recruited from a database of parents who already accepted to participate in a previous developmental study in our laboratory, and came from the Paris area. The parents were informed about the goal of the research and provided informed consent before participating. The experimental protocol was performed in accordance with the declaration of Helsinki.

2.2. Materials

The acoustic stimuli were sentences pronounced by a French female speaker. Each participant heard 40 sentences containing a conventional verb, 40 sentences including an approximate verb, 40 sentences containing a superficially related verb and 40 sentences including a pseudoverb, for a total of 160 sentences presented during the experiment. The semantic approximations presented in the experiment were taken from a corpus of spontaneous productions from 2 to 4 years old French-speaking children (Duvignau, 2002). The mean duration of the spoken verbs was 474 ms (range between 149-1348 ms). Four images of actions corresponding to each conventional verb (one picture for each of the four conditions) were selected from the internet or were created to match the requirement of the task, constituting a total set of 160 images. In this way, a given image was only presented once during the experiment. Four sets of 160 picture-sentence associations were created by associating each type of sentence (the one containing the conventional verb, the approximate verb, the superficially related verb and the pseudoverb) to a different picture (one of the four different pictures describing the same action).

2.3. Procedure

Children and their parents were welcomed in the INCC Babylab. The experiment lasted about 20 minutes and took place in a soundproof chamber. Children were seated on their parent's lap or on their own in front of a computer screen. Parents were asked to avoid communicating with their child during the experiment, whether verbally or nonverbally. The interstimulus interval (ISI) between the presentation of the prime picture and the sentence varied between 750 ms and 1250 ms. The presentation of images was triggered by the experimenter when the child looked at the screen. An attention getter – a colored screen with an indistinct animation – was used if necessary to draw a child's attention to the screen. The

comprehension by their child of the verbs used in the experiment was controlled (see 2.4. EEG recording and analysis) by means of a questionnaire that was completed by the parents while they were at the lab. In addition, a French adaptation of the McArthur Communicative Development Inventory for Words and Sentences (Kern et al., 2010) was distributed to the parents at the end of the experiment with a stamped envelope so that they could send it back to us. However, these data could not be analyzed due to an insufficient return rate.

2.4. EEG recording and analysis

A 128-captor Geodesic Sensor Net (GSN, NetStation EGIS V2.0) referenced on-line to the vertex was used to record continuous EEG (sampling rate: 500 Hz and Band-Pass = 0.1 – 100Hz). Impedances were kept below 50 Ω . EEG was filtered (0.3–30 Hz), segmented (1100 ms, beginning 100 ms before target verb onset), and ocular artifacts were removed with an ocular artifact removal (OAR) algorithm (Gratton, Coles, & Donchin, 1983). The 100 ms pre-stimulus period was used as the baseline for amplitude measures. The epochs including eye-movement artifacts, using the electrodes above and below the eyes, as well as motion artifacts, exceeding $\pm 150 \mu\text{V}$ in any channel, were excluded, as were trials with more than 40 noisy channels. Below this threshold, individual bad channels were replaced using spherical spline interpolation. Trials were excluded from further analyses when they corresponded to verbs that the parent indicated as not understood by their child ($M = 12.1$, $SD = 7.6$). Epochs were first averaged separately for each participant and condition. Then, data was re-referenced to the average of all electrodes. Lastly, the epochs were grand-averaged across all participants for each condition. Data from participants who retained less than 10 artifact-free trials per condition were excluded from the grand average and the statistical analysis.

Nine clusters of 10 electrodes each were divided to cover the main scalp areas (Lai, Main & Curran, 2009; Zucker & Mudrick, 2019): posterior left (60, 66, 70, 73, 69, 65, 59, 58 (P7), 64, 68), posterior middle (61, 78, 77, 76, 82, 74, 75 (Oz), 71, 67, 72), posterior right (85, 91, 96 (P8), 95, 94, 89, 88, 83, 84, 90), central left (36, 42, 47, 52, 51, 50, 46, 45, 41 (C5), 40), central middle (54, 37, 55 (CPz), 80, 87, 79, 31, 53, 86, 62), central right (104, 103 (C6), 102, 101, 97, 98, 93, 92, 108, 109), anterior left (22, 23, 19, 24 (F3), 20, 13, 29, 28, 27, 26), anterior middle (21, 14, 15, 16, 10, 18, 11 (Fz), 5, 12, 6) and anterior right (9, 2, 3, 4, 124 (F4), 123, 117, 118, 112, 111). The main component of interest in the current study was the N400. In line with previous literature (e.g., Friederici et al., 1999; Coulson & VanPetten, 2002; Maguire et al., 2013; Zucker & Mudrick, 2019), we analyzed the N400 in the 300-500 ms measurement window. Because recent studies suggest the relevance of the N300 index to study children's verb representation (Maguire et al., 2013), as well as that of the P600/LNC complex to track reinterpretation's processes (Friederici et al., 1999; Arzouan et al., 2007; Rutter et al., 2012; Zucker & Mudrick, 2019), we also led exploratory analyses on the 100-300 ms and the 500-700 ms temporal windows. All statistical analyses were performed on the mean ERP amplitudes in the four experimental conditions. The analysis of variance (ANOVA) included four factors: Verb Type (conventional verb / approximate verb / superficially related verb / pseudoverb), Temporal Window (100-300 ms / 300-500 ms / 500-700 ms), Lateralization (left / middle / right), and Region (posterior / central / anterior). The Greenhouse-Geisser sphericity correction was applied when necessary.

2. Results

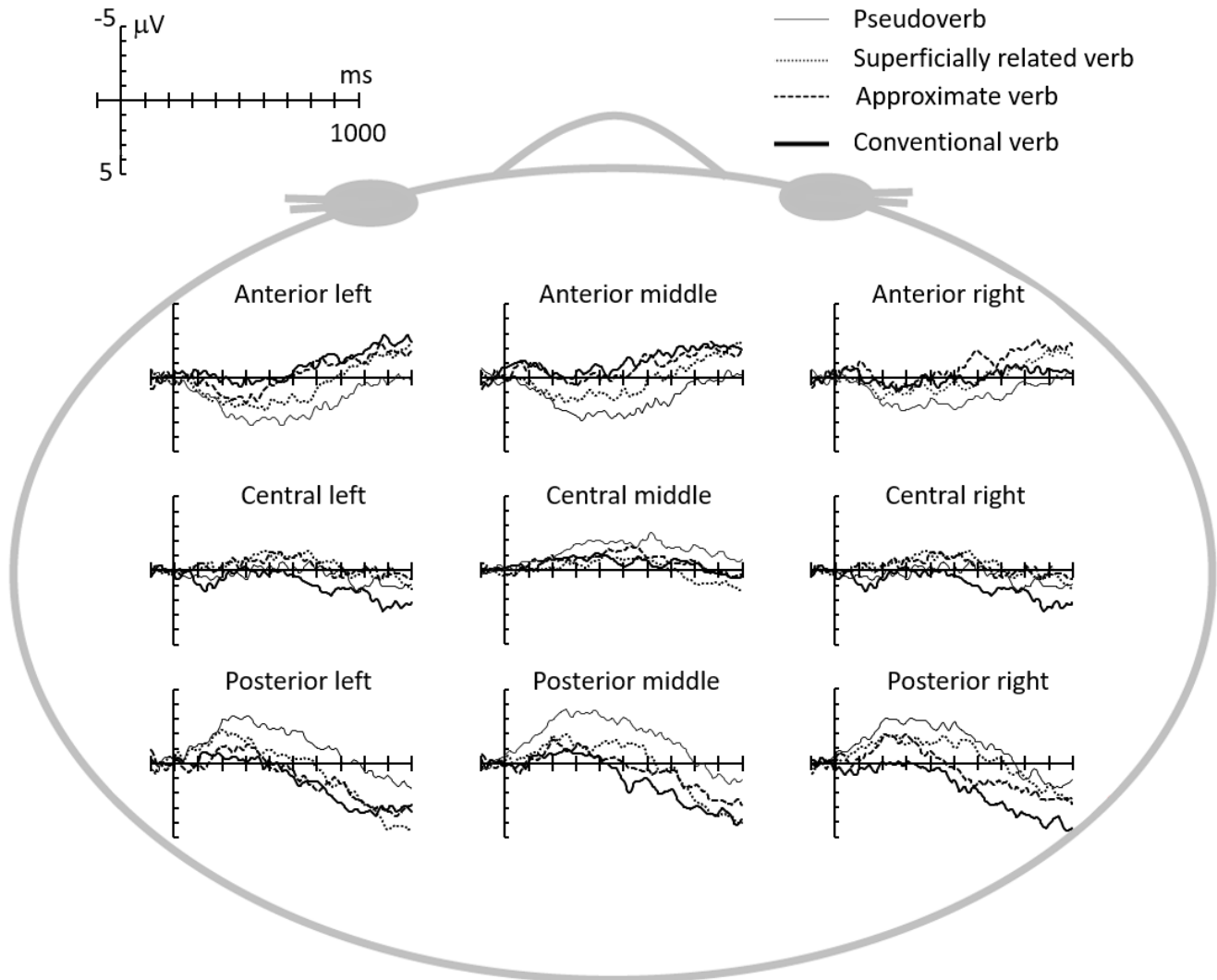


Figure 1: The grand-average ERPs in response to conventional verbs (solid thin lines), approximate verbs (dashed lines), superficially related verbs (dotted lines) and pseudoverbs (solid thick lines) over the anterior, central, and posterior clusters of electrodes. Vertical lines indicate verb onset. The x-axis of the scale is from -100 ms to 1000 ms with respect to verb onset.

Grand average waveforms for the verbs in each experimental condition over the three posterior clusters are displayed in Fig. 1. The amplitudes became more negative as a function of verb type: from

conventional verbs, to approximate verbs, to superficially related verbs, to pseudoverbs over the posterior recording sites, whereas the polarity of this pattern was reversed over the anterior sites. These observations were confirmed by a four-way ANOVA including the factors of Verb Type, Temporal Window, Region and Laterality, showing a significant interaction between Verb Type and Region ($F(6, 34) = 5.69, p < .001, \eta_p^2 = 0.14$). Further analyses focused on the central and posterior sites because of the typical centroparietal distribution of the N400. There was also a significant interaction between Temporal Window and Verb Type ($F(6, 34) = 3.26, p < .05, \eta_p^2 = 0.09$).

Follow up three-way ANOVAs including the factors Verb Type, Temporal Window and Laterality carried out over the posterior sites showed a main effect of Verb Type ($F(3, 34) = 5.83, p = .001, \eta_p^2 = 0.15$) and Temporal Window ($F(2, 34) = 23.05, p < .001, \eta_p^2 = 0.40$). The interaction between Verb Type and Temporal Window was not significant when focusing on the posterior sites. However, based on previous research suggesting that the N400 typically occurs between 300 and 500 ms, and that earlier and later temporal windows may reflect different components, we run separate analyses within 100-300 ms, 300-500 ms and 500-700 ms.

A one-way ANOVA revealed a main effect of Verb Type within each of the three temporal windows (100-300 ms: $F(3, 34) = 4.50, p < .01, \eta_p^2 = 0.12$, 300-500 ms: $F(3, 34) = 4.84, p < .01, \eta_p^2 = 0.13$, 500-700 ms: $F(3, 34) = 5.15, p < .01, \eta_p^2 = 0.13$). The amplitudes of waveforms in the four experimental conditions followed a linear trend at the three temporal windows (100-300 ms: $F(1, 34) = 14.91, p < .001, \eta_p^2 = 0.31$, 300-500 ms: $F(1, 34) = 13.94, p < .01, \eta_p^2 = 0.29$, 500-700 ms: $F(1, 34) = 11.51, p < .01, \eta_p^2 = 0.25$), decreasing from conventional verbs to approximate verbs to superficially related verbs to pseudoverbs. The waveforms for pseudoverbs were significantly more negative than for conventional verbs in the first ($t(34) = 3.54, p = .001, d = 0.60$), the second ($t(34) = 3.34, p < .01, d = 0.57$) and the third temporal windows ($t(34) = 3.01, p < .01, d = 0.51$) (see Fig. 2). The waveforms for approximate and superficially related verbs did not differ significantly in any temporal window (all $ps >$

.05). However, approximate verbs elicited less negative waveforms than pseudoverbs in the three temporal windows (100-300 ms: $t(34) = 2.40, p < .05, d = 0.41$, 300-500 ms: $t(34) = 2.77, p < .01, d = 0.47$, 500-700 ms: $t(34) = 2.97, p < .01, d = 0.50$) and not significantly more negative waveforms than conventional verbs (all $p > .05$). In contrast, superficially related verbs evoked more pronounced negativities than conventional verbs. This difference was significant in the first ($t(34) = 2.16, p < .05, d = 0.37$) and the third ($t(34) = 2.43, p < .05, d = 0.41$) temporal windows, and marginally significant in the second temporal window ($t(34) = 1.67, p = .10, d = 0.28$). Superficially related verbs did not elicit significantly less negative waveforms than pseudoverbs in any temporal window (all $ps > .05$).

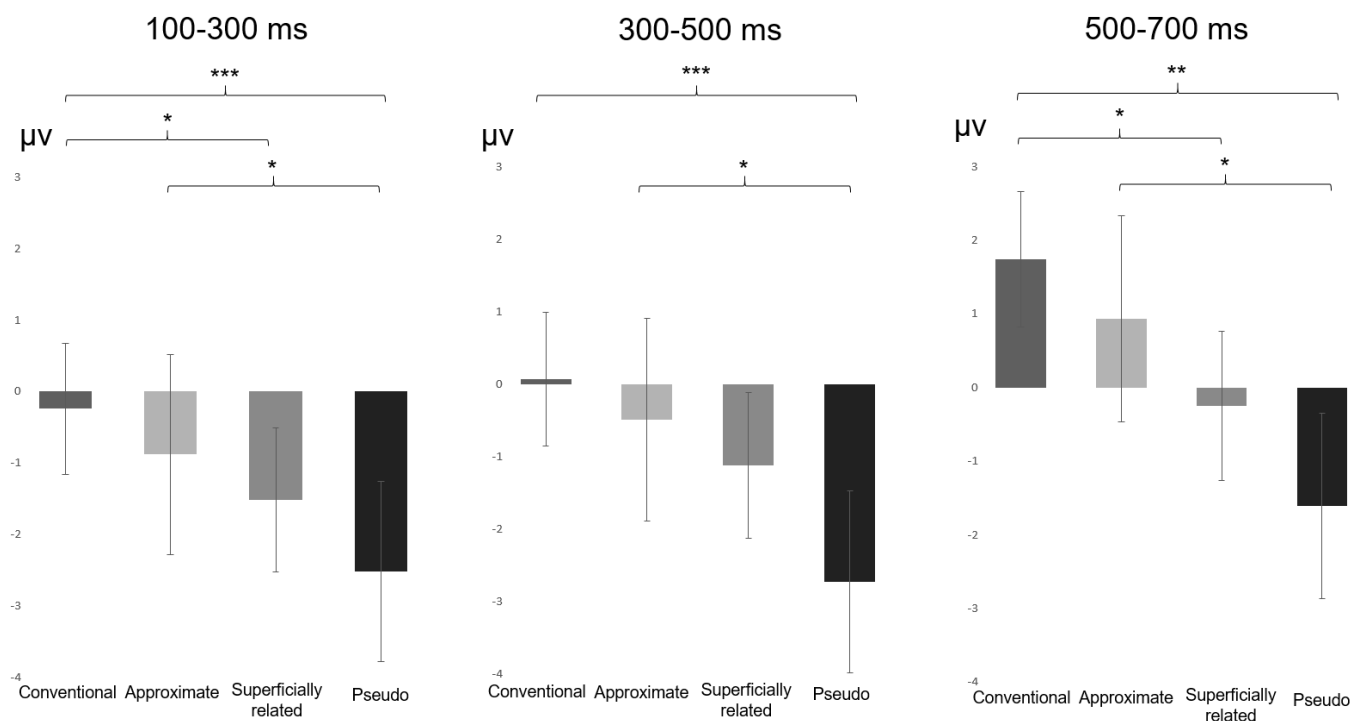


Figure 2: Mean amplitudes in the 100-300 ms, 300-500 ms and 500-700 ms temporal windows over the posterior recording sites for conventional verbs, the approximate verbs, the superficially related verbs and the pseudoverbs. Vertical bars indicate standard deviations. * $p < .05$, ** $p < .01$.

A three-way ANOVA was also performed on the central sites and revealed a main effect of Temporal Window ($F(2, 34) = 4.87, p < .05, \eta_p^2 = 0.13$) and Laterality ($F(2, 34) = 4.87, p < .001, \eta_p^2 = 0.22$), as well as an interaction between Verb Type and Laterality ($F(6, 34) = 2.34, p < .05, \eta_p^2 = 0.06$). One-way ANOVAs carried out over the central left site, the central middle site and the central right site at each of the three time windows showed only a main effect of Verb Type over the central right region between 500 and 700 ms ($F(3, 34) = 4.0, p = .01, \eta_p^2 = 0.11$). Post hoc mean comparisons revealed that the ERP response elicited by conventional verbs differed from the one evoked by the approximate verbs ($t(34) = 2.74, p = .01, d = 0.46$), the superficially related verbs ($t(34) = 3.21, p < .01, d = 0.54$) and the pseudoverbs ($t(34) = 2.37, p < .05, d = 0.40$).

To sum up, a pattern was established over the posterior sites where the N400-like response for conventional verbs < approximate verbs < superficially related verbs < pseudoverbs, confirming our hypothesis that preschoolers process more easily unconventional verb extensions based on abstract relations than superficial object similarities. Significant differences in amplitudes found between approximate verbs and pseudoverbs support the idea that the meaning of unconventional verb extensions based on abstract relations is readily integrated by preschoolers. Although no significant differences were found between the responses elicited by approximate and conventional verbs in the typical N400 window, this difference was identified over the central right site in a later time window. This result suggests that preschoolers process semantic approximations differently than conventional statements, an idea that will be further developed in the General discussion. Lastly, we found that superficially related verbs elicited a sustained incongruity response over the three posterior sites that was significant in the 100-300 ms and the 500-700 ms temporal windows, as well as between 500 and 700 ms over the central right site, suggesting that processing them requires a substantial cognitive effort for preschoolers.

4. General discussion

The goal of the present study was to determine whether brain signals in response to unconventional verb extensions in preschool-aged children reveal their ability to apply verbs by analogy. Children performed a picture-sentence matching task in which images of actions were presented together with sentences containing either a conventional verb, an approximate verb, a superficially related verb, or a pseudoverb. The amplitude of a slow negativity was increasing gradually from conventional verbs to approximate verbs, to superficially related verbs, and finally to pseudoverbs over the posterior recording sites. This graded response comforts the idea that the mapping efforts required to reach semantic integration is increasing from conventional, to approximate, to superficially related verbs. It supports our relational focus hypothesis that preschoolers' unconventional verb extensions are mainly based on abstract relational similarities rather than objects' similarities. Further evidence for this idea comes from the fact that approximate verbs elicited a smaller slow negativity than pseudoverbs, illustrating that semantic approximations are readily integrated by young children. Altogether, the findings provide novel neurophysiological evidence about young children's ability to apply familiar verbs to novel referent on the basis of abstract relational similarity. Our study gives further support to previous findings documenting the use of semantic approximations in production tasks (Duvignau et al., 2007; Bowerman, 2012), receptive tasks (Schaffer, 1978), spontaneous production (Bowerman, 1978, 2005; Gaume et al., 2002; Pouscoulous, 2011), and more broadly to theories assuming that young children flexibly apply words to new referents (Naigles et al., 2009; Hofstadter & Sander, 2013).

Graded amplitudes for different verb types found over the posterior recording sites at all three time windows could be interpreted either as a prolonged N400 component, or as three different components (i.e., a N300, a N400 and a LNC). Maguire et al. (2013) interpreted the absence of N300 during 8-9 year-olds' processing of incongruent verb-pictures association as reflecting overly specific verb

representations. By distinguishing more thinly among different types of verbs in our experimental design, we found a graded N300 response with approximate verbs eliciting N300 of smaller amplitude than superficially related verbs in 4-year-olds. Thus, young children may be less efficient in detecting mismatches between a visual scene and a semantic representation in LTM when they share a general category than when they apply to the same object. It might suggest that preschoolers' verb representations are overly general rather than too specific. Regardless of this possibility, the significant N300 effect elicited by superficially related verbs demonstrates that young children have sufficiently flexible verb representations to rapidly detect mismatches between verbs and actions.

The analysis of the later temporal window also revealed a graded response over the posterior sites, increasing from conventional verbs, approximate verbs, superficially related verbs to pseudoverbs. This graded pattern might be discussed in the light of the findings obtained in the literature on metaphor comprehension, suggesting that the LNC reflects an ongoing effort to integrate two concepts, whereas its decrease indexes a successful reinterpretation of the figurative meaning (Rutter et al., 2012, see also Zucker & Mudrick, 2019). In our study, the graded LNC responses that we found for the different verb types suggests that unconventional verb extensions based on objects require a greater sustained cognitive effort than unconventional verb extensions based on abstract relations to be integrated. The ongoing processing effort required to integrate the meaning of superficially related verbs can also be gleaned from the significant difference in LNC amplitude that they elicited compared to conventional verbs. It may be the case that even after detecting the semantic anomaly, preschoolers were still struggling to find what the conventional verb (e.g., *peel*) and the superficially related verb (e.g., *press*) have in common (e.g., *interaction with an orange*). These data corroborate the idea that young children hardly tend to apply familiar verbs solely based on object similarity.

The difference in amplitude of the responses evoked by approximate and pseudoverbs between 100 and 700 ms over the posterior sites confirms that the meaning of unconventional extensions based on

abstract relations was integrated. Interestingly, approximate verbs did elicit a significant LNC response over the central right site. This result is particularly insightful in the light of Torkildsen et al.'s (2006) findings that within category violations (e.g., when the word *dog* mismatches an image of cat) elicit a topographically restricted late negativity in toddlers. Indeed, this negativity was interpreted as a delayed incongruity effect demonstrating that very young children, who are known to produce taxonomic overextensions, distinguish between the overextended and the conventional concepts (see Pouscoulous, 2011; Walazewska, 2011 for a discussion on this matter). In line, the difference in amplitude between approximate and conventional verbs in the 500-700 ms time window in our study may indicate that preschoolers are aware of the conceptual boundaries between approximate and conventional verbs. On the other hand, the fact that approximate verbs elicited less consistent incongruity effects (i.e., more restricted in topography, delayed, and smaller in amplitude) compared to superficially related verbs could be the result of a greater tendency to confuse verbs sharing an abstract core.

It seems necessary to discuss our findings showing early analogical abilities with regard to alternative proposals that preschoolers initially struggle with representing abstract relations in verbs (Gentner, 2006). Notably, it was shown that children have difficulties in explaining the meaning of novel relational extensions of familiar verbs (Seston et al., 2009) and use object similarity as a privileged cue to overextend verbs (Saji et al., 2011). However, our ERP findings support the idea that preschoolers do rely on abstract similarities when extending familiar verbs, and rely to a lesser extent on objects' similarities. First, different findings in our study and in the study of Seston and colleagues may be at least partly due to methodological factors. Indeed, while assessing children's comprehension of non-literal sentences through paraphrase as Seston and colleagues did may lead to an underestimation of their metaphorical abilities (Pouscoulous, 2011), the use of the ERP technique in our study allowed us to measure comprehension processes independently from production abilities. Next, one possible account for Saji et al.'s (2011) finding that young children are guided by objects similarity when interchanging *carry/hold*

verbs is that they were influenced by both surface similarity and abstract relational similarity since the superficially related verbs still shared a *carry/hold* meaning in common. In contrast, the superficially related verbs in the present study shared only the object type and did not possess a relevant meaning in common (e.g., *repair* versus *drive*). Promising avenues for future developmental research would be to directly compare children's behavioral and brain responses to unconventional verb extensions, as well as to assess whether objects' similarities do play a complementary role in driving these extensions.

5. Conclusions

To sum up, unconventional verb extensions are more easily processed by preschoolers when they share abstract relations rather than objects with the actions, as reflected by graded N400 amplitudes. The early and late negativities elicited by unconventional verb extensions based on objects suggest that preschoolers rapidly detect the mismatch and struggle with finding the similarities these statements are based upon. On the other hand, the reduced negativity evoked by unconventional extensions based on abstract similarities from an early time window illustrate that their meaning is integrated from the earliest stages of semantic processings. This study adds to the literature suggesting that young children readily establish analogies between new situations and familiar concepts. The early ability to apply familiar words to novel referents sharing subtle similarities illustrates the central role of analogy in lexical development.

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Declarations of interest

None

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