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How action context modulates the action-language relationship: a topographic ERP analysis.

Beauprez Sophie-Anne, Laroche Betty, Perret Cyril, & Bidet-Ildei Christel

Université de Poitiers; Université de Tours; Centre National de la Recherche Scientifique;
Centre de Recherches sur la Cognition et l'Apprentissage (UMR 7295), Poitiers, France

Corresponding Author: Christel Bidet-Ildei (christel.bidet@univ-poitiers.fr)
Bâtiment A5 (CeRCA)
5 rue Théodore Lefebvre
TSA 21103 - 86073 Poitiers cedex 9
Phone: +33 (0)5 49 45 46 97

Abstract

The aim of the present study was to investigate how the context in which an action is presented could modulate the effect of action observation on language processing, an effect that is classically observed in the literature. To address this question, we recorded both behavioral (reaction times) and electrophysiological measures (event-related potentials) of participants performing a semantic decision task involving a verb describing an action that was congruent or incongruent with the action presented in a prime picture that had been observed. The prime picture presented an action performed in a usual or an unusual context. The results revealed different behavioral and topographical pattern responses according to the context in which an action is presented. Importantly, only in the usual context, the congruency between the prime picture and the verb stimulus facilitated the semantic processes, leading to shorter response times in this condition compared to the others. Moreover, the topographic analysis revealed that this facilitation was related to reduced processing times for the semantic access to the verb and for the motor preparation for the answer. Taken together, these findings demonstrate that the context of an action is crucial in the link between action and language.

Key words: evoked potential, spatiotemporal segmentation, action perception, action verb processing, context

1. Introduction

Many behavioral and brain studies have investigated the relationship that exists between language and action and have revealed a strong link between them (see Fischer & Zwaan, 2008; Jirak, Menz, Buccino, Borghi, & Binkofski, 2010). Thus, action and the language influence each other (e.g., Liepelt, Dolk, & Prinz, 2012) and activate the same neural network (e.g., Hauk, Johnsrude, & Pulvermüller, 2004), revealing a clear crosstalk between both processes (Pulvermüller, 2005). Interestingly, this effect of action word processing is not limited to action execution but is also present when actions are simply simulated (Khader, Jost, Mertens, Bien, & Rösler, 2010) or observed (Beauprez & Bidet-Ildei, 2017; Bidet-Ildei, Sparrow, & Coello, 2011), suggesting that the link between action and language depends on the activation of common sensorimotor representations (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Bidet-Ildei & Toussaint, 2015).

An issue to be addressed is to determine what features of an action affect the activation of these sensorimotor representations (e.g., Beauprez & Bidet-Ildei, 2018). In the present study, we propose to investigate the role of context in which the action is embedded.

In our everyday life, people perceive others performing actions in a context, and this context is critical since it provides much information that allows an understanding of the intention of the other (Iacoboni et al., 2005). Recently, some researchers have studied how action context can influence action perception. To investigate this question, researchers were interested in unusual actions. Actions can be defined as “usual” when they are presented in a typical and expected context, whereas actions that do not fit a given context are considered “unusual” (Ampe, Ma, Van Hoeck, Vandekerckhove, & Van Overwalle, 2014). Unusual actions and usual actions are processed differently and do not activate the same cerebral networks (Brass, Schmitt, Spengler, & Gergely, 2007; Liepelt, Von Cramon, & Brass, 2008; Van Overwalle & Baetens, 2009). On the one hand, usual actions could be supported by the

activation of the mirror neuron system (Rizzolatti, Fogassi, & Gallese, 2001). On the other hand, the understanding of unusual actions would necessitate the intervention of another system, the mentalizing system, a system involved in rationalization processes (Amodio & Frith, 2006). Thus, the mirror neuron network appears to be insufficient for understanding unusual actions. Since it is known that the mirror neuron network plays a key role in the action-language relationship (Aziz-Zadeh et al., 2006; Rizzolatti & Craighero, 2004), we hypothesized that the context of action presentation could play a role in this relationship and could modulate the effect of action observation on language processing.

In a previous behavioral study (Beauprez, Toussaint, & Bidet-Ildei, 2018), we conducted an experiment to assess this question by observing how action context can affect the subsequent judgments of congruent or incongruent action verbs. The results showed that the semantic processing of action verbs was facilitated when the participants had previously seen that particular action. However, this effect was only obtained when the action observed was in a usual context. For example, the verb “to water” was judged faster after the presentation of a picture representing the action of someone watering a plant (usual context), whereas this effect disappeared when the same action was unusual, as someone watering a computer for example. We interpreted our results as reflecting the activation of different brain systems for usual and unusual actions. More specifically, we suggested that the usual pictures presented to the participants could have activated the mirror system (Rizzolatti, Fogassi, & Gallese, 2001), thereby activating the sensorimotor representation related to this action. In contrast, the unusual pictures presented to the participants could have activated the mentalizing system and less activated the mirror neuron system; consequently, the sensorimotor representation would be reduced or not activated, which would have led to the absence of effect in the unusual context.

To assess this hypothesis, we proposed to replicate this first study while adding ERP measures. Thus, the objective of the present study was to precisely characterize the temporal sequence of the cognitive processes involved when our participants performed a semantic decision task after being primed by usual or unusual action observations.

We used spatiotemporal segmentation analyses to obtain detailed information on the time-windows corresponding to stable configurations of the spatial properties of the electric field and their temporal dynamics across conditions. This analysis will inform about which time-window is affected by the context of production of an action. More precisely, if our hypothesis is true, we should observe different topography when the participants are observing an action in a usual context or in an unusual context. Indeed, the spatiotemporal segmentation technique allows us to observe topographies (or microstates, namely period of coherent synchronized activation of a large scale neuronal network) reflecting that the brain is in a certain information processing step (Brunet, Murray, & Michel, 2011). Thus, across condition, when the same cerebral sources are activated, the same microstates should be observed. On the contrary, different cerebral sources should lead to different microstates. Assuming the involvement of the mirror system for usual pictures and of the mentalizing system for unusual pictures, we hypothesized that the spatiotemporal segmentation should reveal different topographies according to the picture nature.

Moreover, we expected to observe differences during the verb processing. In our previous experiment, we proposed that perceiving an action leads to the activation of the sensorimotor representation of this action. Subsequently, the activation of this sensorimotor representation would facilitate the access to the meaning of the verb (Beauprez et al., 2018). Thereby, differences should be observed during the semantic processing of the verbs. One of the most common indexes of semantic processing is the N400 component (Curran, Tucker, Kutas, & Posner, 1993; Kutas & Hillyard, 1980), a negative deflexion in the ERP wave at

about 400ms, which is known to be greater when there is semantic incongruency. Thus, at this time period (around 400ms), we hypothesized that differences in the spatiotemporal segmentation would be observed. More precisely, we assumed that the semantic processing step would be shorter when the action of the verb has been previously perceived.

2. Method

2.1. Participants

Twenty-five French-speaking, 19- to 25-year-old ($M = 21$ years old, $SD = 1.59$), undergraduate students (15 males) participated in this experiment. All participants were right-handed as determined by the Edinburgh Handedness Scales (Oldfield, 1971; mean quotient of laterality = 95%, max = 100%, min = 83%). They had normal or corrected-to-normal vision and reported no history of motor, perceptual or neurological disorders. All participants provided their written informed consent prior to their inclusion in the experiment and were paid for their participation. They were also unaware of the purpose of the study.

2.2. Materials

Prime Picture:

One hundred different pictures depicting an actor performing an action were used. These pictures were color photographs with a size of 75% of the computer screen (17 in).

Fifty different actions were represented in these pictures. Each action was presented both in a usual and unusual context, leading to a set of 100 pictures (see appendix 1 for examples and appendix 2 for a description of the 100 pictures of the experiment). Thus, a same action (e.g.,

“to water”) had a usual picture (someone watering a plant) and an unusual picture (someone watering a computer).

The choice of these pictures was determined by a pilot study. A questionnaire containing a set of 134 pictures was completed by 15 people. They had to answer three questions for each picture. First, they had to spontaneously name the action represented in the picture by giving one or several verbs corresponding to it (i.e., What is the verb corresponding to this action?). The picture obtained a score of 1 when the answer provided by the participant corresponded to the action, namely, when the participants gave the exact verb of the action or a semantically close verb (e.g., “to lunch” instead of “to eat”). The picture obtained a score of 0 when the answer provided by the participant differed semantically from the one expected (e.g., “to play” instead of “to shoot”). From this score, a percentage of recognition was calculated for each picture. Then, they had to judge whether the verb we chose to label the picture was adequate for characterizing this action (e.g., “Do you think the verb “drink” corresponds to this action?”) using a 5-point scale ranging from “does not fit at all” to “fit perfectly”. Finally, they had to judge the plausibility of the action (“Do you think it is probable that someone would perform this action in this context?”) using a 5-point scale ranging from “very improbable” to “very probable”. The 100 pictures we kept had a mean plausibility score that was high when the action was performed in a usual context (4.8) and low for the unusual context (1.6). Moreover, the actions of these pictures were spontaneously recognized by more than 90% of the participants in the usual and unusual context. Finally, the mean score of adequacy with the label we chose was high for these pictures (4.8).

Stimuli:

One hundred verbs were used. Half of them were “action verbs” corresponding to the 50 actions represented in the pictures, the other half were “non-action verbs”, namely, stative

verbs that do not depict a movement of the body (e.g., “to want”; see appendix 3 for the complete list of verbs). All verbs were presented in French and in the infinitive form.

2.3.Procedure

The participants were tested individually in a soundproof dark room. The presentation of the trials was controlled by the software E-Prime.

The experimental session included 300 trials: presentation of the 100 prime pictures (50 actions in two contexts) that could be followed by three different verbs (congruent action verb, incongruent action verb, and non-action verb). Therefore, in a third of the trials, the prime was followed by a congruent action verb (for example, seeing the picture of someone skiing before seeing the word “to ski”), in another third of the trials, the prime was followed by an incongruent action verb (for example, seeing the picture of someone skiing before seeing the word “to drink”) and in the last third, the prime was followed by a non-action verb (for example, seeing the picture of someone skiing before seeing the word “to think”). This last kind of trial was considered a filler, and these trials were not analyzed. They were included only to propose a task for the participants. Thus, in the end, we analyzed 4 different types of trials (usual picture–congruent action verb; usual picture–incongruent action verb; unusual picture–congruent action verb; and unusual picture–incongruent action verb).

Each trial involved the following procedure: a fixation cross appeared (500 ms), and then the prime picture (2000 ms) was presented. Following another fixation cross (500 ms), the verb stimulus appeared. It remained on the screen until the participant entered a response. The participant’s task was to judge, as quickly and as accurately as possible, whether the verb depicted an action. Participants answered by pressing the left button on the mouse for “yes” (for an action verb as “to water”) the right button on the mouse for “no” (for a non-action verb

as “to want”). Thus, the participant had to perform a semantic decision task on the verb regardless of the picture previously observed.

After the experimental task, the participants had to answer a questionnaire which served as a control measure. The aim of this questionnaire was to check whether each action in the primes had been recognized by the participants and assess whether the actions in the pictures appeared to be relatively probable according to their context. Each picture of the task was presented and the participants had to answer two questions. The first question asked the participants to say what action they thought was depicted. The picture obtained a score of 1 when the answer provided by the participant corresponded to the action (i.e., the participants gave the exact verb of the action or a semantically close verb) and obtained a score of 0 when the answer provided by the participant differed semantically from the one expected. A percentage of recognition per participant was calculated from these scores. The second question asked them to assess the plausibility of each picture using a 5-point scale ranging from “very probable” to “very improbable”. We expected the participants to be able to recognize the action whatever the context (i.e., the percentage of recognition would be similar for the usual pictures and unusual pictures), but we expected them to consider the usual picture more probable than the unusual pictures (i.e., have a score of probability higher for the usual pictures).

2.2.RT analysis

Participants’ response times were analyzed after trials with errors and with response time outliers (± 2.5 standard deviations) were excluded from the analysis (less than 10% of the data). We used the `lmer` function of the `lmerTest` package (Kuznetsova, Brockhoff, & Christensen, 2017) in the R environment (R version 3.3.0, R Core Team © 2016) to build

linear mixed-effects models. Participants and words items were specified as random-effects factors. Two fixed-effects factors were used and included the following: the picture context (usual action x unusual action) and the congruency of the verb according to the prime (congruent x incongruent), as well as their interaction. The p values were obtained for the reported F values (Type III ANOVA) with the error degrees of freedom calculated based on Satterthwaite's approximation. The responses of the recognition questionnaire were assessed with a Wilcoxon signed-rank test. The significance level was set at $p < 0.05$.

2.3.EEG acquisition and preanalyses

EEG was recorded continuously using the Active-Two Biosemi EEG system (Biosemi V.O.F Amsterdam, Netherlands) with 128 channels covering the entire scalp. Signals were sampled at 512 Hz.

First, each trial was visually inspected in order to reject trials contaminated by eye blinking, movements or other noise (20% of the data). ERPs were then bandpass-filtered to 0.16-30 Hz and recalculated against the average reference. After rejection of errors and of contaminated epochs, the remaining epochs were averaged per subject for each of the conditions.

For the prime presentation, epochs of 2000 ms were averaged for each subject according to the context condition (usual x unusual). Therefore, the individual averaged data, as well as the group grand-average, covered the time from the appearance of the prime picture until its disappearance.

For the verb presentation, two averaging procedures, concerning two time periods, were combined: one was performed on stimulus-aligned epochs (forward) of 668 ms starting at the moment the stimulus appeared on the screen and one on response-aligned epochs (backward) of 668 ms starting at the production latency of each individual trial. In other words, stimulus-

aligned epochs started at the moment the verb appeared on screen. Response-aligned epochs started at the moment the participant pressed the mouse to answer. Stimulus-aligned epochs and response-aligned epochs were averaged for each subject according to the context condition (usual x unusual) and the congruency of the verb (congruent x incongruent). This method that combines stimulus- and response-aligned data was introduced by Laganaro and Perret (2011) and allows a full matching between stimulus-aligned and response-aligned ERPs. For the spatiotemporal segmentation analysis (section 2.5), the forward and backward data of each participant were merged according to each participant's RT in each condition. Therefore, the individual averaged data, as well as the group grand-average, covered the time from the appearance of the verb until the response of the participant. In a last step, electrode artifacts were interpolated using 3D spline interpolation (Perrin, Pernier, Bertrand, Giard, & Echallier, 1987).

2.4. Global field power analysis

The ERPs were first analyzed to determine the time periods at which the ERPs of the two conditions for prime presentation and of the four conditions for verbs presentation started to differ significantly from one another. In order to avoid influence of reference choice (Murray et al., 2008), we compared the standard deviation of all electrodes at a given time and at each time points over the entire analyzed periods (Lehmann & Skrandies, 1984). Paired *t*-tests were computed on this *global field power* between conditions at each time-frame, with alpha criterion of 0.05 and a time-window of 24 ms of consecutive significant difference.

2.5. Topographic pattern analyses

Significant variations of the global field power can be the consequence of modulation in the strength of the electric field, of topographical changes in the electric field (revealing distinguishable brain generators), or of latency shifts in similar brain processes. To differentiate these effects, we applied topographic analyses (spatiotemporal segmentation, Brunet et al., 2011) to summarize the ERP data into a limited number of topographical map configurations (stable electrophysiological period, Lehmann & Skrandies, 1984). A map configuration is a period during which the topography of the electrophysiological activity on the scalp remains stable for several tens of milliseconds. Any change of the spatial configuration of the electric field on the scalp was interpreted as revealing a difference in the distribution of the underlying intracranial sources (Brunet et al., 2011).

This method is insensitive to pure amplitude modulations across conditions (i.e., the topographies of normalized maps are compared) and independent of the reference electrode (Michel et al., 2004). To determine the most dominant configurations of the electric field at the scalp (i.e., topographic maps), we used a modified hierarchical clustering analysis (Murray, Brunet, & Michel, 2008). A given topography had to be present for at least 20 time frames (40 ms) and had to be correlated above 95%. To determine the optimal number of maps, a modified cross-validation criterion was used. The procedure is described in detail in Pascual-Marqui et al. (1995).

We applied these spatiotemporal segmentations on the two grand-average data sets of the prime picture presentation and on the four grand average datasets of the verb presentation. Then, the pattern of the map templates observed in the averaged data was statistically tested by comparing each of these map templates with the moment-by-moment scalp topography of individual subjects' ERPs from each condition. Each time point was labeled according to the map with which it best correlated spatially, yielding a measure of map presence. This procedure, referred to as "fitting", allowed a determination how well a cluster map explained

individual patterns of activity (GEV: global explained variance) and its duration. GEV and duration measures observed in each subject's data were analyzed to determine whether one map was more representative of one condition or lasted longer in one condition. For the prime picture presentation, we used paired t-tests to compare the maps of the usual and unusual pictures. For the verb presentation, ANOVAs were performed to compare the maps of the different conditions. The map, the congruency (congruent action x incongruent action) and context (usual x unusual) were set as within-subject factors. When the interaction was significant, comparisons were performed with paired t-tests. This procedure has been regularly used with language data (e.g., Laganaro, 2017; Laganaro, Valente, & Perret, 2012; Perret, Bonin & Laganaro, 2014; Perret & Laganaro, 2012; Python, Fargier, & Laganaro, 2018) and the procedure has been described in detail by Murray and his colleagues (2008).

3. Results

3.1. Behavioral results: response times and recognition questionnaire

The analyses (see Fig. 1) showed that response time varied according to the context ($F(1,3918) = 13.47, p < 0.001$) and varied according to the congruency of the verbs ($F(1,3913) = 53.41, p < 0.001$). Moreover, a significant interaction between the congruency of the verb and context was found ($F(1,3922) = 13.56, p < 0.001$). Student's t-tests revealed that in the usual context, response times for congruent verbs were significantly shorter than the response times for incongruent verbs ($t(24) = 7.54, p < 0.001$). However, in the unusual context, there was no significant difference between the congruent and incongruent verbs ($t(24) = 1.22, p = 0.24$).

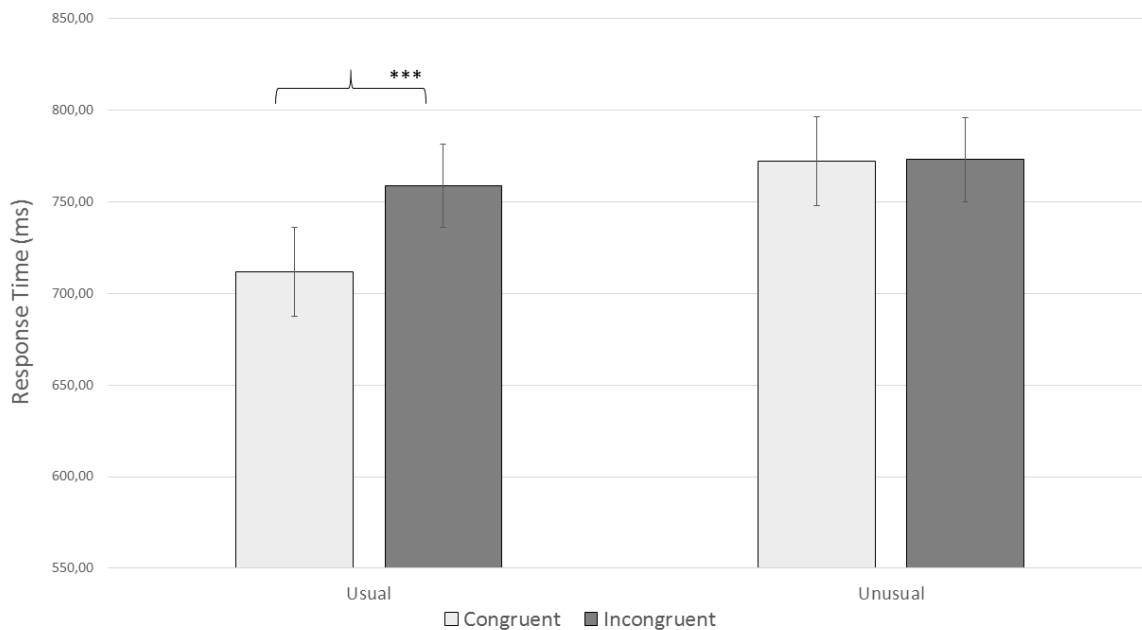


Fig. 1 Mean response times (ms) according to context of the prime picture (usual and unusual) and congruency of the verbs (congruent and incongruent). The error bars indicate the 95% confidence interval. *** significant difference ($p < 0.001$)

Concerning the recognition questionnaire, a Wilcoxon signed-rank test revealed that usual action recognition rate (98%) was not significantly different than the unusual action recognition rate (97%, $Z = 0.75$, $p = 0.49$). Moreover, the usual actions were rated as more probable (4.87) than the unusual actions (1.62, $Z = 4.37$, $p < 0.01$).

3.2. Electrophysiological Data

Prime Picture – Global field power analysis and Spatiotemporal segmentation

The global field power analysis revealed differences between the prime conditions around 1100 ms (see Fig. 2 - A). This result was confirmed by the spatiotemporal segmentation.

This spatiotemporal segmentation, applied to the averaged data of usual and unusual pictures, revealed 4 different electrophysiological periods of stability accounting for 95.39% of the

variance. These four maps were labelled respectively map 0, 1, 2 and 3 according to their order of apparition (see Fig. 2 – C).

The same sequence of topographical maps appeared in both prime conditions (see Fig. 2 - B). The stable maps labelled “0” and “1” seemed to have the same durations across the two prime presentations. The stable map labelled “2” was shorter for usual than for unusual pictures, and shifted the first onset of the next stable map “3” (see appendix 4 for the precise timing of beginning and end of the different maps).

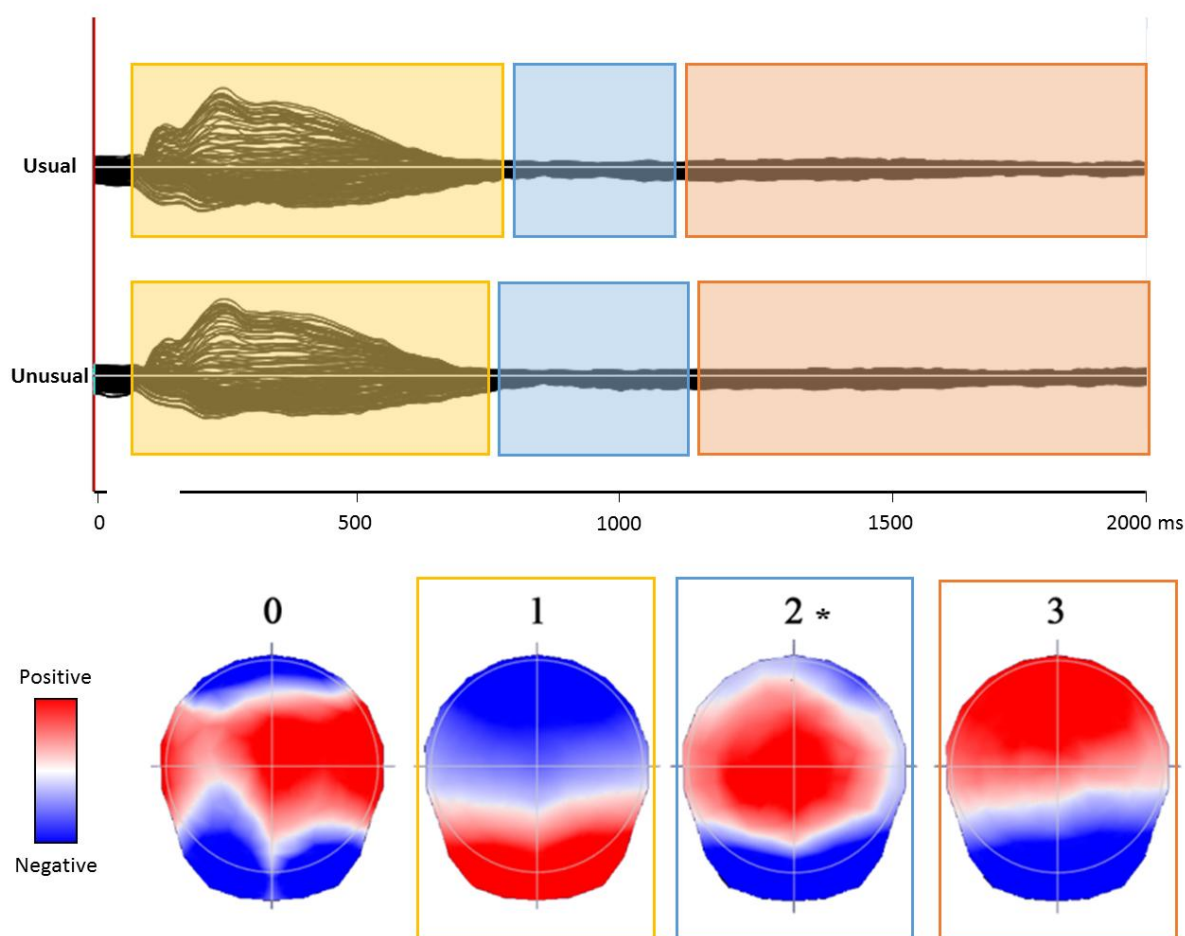


Fig. 2 A. Results of the statistical analysis ($1-p$ -values) of the global field power (GFP). B. Grand-average ERPs (128 electrodes) for each context presentation (usual x unusual) from onset to 2000ms and temporal distribution of the topographic maps revealed by the spatiotemporal segmentation analysis for each data set. C. Map templates for the four stable

topographies revealed by the spatiotemporal segmentation (with positive values in red and negative values in blue).

Prime Picture – Fitting procedure

Then, the fitting procedure was applied. The results of the fitting procedure applied to the individual data supported the results of the global field power analysis and of the spatiotemporal segmentation. The maps “0” and “1” were not different whereas the map labeled as “2” was significantly different for both map duration ($p < 0.002$) and GEV ($p = 0.01$). More precisely, this map lasted longer when the picture was unusual (279 ms, SD = 88ms) than when the picture was usual (201 ms, SD = 91.82ms). Finally, the same duration and GEV were observed for the map “3”.

Verb – Global field power analysis and Spatiotemporal segmentation

In the usual context (when comparing congruent and incongruent conditions) different GFPs were reported, for stimulus-aligned ERPs around 550-600ms. Moreover, different GFPs were also reported around 700 ms for response-aligned ERPs. The analyses of the spatiotemporal segmentation confirmed these periods of difference. In the unusual context, no different GFP was reported (Fig. 3 - A).

The spatiotemporal segmentation applied to the four grand-averaged ERPs (usual congruent, usual incongruent, unusual congruent and unusual incongruent condition) revealed 5 different electrophysiological period of stability accounting for 91.03% of the variance (see Fig. 3). These five maps were labelled respectively map 0, 1, 2, 3 and 4 according to their order of apparition. The same sequence of topographical maps appeared in all conditions (Fig. 3 - B). The stable maps labelled “0”, “1”, and “2” seemed to have the same durations whatever the experimental conditions. However, the stable maps labelled “3” and “4” appeared to be shorter when the participant is processing congruent verbs than incongruent verbs, but only in

the usual condition (see appendix 4 for the precise timing of beginning and end of the different maps).

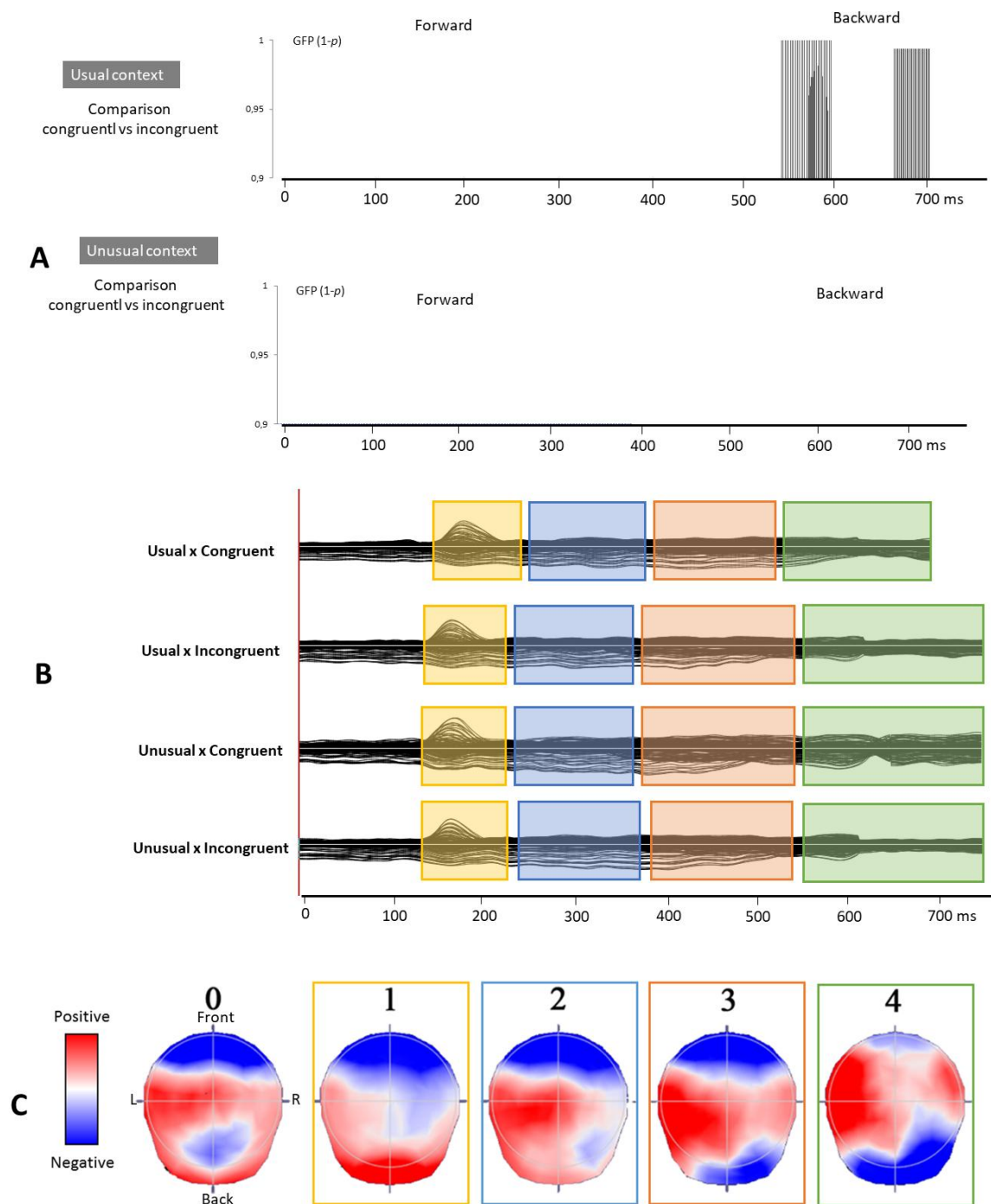


Fig. 3 A. Results of the statistical analysis (1-*p*-values) of the global field power (GFP). B. Grand-average ERPs (128 electrodes) for each condition (usual congruent x usual incongruent x unusual congruent x unusual incongruent) from onset to response and temporal distribution

of the topographic maps revealed by the spatiotemporal segmentation analysis for each data set. C. Map templates for the five stable topographies revealed by the spatiotemporal segmentation (with positive values in red and negative values in blue).

Verb – Fitting procedure

Then, the fitting procedure was applied. Before performing the analyses on each map separately, we tested the interaction between the context, the congruency and the map (0, 1, 2, 3, 4). The results of this global ANOVA are summarized in Table 1.

Table 1.

Results of the ANOVA concerning the durations with the context (usual and unusual), the congruency (congruent and incongruent) and the map (1, 2, 3, and 4) as factors.

	F	P
Map	F(1,24) = 16.24	< 0.001
Context	F(1,24) = 13.35	0.001
Congruency	F(1,24) = 10.14	0.003
Map*Context	F(4,96) = 2.95	0.024
Map*Congruency	F(4,96) = 2.7	0.035
Context*Congruency	F(1,24) = 17.88	< 0.001
Context*Congruency*Map	F(4,96) = 3.55	0.009

Thus, the interaction context*congruency*map was significant ($p = 0.009$), revealing that the interaction between the context and the congruency was dependent on the map. Taking this into account, the following analyses were performed on each map separately.

The global field power and spatiotemporal segmentation analyses were supported by the results of the fitting procedure applied to individual ERPs data in three time-windows: from 0 to 250 ms, from 250 ms to 500 ms and from 500 ms to the participant response.

In the first time window, the same durations and GEV of the stable maps “0”, “1” and “2” were observed in each condition. The results of the fitting procedure applied in the time window from 250 to 500 ms revealed a difference concerning the electrophysiological map

labeled “3”. For the map duration, a significant interaction between context and congruency was found ($F(1,24) = 10.98, p = 0.003$). In the usual context, Student’s t-test revealed that the duration of this map was shorter for the congruent condition (77.11 ms) than the incongruent condition (149.65 ms, $p = 0.004$). In the unusual context however, the map duration was not different in the congruent (131.65 ms) and the incongruent conditions (131.84 ms, $p = 0.99$). The results of the GEV concerning this interaction was close to significance ($F(1,24) = 1.27, p = 0.05$). Finally, the results of a fitting procedure applied in a time window from 500 ms to the end of trial revealed a difference concerning the electrophysiological map labeled “4”. Both GEV ($F(1,24) = 4.67, p = 0.04$) and map duration ($F(1,24) = 8.19, p < 0.001$) showed a significant interaction between context and congruency. In the usual context, Student’s t-test revealed that this map was shorter in the congruent condition (95.39 ms) compared to the incongruent condition (162.38 ms, $p < 0.001$). In the unusual context, the duration of the map was not different in the congruent condition (183.3 ms) and the incongruent condition (179.84 ms, $p = 0.88$).

4. Discussion

The first aim of this study was to replicate the findings of our previous study (Beauprez et al., 2018), namely, to demonstrate that the context of an observed action can affect the relationship between the sensorimotor system and language processing. The behavioral results in the present study confirmed these findings. Indeed, in the usual condition, a facilitation effect was obtained, demonstrated by the fact that the participants were faster to answer when the action verbs were congruent rather than when they were incongruent with the action they had previously seen. In contrast, no difference was obtained between congruent and incongruent action verbs when perceiving an action in an unusual context.

It is worth noting that in our previous study, we used pictures of a cartoon character, whereas in the present study, we used pictures of a real person. We could have expected different results in the present study, since it could be easier to resonate with real human beings rather than with cartoon characters. Indeed, it is known that sensorimotor representations are involved when an observed action matches the perceiver's motor repertoire (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005) and that the closer an action is to our motor repertoire, the stronger the motor resonance will be. However, we found that, even if it should be easier to resonate with a real human being, no effect was obtained in the unusual context. These results seem to indicate a strong involvement of the context in the influence of action perception on semantic activation during word processing.

The second aim of this study was to investigate the temporal course of the cognitive processes involved in this effect. During the picture presentation, we observed that the same maps, but with different duration, were involved in the usual and unusual pictures (see Fig. 2). Assuming that different maps reflect different underlying neurophysiological mechanisms, and that the same map is more likely to reflect the same mechanism, our results suggest that the same process was involved when the participants saw usual or unusual action. However, the process duration was shorter in the usual condition than in the unusual condition. This result appears to be in contradiction to the studies demonstrating that usual and unusual actions do not activate the same cerebral networks (Brass et al., 2007; Van Overwalle & Baetens, 2009).

One possibility could be that in both the usual and unusual condition, sensorimotor representations were activated. Indeed, it is recognized that the perception of actions is associated to motor areas activation (Calvo-Merino et al., 2005; Nishitani & Hari, 2000), thus, we could reasonably assumed that the perception of usual actions led to motor activation. And since the same maps (reflecting the same processing levels) were observed during usual and

unusual actions perception, we could assume that motor areas were also activated for unusual actions. However, the difference in the duration of map 2 could reflect the necessary time to relate the action with motor experience. In the usual context, it would be easier to resonate with the action perceived while this step would be more difficult in the unusual context. This idea agrees with our behavioral results; since the activation of the sensorimotor representation would require more time in the unusual context, the processing of the verbs would not be facilitated, which would explain the absence of facilitation in the unusual condition.

On the other hand, during processing of the verb, the global field power analysis and spatiotemporal segmentation revealed topographical differences in the ERPs latencies. More precisely, the EEG data revealed 5 different maps (see Fig. 3). It appears that the context of the action influenced maps 3 and 4. In contrast, the two first maps were not affected by the context. These results are in agreement with the literature, since we know that the first map could be more related to visual processing of the word and that the second map could be related to orthographic and phonological processes associated with the word. Indeed, map 1 occurred at approximately 150 – 200 ms, a time period which is known to be associated with visual processes (i.e., visual feature analysis and general analysis of complex graphical features; Kuriki, Takeuchi and Hirata, 1998, Dien, 2009). Map 2 occurred approximately 200 – 300 ms which corresponds to the time period during which a word is recognized. It has been suggested that orthographic and phonological processes occur in this time period (Bentin, Mouchetant-Rostaing, Giard, Echallier, & Pernier, 1999; Simon, Bernard, Largy, Lalonde, & Rebai, 2004).

One of the main differences between our conditions is map 3. This map occurred after 300 ms and we propose that it could reflect semantic processing. More precisely, this processing would be related to the task; that is, to decide if the word is an action word involving a movement of the body. Indeed, using ERP analyses, Mari-Beffa and her

colleagues (2005) proposed a dissociation between an initial stage of semantic processing that is automatic and related to semantic priming (≈ 200 ms), and a later stage of semantic processing controlled by the task goal (≈ 400 ms). They proposed that this second semantic step could reflect the necessary processing to convert the activation of a word's meaning into a conscious judgement about this word. Thus, it seems that in the usual condition, the semantic processing of the verbs was facilitated when there was a correspondence between the action of the picture and the action of the verb (congruent trials).

The second difference between our conditions concerned map 4, which occurs after 550 ms and could reflect response preparation in the motor cortex. Indeed, studies involving responses times requiring a button press measured the lateralized readiness potential. This component is considered a reflection of specific motor preparation and generally occurred 100 ms before the response (Killikelly & Szűcs, 2013). For example, Müller & Hagoort (2006) recorded this lateralized readiness potential between 500 and 800 ms, which is in accordance with our map 4.

Thus, it seems that the perception of an action in a congruent context facilitated both the semantic access to the verb and the preparation of the motor response, since these two processes appeared to be significantly faster in this condition. We suggest that the more the action of a verb and the action of a picture correspond the faster these processes could be.

Note that an alternative interpretation could be propose to our results. Since the participants had 500 ms (fixation cross) before the apparition of the verb, they could have used this time to silently name the action after the picture presentation and to prepare the matching motor response. This would explained why the response times were faster when the predicted verb actually appeared. However, we can rule out this possibility because of the results of the recognition questionnaire. Indeed, it indicates that participants recognized the actions of the picture both in the usual and unusual context. So, if the participants strategically

repeated the verb of the action, they should have done it with both usual and unusual actions. Thus, this interpretation does not explain why the congruency effect is not present in the unusual condition. We think it is more probable that the absence of effect in association with congruent unusual actions is related to a decrease in sensorimotor activation.

In brief, our results confirm that the context of the presentation of an action is crucial in the link between action and language. More particularly, we show that the semantic of the word and the motor preparation of the answer were influenced. We propose that the context could modulate the motor resonance, and so, the action-language relationship would be related to the strength of the sensorimotor activations produced during the action perception. Future brain imaging and behavioral studies will have to confirm this point.

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The Cartool software (<http://brainmapping.unige.ch/Cartool.php>) was used for all the EEG analysis.

Ethical approval

The experiments were conducted in accordance with the ethical standards of the institution and with the 1964 Helsinki Declaration.

This study was approved by the ethical committee of the University of Poitiers (CERNI Poitiers – Tours, 2016-10-02).

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Appendix 1: Example of a prime picture: action of pasting



usual context



unusual context

Appendix 2: Description of all the action presented in the prime pictures according to the context

Action	Usual action:	Unusual action:
To staple	Someone stapling paper	Someone stapling paper currency
To light	Someone lighting a candle	Someone lighting pens
To water	Someone watering a plant	Someone watering a laptop
To vacuum	Someone vacuuming in a room	Someone vacuuming in a garden
To sweep	Someone sweeping in a kitchen	Someone sweeping in a garden
To drink	Someone drinking water	Someone drinking detergent
To plug	Someone plugging a charger into a grounded outlet	Someone plugging a USB cable into a grounded outlet
To sunbath	Someone sunbathing next to a pool	Someone sunbathing in a parking lot
To brush	Someone brushing their teeth with a toothbrush	Someone brushing their teeth with a pen
To sing	Someone singing	Someone singing with a construction mask
To paste	Someone pasting paper	Someone pasting a zucchini
To sew	Someone sewing a shirt	Someone sewing a sponge
To cut	Someone cutting paper	Someone cutting a smartphone
To listen	Someone listening to music from a phone	Someone listening to music from an apple
To depilate	Someone depilating a leg	Someone depilating a bottle
To peel	Someone peeling an apple	Someone peeling a mug
To strangle	Someone strangling a person	Someone strangling a stuffed animal
To smoke	Someone smoking a cigarette	Someone smoking a carrot
To inflate	Someone inflating a tire	Someone inflating a belly
To throw	Someone throwing paper in a bin	Someone throwing paper currency in a bin
To play	Someone playing monopoly with the paper money	Someone playing monopoly with a passport
To wash	Someone washing a bowl	Someone washing a keyboard
To read	Someone reading a book	Someone reading a book upside-down
To eat	Someone eating food	Someone eating a camera

To blend	Someone blending an apple	Someone blending furniture
To bite	Someone biting someone	Someone biting a hammer
To pay	Someone paying with money	Someone paying with fake bills
To fish	Someone fishing in a lake	Someone fishing in a street
To comb	Someone combing hair	Someone combing a kettle
To paint	Someone painting a wall	Someone painting a plant
To drill	Someone drilling wood	Someone drilling a window
To weigh	Someone weighing herself standing on her feet	Someone weighing herself standing on her hands
To photocopy	Someone photocopying paper	Someone photocopying her head
To dive	Someone diving in a pool	Someone diving in the stairs
To post	Someone posting a letter	Someone posting a smartphone
To walk	Someone walking a dog	Someone walking a stuffed animal
To rake	Someone raking in a garden	Someone raking in a living room
To iron	Someone ironing clothes	Someone ironing a CD
To tape	Someone taping an envelope	Someone taping an apple
To wash	Someone washing with a washcloth	Someone washing with kitchen sponge
To blow	Someone blowing her nose in tissue	Someone blowing her nose in currency paper
To perfume	Someone putting perfume in her neck	Someone putting perfuming on an apple
To sign	Someone signing with a pen	Someone signing with a carrot
To ski	Someone skiing in a mountain	Someone skiing in grass
To blow	Someone blowing the light of a candle	Someone blowing on a bottle
To call	Someone calling with a smartphone	Someone calling with a banana
To shoot	Someone shooting with a gun	Someone shooting with a banana
To mow	Someone mowing in a garden	Someone mowing in a room
To knit	Someone knitting with wool	Someone knitting with candies
To screw	Someone screwing a screw	Someone screwing a radish

Appendix 3: List of French verbs used as stimuli (English translation between brackets)

Action verbs					
Agrafer	(To staple)	Fumer	(To smoke)	Poster	(To post)
Allumer	(To light)	Gonfler	(To inflate)	Promener	(To walk)
Arroser	(To water)	Jeter	(To throw)	Ratisser	(To rake)
Aspirer	(To vacuum)	Jouer	(To play)	Repasser	(To iron)
Balayer	(To sweep)	Laver	(To wash)	Scotcher	(To tape)
Boire	(To drink)	Lire	(To read)	Se laver	(To wash)
Brancher	(To plug)	Manger	(To eat)	Se moucher	(To blow)
Bronzer	(To sunbath)	Mixer	(To blend)	Se parfumer	(To perfume)
Brosser	(To brush)	Mordre	(To bite)	Signer	(To sign)
Chanter	(To sing)	Payer	(To pay)	Skier	(To ski)
Coller	(To paste)	Pêcher	(To fish)	Souffler	(To blow)
Coudre	(To sew)	Peigner	(To comb)	Téléphoner	(To call)
Couper	(To cut)	Peindre	(To paint)	Tirer	(To shoot)
Ecouter	(To listen)	Percer	(To drill)	Tondre	(To mow)
Epiler	(To depilate)	Peser	(To weigh)	Tricoter	(To knit)
Eplucher	(To peel)	Photocopier	(To photocopy)	Visser	(To screw)
Etrangler	(To strangle)	Plonger	(To dive)		
Non-action verbs					
Adorer	(To worship)	Détester	(To hate)	Posséder	(To possess)
Affectionner	(To like)	Devenir	(To become)	Pouvoir	(To be able)
Appartenir	(To belong)	Devoir	(To have to)	Présumer	(To presume)
Apprécier	(To appreciate)	Douter	(To doubt)	Prévoir	(To predict)
Avoir	(To have)	Envier	(To envy)	Progresser	(To progress)
Choisir	(To choose)	Envisager	(To envisage)	Raisonner	(To reason)
Cogiter	(To cogitate)	Espérer	(To hope)	Reconnaître	(To recognize)
Concevoir	(To conceive)	Estimer	(To esteem)	Refléchir	(To reflect)
Conclure	(To conclude)	Etre	(To be)	Rêver	(To dream)
Connaitre	(To know)	Imaginer	(To imagine)	Savoir	(To know)
Considérer	(To consider)	Innover	(To innovate)	Sembler	(To seem)
Convoiter	(To lust for)	Juger	(To judge)	Songer	(To wonder)
Coûter	(To cost)	Mériter	(To deserve)	Souhaiter	(To wish)
Croire	(To believe)	Nécessiter	(To require)	Supposer	(To guess)
Décider	(To decide)	Paraître	(To appear)	Valoir	(To be worth)
Déplaire	(To displease)	Penser	(To think)	Vouloir	(To want)
Désirer	(To lust for)	Plaire	(To please)		

Appendix 4: Beginning and end of the electrophysiological periods of stability (maps) revealed by the spatiotemporal segmentations

Prime picture presentation				
	Map “0”	Map “1”	Map “2”	Map “3”
Usual Condition	0 – 88 ms	89 – 783 ms	784 – 1098 ms	1099 – 2000 ms
Unusual Condition	0 – 88 ms	89 – 797 ms	798 – 1195 ms	1196 – 2000 ms

Verb presentation					
	Map “0”	Map “1”	Map “2”	Map “3”	Map “4”
Usual congruent	0 – 145 ms	146 – 209 ms	210 – 334 ms	335 – 576 ms	577 – 711 ms
Usual incongruent	0 – 145 ms	146 – 205 ms	206 – 322 ms	323 – 551 ms	552 – 759 ms
Unusual congruent	0 – 145 ms	146 – 211 ms	212 – 287 ms	288 – 506 ms	507 – 773 ms
Unusual incongruent	0 – 145 ms	146 – 205 ms	206 – 313 ms	315 – 586 ms	587 – 773 ms