LIMITS OF UNCONSCIOUS SEMANTIC PRIMING

The limits of unconscious semantic processing

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Abstract

Do supraliminal and subliminal priming capture different facets of words' semantic representations? We used metaphorical priming between space and time as a test bed for this question. While people conceptualize time along the lateral and sagittal axes, only the latter mapping comes up in language (the future is *in front* of you, not *to your right*). We assessed facilitation on temporal target words by lateral (left, right) and sagittal (back, front) primes, in masked and overt conditions. Supraliminally, we observe similar sagittal and lateral priming, while the masked effect is stronger on the sagittal axis, and weak to non-existent on the lateral one. These results are observed in an original and a replication studies; and are strongly confirmed by a Bayesian meta-analysis of the two. We conclude that unconscious word processing is limited to linguistically-encoded information, while consciousness may be needed to fully activate semantic representations.

Keywords: Semantic priming, Consciousness, Space, Time, Metaphor, Masked priming.

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There has been intense debate on the difference between conscious and unconscious cognition. According to one view, virtually any cognitive process that can be carried out by the conscious mind can also be carried out by the unconscious mind. These processes include arithmetic (Sackur et al., 2008), goal setting (Hassin, Bargh, & Zimerman, 2009), and constructing the meanings of sentences (Sklar et al., 2012). On an alternative view, however, there are both quantitative (Kouider & Dehaene, 2007) and qualitative (Nakamura et al., 2018) differences between conscious and unconscious cognitive processing, and consciousness may be necessary for some cognitive functions.

Here we investigated the role of consciousness in constructing the meanings of words. The semantic system is highly complex and multidimensional (Borghesani & Piazza, 2017), thus offering wide room for qualitative differences between conscious and unconscious processing to emerge. Words can be semantically related in many different ways. For example, *cat* may be similar to *dog* because these animals share features (e.g., they are both furry, have four legs, are kept as pets by humans; Quinn & Kinoshita, 2008), or because the words belong to the same category (e.g., animals; Abrams, Klinger, & Greenwald, 2002), or because they are associated with each other in our experience of the world (e.g., are likely to be primary associates in word association norms; Anaki & Henik, 2003), or again, merely because the words *cat* and *dog* often co-occur with each other in written and spoken language (Brunellière, Perre, Tran, & Bonnotte, 2017). While these different facets of word meaning are obviously all available to the fully aware reader, unawareness may allow only partial access to some of them.

Several studies investigated unconscious semantic processing so far, but the evidence is unclear overall. Priming has been reported for highly associated category coordinates (e.g., table–chair) when prime words were kept unconscious (i.e., presented for a very short time and visually

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masked), as well as when they were fully visible (Perea & Rosa, 2002). Similarly, semantic facilitation has been observed for word pairs that were related in terms of feature overlap (e.g., goose–turkey), independently of prime visibility (Bueno & Frenck-Mestre, 2008). Conversely, other studies showed different patterns of semantic facilitation depending on whether the prime was available to conscious report. In a lexical decision task, De Wit and Kinoshita (2015) reported priming only when the prime word was fully visible. Bottini, Bucur and Crepaldi (2016) showed that subliminal semantic priming interpreted as the result of unconscious sensorimotor simulations of the words' referents (e.g., simulating an upward movement to understand the word “up”; Ansorge, Kiefer, Khalid, Grassl, & König, 2010) can also be explained by symbolic associations between response labels.

To date, it is still unclear which aspects of word meaning are gathered unconsciously, and which aspects, instead, need conscious access to be retrieved. Indeed, the vast majority of the previous studies focused on whether masked semantic priming happens at all, rather than what kind of information may foster it. This is for a good reason, of course: it is hard to dissociate different aspects of word meaning experimentally, as they (quite unsurprisingly) correlate strongly. For example, associated words (e.g., cat–dog, fork–knife) tend to share semantic features (Brainerd, Yang, Reyna, Howe, & Mills, 2008), and situated knowledge is often encoded symbolically in language use (e.g., the words *red* and *transparent*, which both refer to vision, co-occur more often than words referring to different perceptual modalities, like *red* and *loud*; e.g., Louwerse & Connell, 2011)

A notable exception to this rule, however, is provided by space–time conceptual metaphors. When people talk about time they often use spatial metaphors. In English and many other languages, the future is *ahead* and the past is *behind* (e.g., Clark, 1973). Thus, time flows along a

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sagittal (front–back) axis. Beyond talking about time using spatial words, it has been shown that people also *think* about temporal sequences using schematic mental representations of physical space. In an experiment using motion capture to assess people’s posture, participants were more likely to lean backward when thinking about the past and forward when thinking about the future (Miles, Nind, & Macrae, 2010). Likewise, participants are faster to judge sentences about the future by moving a joystick forward and faster to judge sentences about the past by moving it backward (Ulrich et al., 2012), consistent with expressions like “looking *forward* to retirement” or “thinking *back* on one’s childhood”.

Within some of the same cultures that talk about time as flowing along a sagittal timeline, people also conceptualize time along a lateral timeline, with earlier events on the left and later events on the right. This lateral mental timeline is not encoded in any known spoken language (e.g., Monday comes *before* Tuesday, not *to the left* of Tuesday; Clark, 1973), yet participants are faster to classify words related to the past by pressing a left key and words related to the future by pressing a right key, compared to the opposite arrangement (e.g., Casasanto & Bottini, 2014a). Patients with left hemi-spatial neglect, who ignore objects on the left side of space, also neglect the “left side” of time (i.e., they show better memory performance for events associated with the future than for events associated with the past; Saj, Fuhrman, Vuilleumier, & Boroditsky, 2013). English speakers have been found to gesture according to the lateral mental timeline more often than the sagittal timeline (Casasanto & Jasmin, 2012). Thus, perhaps counterintuitively, the implicit lateral timeline may be activated even more strongly than the sagittal timeline, despite its complete absence from conventional expressions in language.

Both the sagittal and the lateral mental time lines (MTL) have clear sensorimotor origins. For instance, scanning behavior during reading and writing seems to be an important experience to

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learn and consolidate the horizontal (MTL). In fact, people that read from right to left (e.g., Hebrew speakers) also have a leftward MTL (Fuhrman & Boroditsky, 2010), and the MTL can be transiently reversed by a few minutes of mirror reading (Casasanto & Bottini, 2014a). On the other hand, the sagittal MTL seems to be based on our walking experience in the physical world: as people typically walk in forward direction, they also move forward through both space and time (Clark, 1973). Accordingly, temporal processing can affect step movements along the sagittal space (Rinaldi, Locati, Parolin, Bernardi, & Girelli, 2016).

Overall then, time and space are associated along both a sagittal and a lateral timeline. Both schemas are based on sensorimotor, situated experience, but only the sagittal one also emerges in language use (e.g., looking *forward* to retirement), thus creating a further symbolic, associative tie. Taking advantage of this dissociation, we tested the hypothesis that unconscious semantic processing is limited to these symbolic associations and does not allow access to spatial representations which are activated during conscious word processing.

To this aim, we devised a priming paradigm in which sagittal spatial words (*front*, *back*) and lateral spatial words (*left*, *right*) appeared as primes, and temporal words appeared as targets (e.g., *past*, *future*). Primes were presented both supraliminally and outside of awareness; if our hypothesis is correct, priming should emerge strongly on both axes in the conscious condition, when meaning is fully accessed in all its facets, but should be stronger with sagittal primes in the unconscious condition, when processing would be mostly limited to language-encoded semantic ties.

Experiment 1

Methods

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Participants. 120 students at the University of Trieste were recruited into the experiment (30 males, 90 females; mean age=24y, age range=18y-36y). All subjects were right-handed, native Italian speakers, and had normal or corrected-to-normal vision and no history of neurological disorders. Participants gave written informed consent for participation, and received 8 Euros in exchange for their time.

Material. All stimuli were Italian words. Primes were 2 spatial words related to the lateral axis (*sinistra*, left, and *destra*, right) and 2 spatial words related to the sagittal axis (*davanti*, front and *dietro*, back). Target stimuli were 8 temporal words. Four of them refers to the past (*prima*, earlier, *ieri*, yesterday, *passato*, past, *scorso*, previous), and four refers to the future (*dopo*, later, *domani*, tomorrow, *futuro*, future, *successivo*, next). Each prime word was coupled with every target item, resulting in 32 different pairs. Each pair was presented 12 times, making up a total of 396 experimental trials.

Procedure. Participants were seated in a comfortable chair and saw the stimuli from a distance of approximately 63 cm. We used a chinrest to keep the distance from the monitor constant and secure a forward orientation. All stimuli were shown in Arial font 32, in white against a black background, displayed on a 22'' monitor with a refresh rate of 120 Hz, using MatLab Psychtoolbox (Kleiner et al., 2007). Responses were collected with an external CEDRUS RB-740 response pad.

Each trial started with a fixation point (+) displayed for 750 ms. In the unmasked condition, a blank screen was shown for 200 ms, followed by the prime and by another blank screen, both lasting 50 ms. In the masked condition, where participants were not informed about the presence of the prime, the blank screens were replaced with two visual masks (10 random uppercase letters, e.g. XCBFTYUOIM). Finally, in both conditions, the target word was presented for 1500 ms, or until a response was provided (see Figure 1). Prime visibility was manipulated between subjects,

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i.e., half of the participants were assigned to the masked condition and half to the unmasked condition.

Figure 1. Trial timeline in the visible (left) and masked (right) conditions.

The 396 experimental trials which were divided in two blocks. In one block, participants were instructed to press the central button of the response box when target words were related to the past, whereas in the other they were told to press the same button when target words were related to the future—a go–no go task. The order of the two blocks (go–Past, go–Future) was counterbalanced across subjects. Twelve practice trials were presented before each block. In addition to the main break between blocks, participants took one further period of rest half way through each block.

We stress three important aspects of our design, which guarantee a fair assessment of semantic priming and overcome some limitations in the previous literature. First, the trial timeline was identical in the sub–liminal and supra–liminal conditions: as primes were presented for the same exact amount of time, we ensured that any difference would only depend on awareness, not on prime presentation time. Second, target words never appeared as primes; this excluded the possibility that a priming effect could be due to (non semantic) stimulus–response associations or action-trigger conditions. Moreover, the go–no go paradigm allowed us to avoid lateralized

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responses, i.e., left or right button key presses; this excludes that participants' behavior was influenced by any spatial coding of the response.

Prime visibility. After the main task, participants in the masked condition were informed about the presence of the prime, and were tested for their ability to perceive it consciously in a prime visibility task (Reingold & Merikle, 1988). More precisely, they were asked to assess whether the masked stimulus was a real word (vs. a string of identical lowercase letters, e.g., aaaaaaaaaa, xxxxxxxxxx). As real words, we used the same four spatial words that we employed as primes in the main task. Participants were instructed to press either a left or a right key to provide their response. In order to make sure that participants knew where the prime was within the trial, they saw two examples where prime duration was increased to 150 ms before starting the task, so that the prime became visible even with the visual masks. The prime visibility task included 10 practice and 128 experimental trials.

Statistical analyses. Statistical analyses of the reaction times were conducted via linear mixed models, with subjects and items considered as random effects. Following the principles of the New Statistics (Cumming, 2014), we based our analyses on confidence intervals and did not rely on null-hypothesis significance testing. Models were fitted using the *lme4* package (Bates, Maechler, Bolker, & Walker, 2015) in the statistical software *R*. We had fixed effects for Congruity (prime–target congruent vs. prime–target incongruent), Axis (lateral vs. sagittal), Prime Visibility (masked vs. unmasked), and their interactions. We additionally included random intercepts for Subject and Target Word. We dummy-coded our predictors and set incongruent primes, the sagittal axis and the masked condition as the reference levels for Congruity, Axis and Prime Visibility, respectively. With these settings, *summary(model)* generates three parameters of interest to our predictions. *Congruitycongruent* tracks the contrast between congruent and incongruent primes in the sagittal,

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masked condition, that is, sagittal masked priming. *Congruitycongruent:axislateral* tracks how much more (or less) effective are congruent primes in the lateral, masked condition, as compared with the sagittal, masked condition, that is, the contrast between sagittal and lateral masked priming. Finally, *congruitycongruent:axislateral:maskingunmasked* tracks how much different across masked and visible primes is the difference between lateral and sagittal priming. All these parameters are estimated in milliseconds and, for simplicity, will be referred to as β_1 , β_2 and β_3 in what follows. We will report point estimates and 95% confidence intervals. Model-based estimates of response times in each design cell were obtained via the R package *emmeans* (Lenth, 2018).

Open practices statement. This experiment was not pre-registered. All data and analysis code are available at [URL], and can be accessed independently from the authors.

Results

Overall accuracy in the experiment was 98%. The mean RT on accurate trials was 550 ms. RT analyses were conducted only on accurate go trials. One participant was excluded because of a particularly anomalous performance (mean accuracy= 88.8%, while every other participant was above 93.7%). In order to reduce the effect of extremely long and short RTs, those individual data points standing at more than 2 standard deviations from each participant's mean were also removed from the analyses. This reduced the analysis set to 21648 data points, which corresponds to a loss of ~4.5% of the potentially available dataset.

Sagittal congruent primes determined quicker RTs than incongruent primes in the masked condition, $\beta_1 = -9.89$ ms [-14.63 – -5.15]. This facilitation shrank substantially with lateral primes

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in the masked condition, $\beta_2 = +8.13$ ms [$+1.43 - +14.84$]. In the unmasked condition, instead, the difference between sagittal and lateral priming was reduced, $\beta_3 = -10.54$ ms [$-20.02 - -1.07$].

This pattern of results is represented in the model estimates illustrated in Figure 2. In the masked condition, RTs for congruent prime–target pairs were quicker than for incongruent pairs on the sagittal axis, 505 ms [$489 - 522$] vs. 516 ms [$499 - 535$], but much less so (if not at all) on the lateral axis, 510 ms [$494 - 528$] vs. 513 ms [$496 - 531$]. Supraliminally instead, facilitation was similar with sagittal, 509 ms [$492 - 527$] vs 516 ms [$499 - 534$], and lateral primes, 511 ms [$494 - 529$] vs 517 ms [$500 - 535$].

Figure 2. Estimated priming effect in the masked (left panel) and the visible condition (right panel). Data from the lateral axis are shown via black squares, while data from the sagittal axis are shown via black triangles. Error bars refer to 95% confidence intervals.

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Prime visibility task. No participant reported having noticed the prime. Data in the prime visibility task were analyzed in terms of d -prime, which is based on the ratio between correct YES response (hits) and incorrect YES responses (false alarms) for each participants. The d -prime distribution is shown in Figure 3; the average value was 0.35 [0.25 – 0.44]. These values are widely taken to indicate that primes were effectively masked from perceivers' awareness (Kouider & Dupoux, 2005).

In order to conclusively exclude that prime visibility was an important driver of the facilitation in the sagittal primes condition, we further analyzed the data by regressing the amount of priming against d -prime values (Greenwald, Klinger, & Schuh, 1995). With this linear model, we can estimate facilitation when the d -prime is zero, that is, when prime visibility is null. As illustrated in Figure 3, the 95% CI at the intercept lies entirely above the origin, indicating that priming is indeed estimated to be higher than zero even when primes are completely outside of awareness. According to the model prediction, we would observe a sagittal priming effect of 10ms [5 – 15] when the d -prime is zero. Finally, the individual d -prime values did not correlate with the size of the sagittal masked priming effect, $r = 0.022$ [-0.24 – +0.28], further confirming that facilitation does not depend on prime visibility.

Figure 3. Density plot representing the distribution of the participants' d -prime in the prime visibility task (left panel). Relationship between priming and prime visibility (right panel). Points represent individual participants, and the shaded area indicates the 95% confidence interval of the regression line. Note that priming is measured by subtracting mean RTs on congruent trials from mean RTs on incongruent trials, that is, positive values indicate facilitation.

Discussion

Supraliminal primes generate significant congruity effects on both the sagittal and the lateral axis, consistent with previous studies that provide evidence for sagittal and lateral mental timelines (Casasanto & Bottini, 2014b; Clark, 1973). Furthermore, priming does not differ across axes. The pattern of results is clearly different with masked primes, which yield substantial priming only on the sagittal axis; facilitation on the lateral axis is very small, and substantially smaller than with sagittal primes. These findings comply with the hypothesis under scrutiny—subliminal priming shows little or no sensitivity to semantic ties that are not represented in language use.

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Moreover, any role for some residual visibility of the masked primes was ruled out here, in four ways: (i) none of the participants reported noticing any of the masked primes; (ii) the d -prime analysis indicated that primes were effectively kept outside of participants' awareness, consistent with previous work on unconscious word processing (e.g., Kouider & Dupoux, 2005); (iii) the correlation analysis between prime visibility and the size of the facilitation effect showed no relationship between the two and estimated priming to be significantly above zero when d -prime is zero (i.e., there is no prime visibility whatsoever); (iv) it is unclear why residual visibility would selectively affect lateral, but not sagittal primes.

In order to ensure that these results are solid, and in the light of the recent challenges to reproducibility in Experimental Psychology (Open Science Collaboration, 2015), we carried out a replication study. In this replication, we also improved the design by varying prime visibility within subjects, that is, all participants took part both in the masked and unmasked conditions, thus reducing spurious variance in the comparison between sub-liminal and supra-liminal priming due to individual variability.

Replication Experiment

Method

Participants. 56 students at the University of Trieste were recruited into the experiment (18 males, 38 females; mean age=23y, age range=19y-30y). None of them took part in Experiment 1. All subjects were right-handed, and they all stated being native Italian speakers, with normal or corrected-to-normal vision and no history of neurological disorders. Subjects gave written informed consent for participation, and received 15 Euros in exchange for their time.

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Material, Procedure and Analyses were the same as in Experiment 1, with the only difference that the same participants took up both the masked and unmasked tasks, that is, we adopted a within-subject design for prime visibility too. This required splitting the experimental sessions in two blocks. In the first block, participants underwent the masked priming and prime visibility tasks, while in the second, which took place 3 to 5 days later, they concluded the study with the visible priming condition.

Results

The overall accuracy in the experiment was 98%. The mean RT on accurate trials was 539ms. Both metrics are very similar to the previous experiment. Data trimming led to the exclusion of ~5% of the total observations, resulting in 20374 datapoints available for the mixed-effects linear regression; again, these figures are very similar to the original experiment.

Linear mixed models reveal again that congruent trials yielded faster RTs than incongruent trials in the masked, sagittal condition ($\beta_1 = -7.69 [-12.63 - -2.74]$). With lateral primes, again in the masked condition, this facilitation was reduced ($\beta_2 = +4.42 [-2.57 - +11.41]$). Although both parameters shrink towards zero as compared to the previous experiment (see Figure 4), they seem to confirm the original pattern. β_3 , which tracks the difference between masked and overt priming, varies more substantially as compared to the previous study, and is now close to zero ($\beta = -0.10 [-9.98 - +9.78]$).

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Figure 4. Model estimates for the parameters of interest in the analysis. From top to bottom, we report (i) the difference between congruent and incongruent primes in the sagittal, masked condition (β_1); (ii) the shrinkage of such facilitation when congruent and incongruent conditions are compared along the lateral axis (β_2); (iii) the three-way parameter accounting for lateral priming effect in the visible condition (β_3). The squares refer to the original experiment, while triangles refer to the replication experiment. Error bars refer to 95% confidence intervals.

Despite the rather different three-way interaction parameter, the model estimates of reaction times for each condition more closely resemble the pattern of results observed in the original experiment (see Figure 5, and Figure 2 for comparison). In the masked condition, facilitation is quite larger for sagittal primes (512ms [498 – 525] for related trials vs. 520ms [507 – 535] for unrelated trials) than for lateral primes (518ms [504 – 532] vs. 521ms [508 – 536]). In the overt condition, facilitation is more similar on the two axes (sagittal primes: 483ms [471 – 495] vs. 493ms [480 – 506]; lateral primes: 490ms [478 – 502] vs. 496ms [483 – 508]). These model

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estimates also illustrate why β_3 is different from the original study: while the difference between sagittal and lateral priming shrank in the masked condition (from 11ms vs. 3ms in the original experiment, to 8ms vs. 3ms), it grew with overt primes (from 7ms vs. 6ms in the original experiment, to 10ms vs. 6ms)¹.

So, overall, the masked priming pattern replicated quite nicely. Both parameters tracking this condition shrank slightly towards zero, but they remain very consistent with stronger sagittal than lateral masked priming. Such a pattern is also clearly indicated by the model estimates. The comparison between masked and overt priming is more difficult to interpret. The relevant model parameter changed substantially, and now suggests little difference between subliminal and supraliminal priming. However, the model estimates still seem to indicate that sagittal and lateral priming are more similar supraliminally than subliminally. We will try to resolve this puzzle below, with a meta-analysis of the original and replication studies.

¹ RTs are now also generally shorter in the visible than in the masked condition. This is probably due to the within-subject design, which required participants to be tested twice on the same material. Because subjects needed to be unaware of the presence of the primes in the masked condition, the corresponding session took place first for all participants. As a result, visible primes may have benefitted from an increased familiarity with the task and the testing materials.

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Figure 5. Estimated priming effect in the masked (left panel) and the visible condition (right panel). Data from the lateral axis are shown via black squares, while data from the sagittal axis are shown via black triangles. Error bars refer to 95% confidence intervals.

Prime visibility task. As in the original study, no participant reported having noticed the primes. The d -prime distribution is shown in Figure 6; the average value is 0.39 [0.29 – 0.49], very similarly to the original experiment. The correlation between d -prime and amount of priming turned out to be slightly stronger in this experiment than in the original one, $r = 0.191$ [-0.08 – +0.43] (see Figure 6). The estimated priming when the d -prime is null is still a rather substantial 5 ms [-1 – 11], suggesting again the presence of sagittal masked priming outside of awareness. On the prime visibility data, then, we get a nice replication of the original results.

Figure 6. Density plot representing the distribution of the participants' d -prime in the prime visibility task (left panel) . Relationship between priming and prime visibility (right panel). Points represent individual participants, and the shaded area indicates the 95% confidence interval of the regression line.

Meta-analysis of the original and replication experiments

To deliver the full potential of the data collected in this work, and to clarify the different model estimates for the three-way interaction parameter observed in the original and the replication experiment, we pulled the two studies together in a meta-analysis. The Bayesian approach is particularly suitable here, as it allows to build cumulatively on previously acquired knowledge, i.e., the posterior of the original experiment becomes the prior for the replication (Kline, 2013). Following this approach, we computed a mean RT for each subject in each design cell (i.e., congruent, sagittal, masked primes; incongruent, sagittal, masked primes; congruent,

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lateral, masked primes; and so on), and then carried out a Bayesian t test for each congruent–incongruent contrast; this procedure allowed us to estimate facilitation for sagittal and lateral primes, in the masked and unmasked condition. For the original experiment, we used an uninformative Cauchy prior (scale parameter = .707; Strachan & Van Dijk, 2003), with a directional hypothesis (we hypothesized that congruent primes could only determine quicker response times); the posterior distribution in the original experiment then became the prior for the replication. This analysis was carried out with JASP, while the posterior distribution in the original experiment was estimated in R.

Results are illustrated in Figure 7. Bayes factors in favor of the alternative hypothesis that congruent primes yield quicker RTs than incongruent primes are 16.46, .86, 20.30 and 20.66 for masked sagittal, masked lateral, unmasked sagittal and unmasked lateral primes, respectively. There is thus strong evidence for priming in all conditions, except for the lateral primes, subliminal one. Importantly, while the 95% credible intervals are very similar for sagittal and lateral primes in the unmasked condition, [-.497, -.099] vs. [-.508, -.152]², they are very different outside of awareness, where sagittal prime generate a strong effect, [-.758, -.362], while lateral primes only yield very weak (if any) facilitation, [-.263, -.009].

² The values reported here are standardized effect sizes as computed in JASP, and are interpretable similarly to Cohen's d .

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Figure 7. Results from the Bayes factor (BF) replication test for the different conditions.

General discussion

In this study we investigated what kind of semantic information is extracted when people process words unconsciously. We proposed and tested the hypothesis that sub-liminal processing is limited to language-encoded semantic ties. To this aim, we took advantage of the fact that Westerners scaffold time onto space along a sagittal and a lateral timeline, but only the former is expressed in language (e.g., Monday comes *before*, not *to the left* of Tuesday). Consistent with the hypothesis, we found strong and comparable space-time congruity effects along the sagittal (front-

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back) and lateral (left-right) timelines when primes were visible. By contrast, when participants read the same prime words unconsciously, the sagittal primes produced much stronger effects than the lateral ones, which only yielded very weak facilitation (if any).

These results shed new light on unconscious semantic processing, at least as indexed by masked priming. In most circumstances it is impossible to isolate the role of linguistic experience in the computation of word meaning, because words that are semantically related are typically also related in language use. Our lateral prime-target pairs, by contrast, are related in semantic memory, but not in conventional linguistic expressions (Clark, 1973). Therefore, the finding that lateral spatial primes affected temporal judgments when the prime was read consciously, but much less (if not at all) when it was read unconsciously, supports a reinterpretation of the catalog of results showing unconscious semantic priming (e.g. Kouider & Dehaene, 2007). That is, readers may not access their semantic system to a full extent when exposed to words subliminally. Rather, they may navigate their the lexical–semantic system based on how words are linked to each other in language use (in this case, as related to linguistic metaphors).

Notably, in the present study awareness was manipulated via visual masking, while prime presentation time was kept identical in the sub–liminal and supra–liminal conditions. In some previous studies, awareness was manipulated via prime presentation time (e.g., Brunellière, Perre, Tran, & Bonnotte, 2017). Thus, we show that prime presentation time is not the main driver of the asymmetry between masked and overt priming— the same stimuli, presented for the same duration, activate different semantic representations depending on whether they are processed consciously or unconsciously.

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How does backward masking change the meanings of words? One possible mechanism is that masking prevents words from reaching consciousness by limiting the flow of information within the lexical semantic network (Dehaene et al., 2001). This interpretation is compatible with neuroimaging findings. In fMRI experiments, neural activity related to unconsciously perceived words appears to be limited to occipital–temporal visual areas within the brain word processing network (Price & Devlin, 2011). By contrast, consciously perceived words produce a highly distributed pattern of activations in the cerebral cortex, including not only occipital and temporal areas, but also parietal, motor, and prefrontal areas (Gaillard et al., 2009). These data were taken to support models of consciousness suggesting that stimuli become conscious by activating a “global workspace” (Dehaene & Naccache, 2001), where distant cortical areas can communicate with each other, and a fronto–parietal network can send top-down amplification signals to more posterior and primary sensory areas (Gaillard et al., 2009). The activation of a global workspace network may also facilitate the integration of information coming from different modalities (e.g., visual, auditory) or from brain networks that implement different kinds of mental content (e.g., wordforms, spatial schemas). From this point of view, unconscious processing is likely to be more segregated than conscious processing (Kouider & Dehaene, 2007), and access to the global workspace network with reverberating and sustained activity at the whole-brain scale may be crucial for making the leap from form to meaning in language.

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References (40\40)

Abrams, R. L., Klinger, M. R., & Greenwald, A. G. (2002). Subliminal words activate semantic categories (not automated motor responses). *Psychonomic Bulletin and Review*.

<https://doi.org/10.3758/BF03196262>

Anaki, D., & Henik, A. (2003). Is there a “strength effect” in automatic semantic priming?

Memory and Cognition. <https://doi.org/10.3758/BF03194385>

Ansorge, U., Kiefer, M., Khalid, S., Grassl, S., & König, P. (2010). Testing the theory of embodied cognition with subliminal words. *Cognition*.

<https://doi.org/10.1016/j.cognition.2010.05.010>

Bates, D., Maechler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*. <https://doi.org/10.18637/jss.v067.i01>

Borghesani, V., & Piazza, M. (2017). The neuro-cognitive representations of symbols: the case of concrete words. *Neuropsychologia*.

<https://doi.org/10.1016/j.neuropsychologia.2017.06.026>

Bottini, R., Bucur, M., & Crepaldi, D. (2016). The nature of semantic priming by subliminal spatial words: Embodied or disembodied? *Journal of Experimental Psychology: General*.

<https://doi.org/10.1037/xge0000197>

Brainerd, C. J., Yang, Y., Reyna, V. F., Howe, M. L., & Mills, B. A. (2008). Semantic processing in “associative” false memory. *Psychonomic Bulletin and Review*.

<https://doi.org/10.3758/PBR.15.6.1035>

Brunellière, A., Perre, L., Tran, T. M., & Bonnotte, I. (2017). Co-occurrence frequency evaluated with large language corpora boosts semantic priming effects. *Quarterly Journal of*

Experimental Psychology. <https://doi.org/10.1080/17470218.2016.1215479>

LIMITS OF UNCONSCIOUS SEMANTIC PRIMING

Bueno, S., & Frenck-Mestre, C. (2008). The activation of semantic memory: Effects of prime exposure, prime-target relationship, and task demands. *Memory and Cognition*.

<https://doi.org/10.3758/MC.36.4.882>

Casasanto, D., & Bottini, R. (2014a). Mirror reading can reverse the flow of time. *Journal of Experimental Psychology: General*. <https://doi.org/10.1037/a0033297>

Casasanto, D., & Bottini, R. (2014b). Spatial language and abstract concepts. *Wiley Interdisciplinary Reviews: Cognitive Science*. <https://doi.org/10.1002/wcs.1271>

Casasanto, D., & Jasmin, K. (2012). The hands of time: Temporal gestures in english speakers. *Cognitive Linguistics*. <https://doi.org/10.1515/cog-2012-0020>

Clark, H. H. (1973). Space, time, semantics, and the child. In T. Moore (Ed.), *Cognitive development and the acquisition of language* (pp. 27–63). New York, New York, USA: Academic Press.

Cumming, G. (2014). The New Statistics: Why and How. *Psychological Science*.
<https://doi.org/10.1177/0956797613504966>

De Wit, B., & Kinoshita, S. (2015). The masked semantic priming effect is task dependent: Reconsidering the automatic spreading activation process. *Journal of Experimental Psychology: Learning Memory and Cognition*. <https://doi.org/10.1037/xlm0000074>

Dehaene, S., Naccache, L., Cohen, L., Bihan, D. L., Mangin, J. F., Poline, J. B., & Rivière, D. (2001). Cerebral mechanisms of word masking and unconscious repetition priming. *Nature Neuroscience*, 4(7), 752–758. <https://doi.org/10.1038/89551>

Dehaene, Stanislas, & Naccache, L. (2001). Towards a cognitive neuroscience of consciousness: Basic evidence and a workspace framework. *Cognition*, 79(1–2), 1–37.
[https://doi.org/10.1016/S0010-0277\(00\)00123-2](https://doi.org/10.1016/S0010-0277(00)00123-2)

LIMITS OF UNCONSCIOUS SEMANTIC PRIMING

Fuhrman, O., & Boroditsky, L. (2010). Cross-Cultural Differences in Mental Representations of Time: Evidence From an Implicit Nonlinguistic Task. *Cognitive Science*.

<https://doi.org/10.1111/j.1551-6709.2010.01105.x>

Gaillard, R., Dehaene, S., Adam, C., Clémenceau, S., Hasboun, D., Baulac, M., ... Naccache, L. (2009). Converging intracranial markers of conscious access. *PLoS Biology*.

<https://doi.org/10.1371/journal.pbio.1000061>

Greenwald, A. G., Klinger, M. R., & Schuh, E. S. (1995). Activation by marginally perceptible (“subliminal”) stimuli: dissociation of unconscious from conscious cognition. *Journal of Experimental Psychology. General*, 124(1), 22–42. [https://doi.org/10.1037/0096-](https://doi.org/10.1037/0096-3445.124.1.22)

3445.124.1.22

Hassin, R. R., Bargh, J. A., & Zimmerman, S. (2009). Automatic and flexible: The case of nonconscious goal pursuit. *Social Cognition*. <https://doi.org/10.1521/soco.2009.27.1.20>

Kleiner, M., Brainard, D. H., Pelli, D. G., Broussard, C., Wolf, T., & Niehorster, D. (2007). What’s new in Psychtoolbox-3? *Perception*. <https://doi.org/10.1068/v070821>

Kline, R. B. (2013). Beyond significance testing: Statistics reform in the behavioral sciences (2nd ed.). In *Beyond significance testing: Statistics reform in the behavioral sciences (2nd ed.)*. <https://doi.org/10.1037/14136-000>

Kouider, S., & Dehaene, S. (2007). Levels of processing during non-conscious perception: A critical review of visual masking. *Philosophical Transactions of the Royal Society B: Biological Sciences*. <https://doi.org/10.1098/rstb.2007.2093>

Kouider, S., & Dupoux, E. (2005). Subliminal speech priming. *Psychological Science*.

<https://doi.org/10.1111/j.1467-9280.2005.01584.x>

Lenth, R. (2018). emmeans: Estimated Marginal Means, aka Least-Squares Means. R package

LIMITS OF UNCONSCIOUS SEMANTIC PRIMING

version 1.0.

Louwerse, M., & Connell, L. (2011). A Taste of Words: Linguistic Context and Perceptual Simulation Predict the Modality of Words. *Cognitive Science*.

<https://doi.org/10.1111/j.1551-6709.2010.01157.x>

Miles, L. K., Nind, L. K., & Macrae, C. N. (2010). Moving Through Time. *Psychological Science*, 21(2), 222–223. <https://doi.org/10.1177/0956797609359333>

Nakamura, K., Makuuchi, M., Oga, T., Mizuochi-Endo, T., Iwabuchi, T., Nakajima, Y., & Dehaene, S. (2018). Neural capacity limits during unconscious semantic processing. *European Journal of Neuroscience*. <https://doi.org/10.1111/ejn.13890>

Open Science Collobaration. (2015). Estimating the reproducibility of psychological science: Open Science Collobaration. *Science*. <https://doi.org/10.1126/science.aac4716>

Perea, M., & Rosa, E. (2002). The effects of associative and semantic priming in the lexical decision task. *Psychological Research*. <https://doi.org/10.1007/s00426-002-0086-5>

Price, C. J., & Devlin, J. T. (2011). The Interactive Account of ventral occipitotemporal contributions to reading. *Trends in Cognitive Sciences*. <https://doi.org/10.1016/j.tics.2011.04.001>

Quinn, W. M., & Kinoshita, S. (2008). Congruence effect in semantic categorization with masked primes with narrow and broad categories. *Journal of Memory and Language*. <https://doi.org/10.1016/j.jml.2007.03.004>

Reingold, E. M., & Merikle, P. M. (1988). Using direct and indirect measures to study perception without awareness. *Perception & Psychophysics*. <https://doi.org/10.3758/BF03207490>

Rinaldi, L., Locati, F., Parolin, L., Bernardi, N. F., & Girelli, L. (2016). Walking on a mental

LIMITS OF UNCONSCIOUS SEMANTIC PRIMING

time line: Temporal processing affects step movements along the sagittal space. *Cortex*.

<https://doi.org/10.1016/j.cortex.2016.02.013>

Sackur, J., Naccache, L., Pradat-Diehl, P., Azouvi, P., Mazevet, D., Katz, R., ... Dehaene, S.

(2008). Semantic processing of neglected numbers. *Cortex*.

<https://doi.org/10.1016/j.cortex.2007.02.003>

Saj, A., Fuhrman, O., Vuilleumier, P., & Boroditsky, L. (2014). Patients With Left Spatial

Neglect Also Neglect the “Left Side” of Time. *Psychological Science*.

<https://doi.org/10.1177/0956797612475222>

Sklar, A. Y., Levy, N., Goldstein, A., Mandel, R., Maril, A., & Hassin, R. R. (2012). Reading

and doing arithmetic nonconsciously. *Proceedings of the National Academy of Sciences of*

the United States of America. <https://doi.org/10.1073/pnas.1211645109>

Strachan, R. W., & Van Dijk, H. K. (2003). Bayesian Model Selection with an Uninformative

Prior. *Oxford Bulletin of Economics and Statistics*. <https://doi.org/10.1046/j.0305->

9049.2003.00095.x

Ulrich, R., Eikmeier, V., de la Vega, I., Fernández, S. R., Alex-Ruf, S., & Maienborn, C. (2012).

With the past behind and the future ahead: Back-to-front representation of past and future

sentences. *Memory and Cognition*. <https://doi.org/10.3758/s13421-011-0162-4>

Weger, U. W., & Pratt, J. (2008). Time flies like an arrow: Space-time compatibility effects

suggest the use of a mental timeline. *Psychonomic Bulletin & Review*, 15(2), 426–430.

<https://doi.org/10.3758/PBR.15.2.426>