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Unconscious semantic processing: Insights from metaphorical priming

Chiara Saponaro [a,*], Andrea Nadalini [b], Daniel Casasanto [c], Davide Crepaldi [d], Roberto Bottini [e]

[a] Department of Psychology, University of Milano-Bicocca, Piazza dell'Ateneo Nuovo 1, Milano 20126, Italy
[b] Institute for Computational Linguistics, Italian National Research Council, Roma 00185, Italy
[c] Department of Psychology, Cornell University, Ithaca, NY, USA
[d] Department of Psychology, University of Pavia, Piazza Botta 11, Pavia 27100, Italy
[e] Center for Mind/Brain Sciences (CIMeC), University of Trento, P.zza Manifattura 1, Rovereto 38068, Italy

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ABSTRACT

The limits of unconscious processing in the semantic domain are highly debated. While prior research presents polarized views on whether word representations are accessible when presented subliminally, this work proposes a more fine-grained investigation into which aspects of word meaning can be accessed unconsciously. Specifically, we explore the conditions under which high-level semantic information, such as metaphorical relations, can be processed subliminally. We rely on space–time and space-number metaphorical mappings, which have been observed in many experiments as well as in spontaneous behavior, such as the association of the past (or subtraction) and the future (or addition) with "left" and "right", respectively. We exploited the fact that some of these conceptual associations (i.e., sagittal or vertical mappings) are also present in language (e.g., "you have a bright future in front of you"; "taxes are going down"), whereas others (i.e., lateral mapping) are not (e.g., "you have a bright future on your right"; "taxes are going left"). In two experiments, space–time and space-number semantic priming consistent with canonical metaphorical mappings emerged when both prime (e.g., "right") and target (e.g., "tomorrow") were consciously perceived, confirming their conceptual association. However, with masked priming, only language-encoded associations were activated. These results suggest that consciousness is necessary to process even ubiquitous and overlearned metaphorical associations and that putatively unconscious semantic priming, when present, may be lexical in nature.

1. Introduction

As humans, we store conceptual representations of words in semantic memory, combine them creatively, and retrieve them appropriately. Do we need consciousness to do all this? Previous studies have reported subliminal processing at the morphological level, suggesting that when a visual word is presented outside of awareness human participants are able to decompose it and process its morphological and orthographic features (e.g., Amenta & Crepaldi, 2012; Rastle et al., 2004). Moreover, other literature has found that subliminal processing can reach the syntactic level, showing that abstract representations of syntactic features shared between word categories can be formed without consciousness (e.g., Berkovitch & Dehaene, 2019). However, if the existing findings on the subliminal processing of morphological and syntactic aspects have received a large consensus, the debate on whether a word's meaning can be comprehended outside of conscious awareness remains open.

Among the methodologies employed in this research field, the visual masked priming technique (Forster & Davis, 1984) has been used broadly in the literature. It is an adaptation of the semantic priming paradigm, testing how the perception of a prime word influences participants' performance. Semantic priming effects refer to the phenomenon whereby a target word is processed more quickly after a semantically related prime than an unrelated one (Meyer & Schvaneveldt, 1971), as the prime acts as a retrieval cue that facilitates access to semantic memory. In subliminal priming, the prime is rendered invisible or less accessible through techniques such as masking, where random character screens are presented before (forward masking) and sometimes also after (backward masking) the prime, combined with brief prime durations (≤50 ms) to prevent conscious perception. In this framework, Dehaene et al. (1998) found that participants were faster in categorizing a target digit as larger or smaller than the reference number

* Corresponding author.
E-mail addresses: chiara.saponaro@unimib.it (C. Saponaro), andrea.nadalini@ilc.cnr.it (A. Nadalini), casasanto@alum.mit.edu (D. Casasanto), davide.crepaldi@unipv.it (D. Crepaldi), roberto.bottini@unitn.it (R. Bottini).

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5 when the prime number belonged to the same category "lower than 5" (e.g., 1) in comparison with a prime belonging to a different category, such as "higher than 5" (e.g., 8). This *category congruence effect* was replicated several times (e.g., Dehaene et al., 2001; Kunde et al., 2003; Li et al., 2024; Naccache & Dehaene, 2001; Quinn & Kinoshita, 2008) and expanded with word stimuli (e.g., Bottini et al., 2016; Ortells et al., 2016; Quinn & Kinoshita, 2008; Van Opstal et al., 2010), hinting at unconscious semantic processing of single word items. Further evidence suggests that subliminal semantic processing not only occurs with isolated numbers or words that share semantic similarities (Ansorge et al., 2010; Finkbeiner, 2011; Kouider & Dehaene, 2007), but even with complex arithmetic operations and multi-word expressions. Sklar and colleagues (2012) found that participants were faster in responding to a number if it was the correct result of a subliminal arithmetic equation displayed before, and they were sensitive to semantic violations in sentences presented outside of awareness (e.g., "I ironed coffee"). Further evidence confirmed that multiple numbers presented subliminally can be summed and give rise to priming effects (Ric & Muller, 2012), as well as multiple words (Armstrong & Dienes, 2013; Hung & Hsieh, 2021). Sensational effects like these ones have pushed several scholars to embrace the "Yes It Can" (or YIC) principle, according to which unconscious processing can perform the same fundamental high-level functions as conscious processing (Hassin, 2004, 2009, 2013).

However, many other studies have instead shown the limits of unconscious semantic processing, coming sometimes to radically different conclusions. Quinn and Kinoshita (2008) found that category congruence effects occurred between prime and target words within narrow semantic categories (e.g., planets: participants were faster in categorizing "Venus" as a planet if it followed the prime "Mars" rather than "tree"). However, for broader semantic categories such as animals priming emerged only when the target (e.g., eagle) followed a prime with which it shared many semantic features (e.g., hawk) but was absent when it followed a prime which was not similar (e.g., mole). The authors suggested that the strength of subliminal priming depends on the degree of semantic overlap: when prime and target share many features, as in Venus-Mars but also in hawk-eagle, the information needed for categorizing the target is readily available, resulting in faster responses. By contrast, when prime and target are less similar, accessing their relationship likely requires higher-level retrieval processes that may not be activated automatically. In a similar vein, Van den Bussche et al. (2009) conducted a meta-analysis of 46 studies claiming the existence of unconscious semantic processing by focusing on papers that employed the most common tasks in priming paradigms, such as semantic categorization, lexical decision, and naming tasks. The authors found that several factors can influence the strength of the priming effect, such as the prime-target degree of semantic relatedness (see also Van den Bussche et al., 2012) or the nature of the experimental design: masking the prime reduces or eliminates the priming effect on the target during lexical decision tasks, while priming effects are preserved in semantic categorization tasks independently from the prime's visibility (further supported by de Wit & Kinoshita, 2014).

Moreover, several studies did not find any unconscious semantic effect at all. Nakamura et al. (2018) did not report any behavioral effect in the processing of sentences comprising masked words. Further negative evidence comes from studies that combined masked priming with Continuous Flash Suppression (CFS) – a technique that induces interocular suppression to render stimuli invisible. These studies failed to find facilitation effects of subliminally presented pictures (Stein et al., 2020) or words (Heyman & Moors, 2014) on target word recognition, raising serious concerns about the existence of unconscious semantic processing. Kouider and Dupoux (2004) argued that apparent unconscious semantic priming effects could result from partial awareness, where fragments of a masked prime are consciously perceived, leading to an illusion of subliminal processing. In line with this, multiple replication attempts have failed to support claims of high-level unconscious processing, such as arithmetic or sentence comprehension, further undermining the validity of the YIC principle (Moors & Hesselmann, 2019; Rabagliati et al., 2018; Tal & Mudrik, 2024). For instance, Rabagliati et al. (2018) failed to replicate Sklar and colleagues' (2012) results and did not find any evidence that individuals can access a word's or sentence's meaning outside of awareness in 10 high-powered studies, showing instead that only low-level elements, such as word length, can be processed unconsciously. Tal and Mudrik (2024) tried and failed to replicate earlier positive results concerning unconscious arithmetic (Ric & Muller, 2012). In a masked priming experiment, they found that participants could not integrate a masked priming instruction "add" with masked priming digits, resulting in a null effect on the target number (which could be either the correct output of the operation or not).

2. A nuanced approach to unconscious processing

As we reviewed in the previous paragraphs, much of the debate regarding unconscious semantic processing has been between one side of the literature claiming that we can process words up to their meaning even when we do not perceive them consciously (e.g., Dehaene et al., 1998; Sklar et al., 2012), and another one bringing evidence against this statement (e.g., Moors & Hesselmann, 2019; Rabagliati et al., 2018). This black-and-white approach, however, falls short of adequately accounting for the richness of the current body of data, which presents instances where category congruence effects are clearly attested and others where they are not (e.g., Ansorge et al., 2010; Bottini et al., 2016; de Wit & Kinoshita, 2014; Nakamura et al., 2018; Quinn & Kinoshita, 2008). So, the core question does not appear to be *whether* semantic processing happens outside of awareness, but rather *what* kind of information can be processed unconsciously and under which conditions.

The Integration Window Approach (Hirschhorn et al., 2021; Mudrik et al., 2014; Zher-Wen & Yu, 2023) addresses this issue by proposing that many cognitive effects depend on the integration of multiple pieces of information over time and space. In this view, semantic relations are a form of information integration, insofar as they require linking distinct signals into a coherent representation (Mudrik et al., 2014). Crucially, the approach distinguishes between low-level integration, which relies on relatively simple, feature-based or categorical associations (e.g., recognizing that two digits belong to the same category, or that two traffic signs are visually or categorically related), and high-level integration, which requires combining information across modalities, contexts, or abstract concepts (e.g., inferring indecision from a complex visual scene, such as a street sign pointing in multiple directions combined with a confused facial expression, indicating that a person is facing a dilemma or uncertainty; Mudrik et al., 2014). According to this framework, higher-level integration requires a wider Semantic Processing Integration Window (SPIW) – that is, more processing resources and a longer temporal window, conditions that are typically available only under conscious awareness. As a result, unconscious processing should be sufficient for low-level semantic relations but insufficient for high-level ones. Importantly, Mudrik and colleagues emphasize that there is no clear line between low- and high-level processing, which makes it difficult to draw definitive conclusions about the limits of unconscious cognition. Nonetheless, they identify metaphorical associations as a prototypical case of high-level semantic integration, because they require mapping structure across distinct conceptual domains (e.g., space and time, or ice cubes and unaffectionate individuals). From this perspective, metaphorical mappings provide an ideal test case for assessing whether unconscious processing can support genuinely conceptual integration, beyond simple associative or feature-based relations.

However, not all metaphors are created equal. For instance, some metaphorical or idiomatic expressions are highly culture-dependent and lack productivity, in the sense that they cannot easily be situated within a systematic conceptual schema. Take the famous verse by Emily Dickinson "Hope is the thing with feathers": although the metaphorical mapping becomes clearer throughout the poem, it certainly requires a good deal of associative steps to be understood (i.e., first, that the author is referring to birds, then that birds can fly everywhere, then that flight symbolizes escape and freedom, etc.). Even then, there is more than one interpretation of such a metaphor (multiple mappings), which can be partly culture-dependent. Moreover, this metaphor lacks productivity and systematicity since it certainly does not make "despair" (the opposite of hope) a featherless thing! Metaphors like this are likely to require a large integration window in order to be processed. However, the large majority of our metaphorical language is instead entrenched in what cognitive linguists call *conceptual metaphors* (e.g., Lakoff & Johnson, 1980). Conceptual metaphors are central to cognition because they offer a structure for organizing abstract knowledge by relating it to everyday experience. For example, when we say "he attacked my position", we are using a metaphor that structures our understanding of verbal discussions through the concept of combat – an instance of the conceptual metaphor ARGUMENT IS WAR. Similarly, the expression "you're wasting my time" reflects how we conceptualize time as a valuable resource, illustrating the metaphor TIME IS MONEY. Conceptual metaphors are fundamental cognitive tools that shape how we perceive and understand the world, allowing us to conceptualize abstract ideas through more concrete, familiar experiences (e.g., Boroditsky, 2000; Casasanto & Bottini, 2014; Clark, 1973; Dehaene et al., 1993; Gentner et al., 2001; Tversky et al., 1991). Metaphorical relations are pervasive in everyday language and thought to the extent that some authors suggested they can operate below the level of conscious awareness (Lakoff & Johnson, 1980). Given the cognitive and linguistic pervasiveness of metaphorical mappings – and the claim that they operate automatically – metaphors provide a crucial test case for examining the limits of unconscious processing, especially in light of arguments that they can only be understood consciously (Mudrik et al, 2014).

Recently, Chien et al. (2023) tested the SPIW model using the conceptual metaphor between thermal qualities and personality traits (such as "cold-hearted" to describe an unkind person or "warm and friendly" to indicate kindness and approachability). In a priming experiment, primes were thermal terms (e.g., "freeze", "burning"), while targets were either related to thermal qualities (e.g., "snowman", "desert") or personality traits (e.g., "cruel", "big-hearted"). Both categories were classified as cold or warm, allowing for congruent vs. incongruent pairings. Participants performed a semantic decision task with visible or masked primes (via CFS). When primes were visible, responses were faster for congruent pairs in both thermal and personality-related conditions. However, with subliminal primes, only thermal terms showed an effect, and unexpectedly, congruent pairs led to longer reaction times. No category congruence effects were observed for metaphorical mappings under unconscious conditions, suggesting that high-level semantic links require awareness. However, some limitations of Chien et al.'s (2023) study should be carefully considered. First, the sample sizes are very limited, ranging from 12 to 24 participants per experiment. Second, while the metaphorical link between temperature and personality traits is crucial for understanding affective knowledge, it can sometimes be ambiguous, especially considering the items used in their experiment. For instance, a "snowman" or "winter" may evoke positive emotions, whereas the "desert" and a "scorching sun" may be associated with negative feelings. This ambiguity could have introduced noise, potentially contributing to the null result observed at the unconscious level. Third, it has been argued that CFS, being a form of interocular suppression, may suppress stimuli too effectively, potentially hindering high-level processing such as semantic analysis (Yang et al., 2017). Third, the reverse priming effect obtained in the non-metaphorical control condition by Chien and colleagues, when the prime was masked, is highly unexpected; this finding casts doubts on both the methodology employed and the validity of interpreting the null result in the metaphorical condition. Thus, in our opinion, whether or not the processing of conceptual metaphors needs awareness remains an open question.

3. The current study

In the current study, we evaluate the SPIW model using conceptual metaphors of time and quantity. Indeed, time and quantity (or numbers) are often talked about in language using spatial metaphors – common examples are "you have a bright future in front of you", "the deadline is approaching", "prices are rising", or "the stock market went down". Moreover, there is a plethora of experimental evidence showing that spatial mappings are activated when thinking about time, quantities, or numbers. In reaction time paradigms, people are faster in associating a left key with the past or lower numbers and a right key with the future or higher numbers compared to vice versa (Casasanto & Bottini, 2014; Dehaene et al., 1993; Santiago et al., 2007; Weger & Pratt, 2008). Similar effects also emerge on the sagittal axis (back/front) for time (Boroditsky, 2000, 2001), and the vertical axis (up/down) for quantities and numbers (Hartmann et al., 2014; Sell & Kaschak, 2011). When people are asked to generate random numbers, they name smaller or larger numbers when their eyes move left (or down) and right (or up), respectively (Grade et al., 2013; Loetscher et al. 2008, 2010; Viganò et al., 2024; Winter & Matlock, 2013), and when engaging in mathematical operations the gaze shifts left for subtractions and right for additions (Masson & Pesenti, 2014; Mathieu et al., 2016; McCrink et al., 2007; Werner & Raab, 2014). In more ecological settings, spontaneous gestures that accompany speech also reflect these spatial schemas: people spontaneously gesture toward the left (or back) when talking about the past and toward the right (or front) when talking about the future (Casasanto & Jasmin, 2012; Cienki & Müller, 2008; Cooperrider & Núñez, 2009; Miles et al., 2010). These and several other experiments (e.g., Knops et al., 2009; Lugli et al., 2013; Pinhas & Fischer, 2008; Ulrich & Maienborn, 2010; Viganò et al., 2024; Wiemers et al., 2014; for reviews, see Fischer & Shaki, 2014; Winter et al., 2015) demonstrate that the spatial mapping of time and quantities – often referred to as Mental Time Line (MTL) and Mental Number Line (MNL) – are a robust cognitive phenomenon and an important component of our temporal and numerical representations, as suggested by conceptual metaphor theories. Whether or not consciousness is necessary to establish such metaphorical mappings is the question behind the two experiments of this paper.

To answer this question, we employ the masked priming technique, comparing subliminal and supraliminal metaphorical priming in different groups of participants. We aim to investigate whether a category congruence effect emerges when the prime (e.g., "right) is masked, and thus its metaphorical relationship to a related target (e.g., "future") is not accessible to participants' awareness. We chose to present participants with a semantic categorization task rather than lexical decision or naming tasks because categorization necessarily requires semantic processing to answer whether the target is member of a category, whereas the other tasks do not (see de Wit & Kinoshita, 2014; Kinoshita & Norris, 2012 for detailed discussion).

Interestingly, choosing the MTL and the MNL as a testbed for our investigation allows us to introduce another experimental condition, since only some of these mental metaphors are encoded in language. Indeed, even though spatial metaphors of time are widespread, only the sagittal mapping is represented in language, while there is no evidence for a linguistic realization of the lateral MTL: we can push the meeting forward, but not to the right (Clark, 1973; Eikmeier et al., 2015; Haspelmath, 1997; Radden, 2004; Ulrich & Maienborn, 2010). Similarly, only the vertical mapping of space-quantity metaphors is encoded in language: expressions such as "the prices are rising" or "to lower the taxes" are common in our everyday language, but we never hear that "the prices are going to the right" or that "taxes have been moved left" (Nouwen, 2016; Pitt & Casasanto, 2022). This state of affairs allows us to test whether being or not encoded in everyday language makes a difference in the unconscious processing of conceptual metaphors. In the context of the SPIW model, being encoded in language may further strengthen the metaphorical conceptual mapping between domains and reduce the integration window needed for the association.

4. Experiment 1 – Temporal metaphors

We presented participants with an exploratory priming experiment in which spatial words were used as primes and temporal terms as targets, and we manipulated the prime visibility across two groups. According to the SPIW model, metaphorical priming effects should emerge in the supraliminal condition but disappear in the masked condition. We tested this hypothesis, contrasting it with the hypothesis that being encoded in language decreases the needed integration window to process metaphorical mappings and, thus, permits unconscious processing.

4.1. Methods

The experiment employed a $2 \times 2 \times 2$ design, with the factors Prime Visibility (visible/masked), Axis (sagittal/lateral), and Congruity (incongruent/congruent). We randomly divided participants into a supraliminal group ($N = 60$) and a subliminal group ($N = 60$) based on the between-subjects factor Prime Visibility. Each group performed a semantic categorization task in a priming experiment, in which prime-target pairs were manipulated according to the two within-subjects factors of Congruity and Axis: prime items could be congruent or incongruent with the target word, according to their metaphorical mapping, and represented along either the sagittal or the lateral spatial axis. To prevent participants in the subliminal condition to access the prime-target relationship, we adopted a masked priming technique. Both groups were presented with the same prime-target pairs and performed a semantic decision task using a go/no-go procedure: participants responded by clicking on a button only when the target word belonged to one category (e.g., future) and withheld their response when it belonged to the other one (e.g., past). Reaction times were recorded and compared between the two groups. After the priming experiment, participants in the subliminal condition completed a visibility task to quantitatively confirm their lack of awareness of the subliminally presented prime words.

4.2. Participants

We recruited 120 participants for this experiment, including both university students and individuals recruited from the local community. We aimed to recruit a sample size that was substantial while remaining comparable to the existing unconscious semantic priming literature, where the average sample size is approximately 20 participants (Van den Bussche et al., 2009). Accordingly, we initially targeted 60 participants for each of the two groups, the supraliminal and the subliminal; however, because half of the collected trials (i.e., “no-go” trials) were not included in the analyses, this resulted in an effective sample size of 30 participants per group. We divided participants into two groups following a pseudo-randomized criterion to balance the two groups by age and gender: the supraliminal group presented 44 female participants and 16 males, and the mean age was 24 years ($SD = 3$), while the subliminal group consisted of 46 females and 14 males with a mean age of 24 years ($SD = 3.5$). All participants were native Italian speakers with normal or corrected-to-normal vision and no history of neurological disorders. We did not select participants based on handedness since the go-no go procedure avoided any potential confound from the spatial position of the response. All participants signed a written informed consent approved by the SISSA Research Ethics Committee.

4.3. Stimuli and material

In the priming experiment, we employed four spatial words as prime items, i.e., *davanti* (“front”) and *dietro* (“back”) for the sagittal axis, and *destra* (“right”) and *sinistra* (“left”) for the lateral axis. Eight temporal words were used as targets, four that refer to the past (*prima*, “earlier”, *ieri*, “yesterday”, *passato*, “past”, *scorso*, “previous”), and four that refer to the future (*dopo*, “later”, *domani*, “tomorrow”, *futuro*, “future”, *successivo*, “next”). Table A1 in the Appendix reports the list of target stimuli, with their corresponding English translation, Zipf frequency (taken from SUBTLEX-IT, Crepaldi et al., 2016), number of letters, and grammatical category. Each prime word was associated with each target word, resulting in 32 unique trial pairs. Therefore, each target was associated with a congruent prime on the sagittal axis, a congruent prime on the lateral axis, an incongruent prime on the sagittal axis, and an incongruent prime on the lateral axis. Table 1 provides an example of the prime-target relationships for each combination of Axis and Congruity, along with the expected reaction time patterns in the supraliminal and subliminal conditions, based on the linguistic encoding of metaphorical mappings. Each pair was presented 12 times, resulting in a total of 384 experimental trials divided into two blocks. We created 12 additional practice trials.

4.3.1. The visibility task

As mentioned above, we designed a visibility task to evaluate whether participants in the subliminal group were aware of the presence of a prime word. The paradigm was similar to the experimental priming task, but here, we replaced half of the prime items with strings of identical lowercase letters (<aaaaaaaa>). Combining prime words/non-words and target words, we obtained 128 testing trials and 12 practice trials, for a total of 140 trials.

4.3.2. Apparatus

Stimuli were displayed on a 22″ monitor with a refresh rate of 120 Hz, using MATLAB Psychtoolbox-3 (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). Words were presented in a white Arial font (font size 32) against a black background. Responses were recorded through a CyNexo response box based on an Arduino processor. We used a chin rest to ensure that all participants were at the same distance of approximately 63 cm from the monitor.

4.4. Procedure

Participants were seated on a comfortable armchair, with the response pad and the monitor in front of them. In the supraliminal group, participants were presented with a sequence of five screens: they saw first a fixation point “+” (750 ms), then a blank screen (200 ms), the prime word (50 ms), another blank screen (50 ms) and finally the target word (displayed until a response was provided, with a time out of 1500 ms). Fig. 1 shows a congruent trial with primes mapped along the two axes.

Participants performed a semantic decision task in which they judged whether the target word referred to the concept of the future or the past using a go/no-go procedure. In each block, participants were instructed to press the button on the response pad with the index finger of their dominant hand only when the target belonged to the designated category (future or past) and to withhold responses for the other category. Trials were divided into two blocks – one for future responses and one for past responses – with the order of presentation counterbalanced across participants. Within each block, trials were presented in a pseudo-randomized order. We adopted a go-no go procedure to avoid any potential confounds from the spatial coding of the response, even though this decision resulted in the exclusion of half of the data points from the analysis. Participants were asked to be accurate and fast at the same time, and we recorded the response type and reaction times.

The procedure for the subliminal condition was identical to the supraliminal one, except that prime words were rendered invisible by two visual masks placed in the screens immediately before and after the prime item, as shown in Fig. 2. We obtained the two masks by randomly shuffling ten uppercase letters for each trial. This procedure allowed us to maintain the trial timeline and the temporal duration of the prime word identical across the two conditions, which differed only in terms of

Table 1
Example of prime-target relationships in Experiment 1 for each combination of Axis and Congruity and expected reaction time patterns in the supraliminal and subliminal conditions.

Axis	Congruity	Prime-target example	Linguistically encoded?	Supraliminal prediction	Subliminal prediction: SPIW hypothesis	Subliminal prediction: Alternative hypothesis
Sagittal	Congruent	*davanti-domani* (front-tomorrow)	✓	Faster RTs for congruent than incongruent trials	No congruency-related RT difference	Faster RTs for congruent than incongruent trials
Sagittal	Incongruent	*davanti-ieri* (front-yesterday)				
Lateral	Congruent	*destra-domani* (right-tomorrow)	×	Faster RTs for congruent than incongruent trials	No congruency-related RT difference	No congruency-related RT difference
Lateral	Incongruent	*destra-ieri* (right-yesterday)				

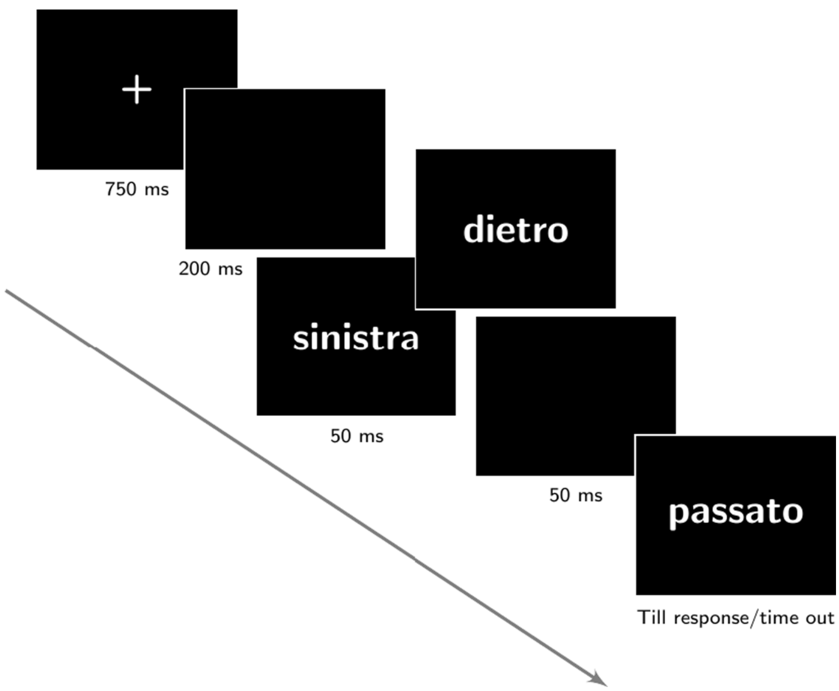

Fig. 1. Example trial procedure in the supraliminal condition.

the prime visibility. This methodology has been used in several previous masked priming experiments (e.g., Ansorge et al., 2010; Bottini et al., 2016; Dehaene et al., 1998) and permits a rigorous comparison between the supraliminal and subliminal conditions.

4.4.1. The visibility task

At the end of the priming experiment, participants in the subliminal group performed a visibility task. They were presented with a sequence of screens identical to the subliminal condition, but they were required to pay attention to the prime word, not the target term. They were asked to perform a lexical decision task by pressing one of the two buttons of the response pad if they judged the prime item to be a real word and the other button if they considered it a non-word. Two examples of trials were displayed in the instructions with a longer presentation of the prime item (150 ms instead of 50 ms) to ensure that participants understood the sequence of screens. No time out was included in this task, and participants could pass to the following trial only by pressing one of the two buttons on the response pad. Trials were presented in a randomized order. We recorded only the button pressed, but not the reaction times associated with it, since we favored the accuracy of the response over its promptness.

4.5. Data analysis

We conducted statistical analyses only on "go" trials after discarding practice and "no go" ones. On a subject-wise basis, we excluded inaccurate trials and data points that stood at more than two standard deviations from the average reaction time of each participant to remove extremely slow or fast responses (Ansorge et al., 2010; Bottini et al., 2016). We then employed linear mixed-effects regression models (Baayen et al., 2008) and set Congruity (incongruent/congruent), Axis (sagittal/lateral), and Prime Visibility (visible/masked) as fixed effects and subjects and targets as random effects. We dummy-coded our fixed effects by setting the visible condition, incongruent primes, and the sagittal axis as the reference levels for Prime Visibility, Congruity, and Axis, respectively. We included only the intercepts of the random effects in the model to avoid non-convergence and singular fit errors, following the procedure suggested by Barr (2013). Including targets' length and frequency in the model as fixed effects did not improve the models' goodness of fit, so we decided to remove them. We used the lme4 package (Bates et al., 2015) in the R software (R Core Team 2021) to conduct these analyses. All the analyses were performed on the inverse transformation of the data (−1000/value in ms), which allowed us to have a normalized dataset. All data and analysis scripts are publicly available; see the Data availability statement at the end of the

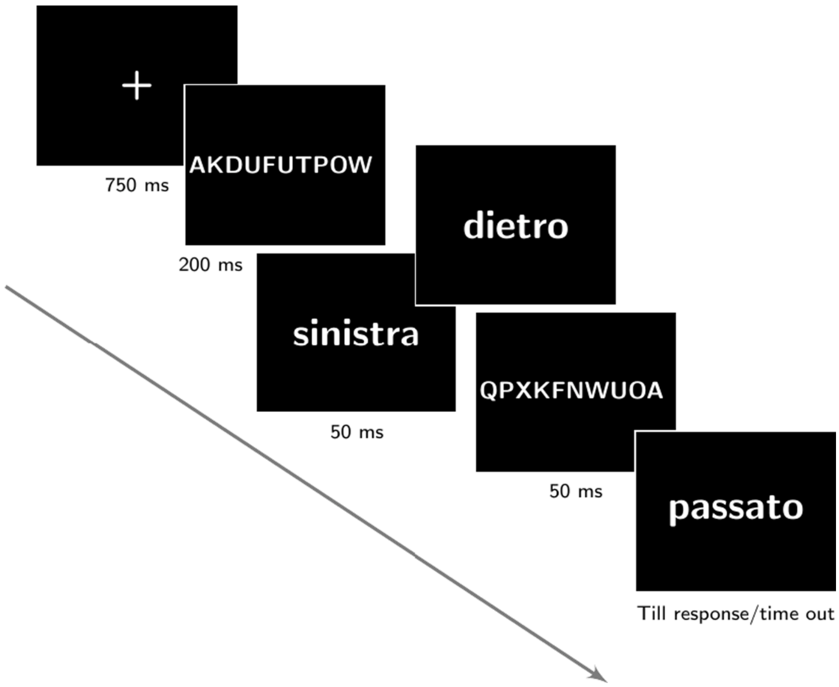

Fig. 2. Example trial procedure in the subliminal condition.

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4.5.1. *Measures of awareness*

We assessed participants' performance in the visibility task included in the subliminal condition by computing a d-prime score (d') for each participant. Hits were defined as correctly identifying signal-present (i.e., signal + noise) trials as containing the signal, whereas false alarms were noise-only trials incorrectly classified as signal-present. The d' score was computed as:

$$d' = z(H) - z(F)$$

Because our goal was to verify the absence of sensitivity to the prime item, lower d' values indicate reduced awareness, with a d' of 0 corresponding to chance-level performance for our purposes. We employed the Greenwald regression measure to further explore the influence of prime visibility on the priming effect (Greenwald et al., 1995). To do, we calculated the priming effect for each participant by subtracting mean reaction times on congruent trials from mean reaction times on incongruent trials: hence, positive results demonstrated a facilitation effect. Then, we regressed the amount of priming effect against d-primes: if the regression line's intercept was significantly above the origin (with a 95% confidence interval), the priming effect would be significantly higher than 0 when the d-prime value was equal to 0, indicating a null sensitivity to the prime item, and we could conclude that the priming effect happened in absence of awareness.

4.6. *Results*

After excluding practice and "no go" trials, the overall accuracy in the experiment was 99.2%, while the average response time on accurate trials was 549.6 ms. In the supraliminal condition, the average response time was 553.4 ms, while in the subliminal condition it was 536.8 ms. After removing error trials, we lost an additional 1.5% of data points, and after excluding individual data points standing at more than 2 *SD* from the subjective mean we lost a further 4.5%. The final database comprised 21,648 data points.

At this point of the analysis, raw reaction times in the supraliminal condition presented an average value of 537.1 ms, while in the subliminal condition it was equal to 525.4 ms. Table 2 reports the raw means for each condition derived from the combinations of Prime Visibility, Congruity, and Axis levels. As an initial observation, we computed the priming effect for each condition derived from the combinations of the three factors' levels. This revealed a facilitation effect driven by congruent trials that was similar between the sagittal (4.0 ms) and the lateral (6.3 ms) axes in the supraliminal condition, but appeared much stronger on the sagittal axis (9.7 ms) compared to the lateral one in the subliminal condition (1.6 ms). In the following section, we formally analyze these effects to determine whether these patterns are supported by statistical testing.

4.6.1. *Linear mixed models of regression*

To analyze our data, we built a mixed-effects regression model with inverse-transformed reaction times as the dependent variable and Congruity, Axis, Prime Visibility and their interaction as fixed effects. We also included random intercepts for participants and targets.[1] We dummy-coded our fixed effects by setting the visible condition, incongruent prime-target relations, and the sagittal axis as the reference levels for Prime Visibility, Congruity, and Axis, respectively.

The results of the analyses are illustrated in Fig. 3. Critically, we found a significant three-way interaction between Congruity, Axis, and Prime Visibility ($\chi^2(1) = 4.81$, $p = 0.028$). This interaction reflects the fact that participants were faster on congruent targets compared to incongruent ones when the metaphorical mapping occurred on the sagittal axis and the primes were visible, as the main effect of Congruity suggests ($\beta = -0.025$, $SE = 0.008$, $t(21512) = -3.313$, $p < 0.001$). This facilitation effect did not change when the mapping occurred on the lateral axis, again with visible primes, as the non-significant interaction between Congruity and Axis reveals ($\beta = 0.002$, $SE = 0.016$, $t(21512) = 0.169$, $p = 0.866$). Essentially, supraliminal priming was equivalent on the two axes. In contrast, while the effect on the sagittal axis appeared relatively stable when the primes were masked, as shown by the non-significant interaction between Congruity and Prime Visibility ($\beta =$

[1] m ←lmer(−1000/RT ~ Congruity*Axis*PrimeVisibility + (1|SubjectID) + (1|Target)).

Table 2
Raw reaction times for each condition.

Supraliminal				Subliminal			
Axis	*Congruity*	*Mean RTs*	*SD*	*Axis*	*Congruity*	*Mean RTs*	*SD*
sagittal	con	535.2	130.8	sagittal	con	520.5	99.0
sagittal	inc	539.2	123.8	sagittal	inc	530.2	93.3
lateral	con	533.9	122.9	lateral	con	524.6	96.5
lateral	inc	540.2	124.9	lateral	inc	526.2	93.7

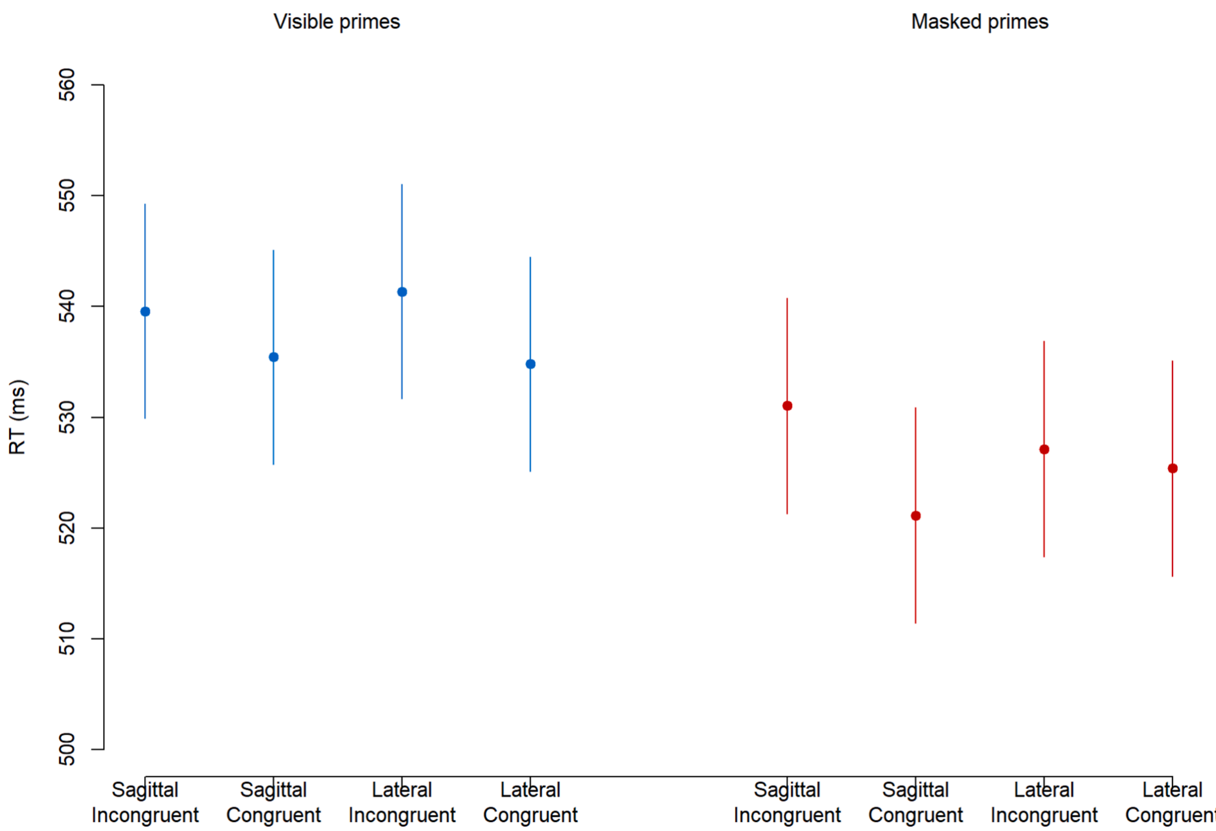

Fig. 3. Estimated reaction times (RTs) from a mixed-effects model including a three-way interaction between Prime Visibility (visible/masked), Congruity (incongruent/congruent), and Axis (sagittal/lateral). Points represent model-predicted RTs for each condition, with vertical lines indicating standard errors.

-0.019, $SE = 0.011$, $t(21512) = -1.783$, $p = 0.075$), it seemed to shrink when the primes were presented subliminally and the mapping occurred on the lateral axis, as suggested by the 3-way interaction of Congruity, Axis, and Prime Visibility ($\beta = 0.033$, $SE = 0.015$, $t(21512) = 2.194$, $p = 0.028$). To corroborate these results, we conducted an additional analysis with Anova, which confirmed the significant 3-way interaction between our factors ($F(1, 117) = 5.363$, $p = 0.022$, $\eta p^2 = 0.044$). All the results are publicly available (see the Data availability statement at the end of the paper).

4.6.2. *Measures of awareness*

First, observing the data, we had to exclude a participant who always pressed the same button on the response pad in the visibility task. Then, as explained in the Data analysis section, we calculated the d-prime index for each participant in the subliminal condition. The overall average value was 0.345 ($SD = 0.376$), which was different from 0 ($t(57) = 6.983$, $p < 0.001$). To examine whether it influenced participants' performance in the semantic categorization task, we calculated the priming effect for each participant and conducted a correlational test with d-prime values: we did not find any significant correlation either in the sagittal ($t(56) = 0.165$, $p = 0.870$, corr $= 0.02$) or in the lateral condition ($t(56) = -1.174$, $p = 0.245$, corr $= -0.15$). Then, we regressed the amount of priming effect against d-prime results to explore whether partial visibility might lead to the facilitation effect, employing the Greenwald regression method (Greenwald et al., 1995). Since only the sagittal axis presented a significant effect of Congruity in the masked condition, we report here only the results obtained in that condition (but the ones in the lateral axis can be found in the public analysis folder; see the Data availability statement). As we can observe in Fig. 4, we found a significant priming effect on the masked sagittal axis in the absence of awareness since the 95% confidence interval at the intercept lay above the origin (i.e., at d' = 0).

4.7. *Discussion*

The results of Experiment 1 only partially support the SPIW model. On the one hand, space–time mappings on the lateral axis led to category congruence effects in the supraliminal condition, but not in the subliminal condition, according to the model. On the other hand, sagittal metaphors seemed to be processed in both conditions, suggesting that consciousness was not needed to integrate spatial and temporal terms metaphorically. Interestingly, the lateral mapping, contrary to the sagittal one, is not encoded in language. This suggests, as hypothesized, that language use may somehow facilitate metaphorical semantic

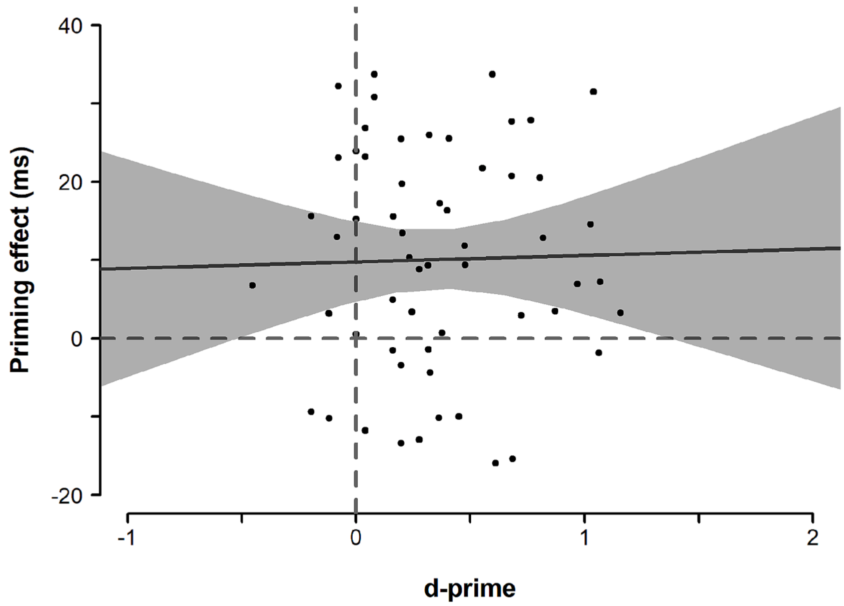

Fig. 4. The Greenwald regression on the masked sagittal condition.

integration at the unconscious level. To confirm and extend these results, we conducted Experiment 2, testing a different conceptual domain.

5. Experiment 2 – Numerical metaphors

The logic behind this experiment was the same as the one behind the first one: to explore the mechanisms underlying masked priming effects, we employed spatial metaphors of numerical operations for dissociating what is both conceptually and linguistically represented – in this case, the metaphorical mapping along a vertical spatial axis – and what instead is only represented in our mind but not in the lexical associations – in this case, the lateral spatialization. The methodology employed in this experiment was very similar to the one used in the first experiment; we summarize the details briefly below. This second experiment was preregistered at https://aspredicted.org/mpv8-t47p.pdf.[2] Following the results of Experiment 1, we hypothesized that spatial words can have a priming effect on the semantic categorization of metaphorically related numerical targets if the prime-target relationship is consciously perceived. When instead it is masked from participants' awareness, we expect the prime to have an effect on congruent targets only if the metaphorical relation is entangled in language, that is, when the mapping occurs on the vertical but not on the lateral axis.

5.1. Methods

In a 2 × 2 × 2 design, participants were randomly assigned to a supraliminal condition ($N = 60$) and a subliminal one ($N = 60$). As in the first experiment, the factors of interest were Prime Visibility (visible/masked), Axis (vertical/lateral), and Congruity (incongruent/congruent). Participants performed a semantic decision task in a priming experiment, in which spatial words were primes and items referring to the semantic sphere of addition or subtraction were targets.

5.2. Participants

We recruited another 120 Italian-speaking participants for this experiment, including both university students and individuals recruited from the local community. Half of them were assigned to the supraliminal condition (37 females, 23 males; mean age of 25;8 with $SD = 8.2$) and the other half to the subliminal one (39 females, 21 males; mean age of 25;5 with $SD = 8.3$). All of them signed a written informed consent approved by the Research Ethics Committee of the University of Trento.

5.3. Stimuli and material

In the priming task, four spatial words were employed as prime items, i.e., *sopra* ("above") and *sotto* ("below") for the vertical axis, and *destra* ("right") and *sinistra* ("left") for the lateral axis. We selected 16 numerical words as target items, eight of which referred to the semantic sphere of addition and the other eight to the domain of subtraction. They were matched for frequency, word length, and grammatical category across the two semantic domains. We avoided using words that might produce orthographic priming (e.g., we excluded all the derivatives from *sottrazione,* "subtraction", to prevent matching with the prime word *sotto,* "below"). Table A2 in the Appendix reports the list of target stimuli, with their corresponding English, translation, Zipf frequency (taken from SUBTLEX-IT, Crepaldi et al., 2016), number of letters, and grammatical category. Each prime word was associated with each target word, resulting in 64 unique trial pairs. Each target was thus paired with a congruent or incongruent prime, presented on the vertical or the lateral axis. Table 3 provides an example of the prime-target relationships for each combination of Axis and Congruity, along with the expected reaction time patterns in the supraliminal and subliminal conditions, based on the linguistic encoding of metaphorical mappings. We repeated each unique prime-target pair six times, obtaining 384 testing stimuli, as in Experiment 1, with 16 additional practice trials.

5.3.1. The visibility task

We maintained the same prime and target words as in the priming experiment and created four non-words, each matching one of our prime words by the initial letter and the word length. We then randomly shuffled letters, obtaining "soart", "dvncre", "sqotz", and "suttbifr" to be paired with "sopra". By combining prime words/non-words and target words, we obtained 128 testing and 12 practice trials, for a total of 140 trials. Half of the testing trials contained a real word as prime, and the other half a non-word; 64 testing trials presented a term referring to the

[2] As explained in detail in the Data Analysis section below, we made a limited number of justified deviations from the preregistered analysis plan.

Table 3
Example of prime-target relationships in Experiment 2 for each combination of Axis and Congruity and expected reaction time patterns in the supraliminal and subliminal conditions.

Axis	Congruity	Prime-target example	Linguistically encoded?	Supraliminal prediction	Subliminal prediction
Vertical	Congruent	*sopra-aumentare* (above-to add)	✓	Faster RTs for congruent than incongruent trials	Faster RTs for congruent than incongruent trials
Vertical	Incongruent	*sopra-diminuire* (above-to diminish)			
Lateral	Congruent	*destra-aumentare* (right-to add)	×	Faster RTs for congruent than incongruent trials	No congruency-related RT difference
Lateral	Incongruent	*destra-diminuire* (right-to diminish)			

concept of addition, and the other 64 to subtraction.

5.3.2. Apparatus

Stimuli were displayed on a macOS laptop, with a 13″ monitor and a refresh rate of 60 Hz, using MATLAB Psychtoolbox-3 (Brainard, 1997; Pelli, 1997; Kleiner et al., 2007). Words were presented in white Arial font (font size 40) against a black background. Responses were recorded through a CyNexo response box based on an Arduino processor. We used a chin rest to ascertain that all participants were at the same distance of approximately 52 cm from the monitor.

5.4. Procedure

The procedure of the priming experiment was the same as Experiment 1, with the only exception of a "*" as the fixation point: we decided not to use the previous "+" to avoid that spatially congruent associations (e.g., a following "addition" target) led to faster responses than incongruent ones (Pinhas et al., 2014). Fig. 5 displays the sequence of screens in the two experimental conditions.

In a go-no go procedure, participants were required to press the button when the target word referred to the concept of addition or subtraction, depending on the instructions. We divided our trials into two blocks – one where participants responded to addition-related item trials and the other where they responded to subtraction-related words – and counterbalanced the order of the two blocks between participants; trials within each block were displayed in a pseudo-randomized order, with the constraint of not presenting two trials with the same target word sequentially.

5.4.1. The visibility task

This procedure was the same as in Experiment 1: participants in the subliminal condition were presented with a sequence of screens identical to the supraliminal condition, but they were instructed to pay attention to the prime word. They were asked to press one of the two buttons of a response pad if they judged the prime item to be a real word and the other button if they considered it a non-word.

5.5. Data analysis

We analyzed the data on the priming experiment and the visibility task following the same protocol employed in Experiment 1, which in this case we preregistered. However, we deviated from the preregistered plan in three respects. First, we excluded participants who verbally reported having seen the prime items in the visibility task, in order to obtain a more homogeneous sample with respect to prime awareness. Second, we did not exclude participants whose error rates exceeded 2 *SDs* above the average, because the only three participants who met this exclusion criterion performed above 90% accuracy, which still reflects a highly accurate performance overall. Third, we decided to conduct our analyses on transformed rather than raw reaction times, in line with common practice in the literature (e.g., Baayen, 2008). To ensure that these deviations and other choices (e.g., using an inverse rather than a log transformation of reaction times) did not affect our results, we conducted a multiverse analysis, following Steegen et al. (2016). We generated different datasets based on alternative inclusion criteria and transformation methods and ran the same analysis protocol on all of them. This analysis revealed no significant differences between datasets, confirming that our findings are robust to these preprocessing decisions. The analysis scripts and full results are publicly available (see the Data availability statement at the end of the paper).

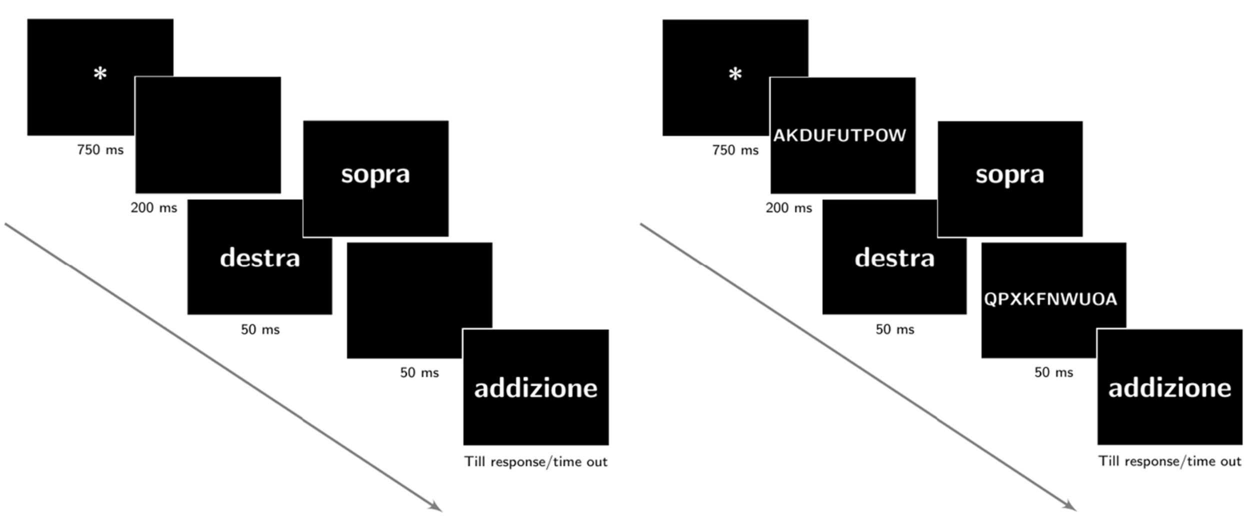

Fig. 5. Example trial procedure in the supraliminal and subliminal conditions.

5.6. Results

After excluding practice and "no go" trials, the overall accuracy in the experiment was 99.7%, while the average response time on accurate trials was 518.2 ms. In the supraliminal condition, the average response time was 508.3 ms, while in the subliminal condition it was 525.4 ms. We excluded five participants from the subliminal group for the following analyses, as they reported having recognized all four prime items. At this point, the database comprised 22,080 data points. After removing error trials, we lost an additional 0.3% of data points, and after excluding individual data points standing at more than 2 *SD* from the subjective mean, we lost a further 4.5%. The final data set comprised 20,132 data points.

At this point of the analysis, raw reaction times in the supraliminal condition presented an average value of 493.6 ms, while in the subliminal condition it was equal to 509.3 ms. Table 4 reports the raw means for all the conditions. As a preliminary observation, we computed the priming effect for each condition. This revealed a facilitation effect driven by congruent trials on both the vertical (17.7 ms) and the lateral (5.7 ms) axes in the supraliminal condition, and on the vertical axis in the subliminal condition (2.5 ms), whereas no effect was detected on the subliminal lateral axis, as predicted (∼ 0).

5.6.1. Linear mixed models of regression

As in Experiment 1, we built a mixed-effects regression model to predict inverse-transformed reaction times by including the interaction between Congruity (incongruent/congruent), Axis (vertical/lateral), and Prime Visibility (visible/masked) as fixed effects and participants' and trials' intercepts as random effects[3]. We dummy-coded our fixed effects by setting the visible condition, incongruent prime-target relations, and the vertical axis as the reference levels for Prime Visibility, Congruity, and Axis, respectively.

The results of are illustrated in Fig. 6. As for Exp. 1, we found a significant three-way interaction between Congruity, Axis, and Prime Visibility ($\chi^2(1) = 4.67$, $p = 0.03$). This interaction came from the following pattern of results. Similar to the previous experiment, participants were faster in responding to congruent rather than incongruent targets when the metaphorical mapping occurred on the vertical axis and the primes were visible, as the main effect of Congruity suggested ($\beta = -0.084$, $SE = 0.007$, $t(20900) = -11.810$, $p < 0.0001$). This facilitation effect diminished when the mapping occurred on the lateral axis with visible primes, as revealed by the interaction between Congruity and Axis ($\beta = 0.059$, $SE = 0.01$, $t(20900) = 5.881$, $p < 0.0001$). Similarly, the effect on the vertical axis decreased when the primes were masked, as shown by the interaction between Congruity and Prime Visibility ($\beta = 0.059$, $SE = 0.01$, $t(20900) = 5.805$, $p < 0.0001$). Although priming was smaller with visible lateral primes and masked vertical primes, the critical finding is that it was significantly reduced when the primes were subliminal and the prime-target mapping occurred on the lateral axis, as suggested by the 3-way interaction of Congruity, Axis, and Prime Visibility ($\beta = -0.032$, $SE = 0.015$, $t(20900) = -2.161$, $p = 0.031$). These results were confirmed by additional preregistered analyses, i.e., two mixed regression models we conducted separately for the supraliminal and the subliminal conditions, and an Anova model we ran on the whole dataset. This latter analysis supported the 3-way interaction between our factors ($F(1, 113) = 3.982$, $p = 0.048$, $\eta p^2 = 0.034$). The results are publicly available (see the Data availability statement at the end of the paper) (Fig. 6).

5.6.2. Measures of awareness

The overall average d-prime value was 0.159 ($SD = 0.311$), which was different from 0 ($t(54) = 3.798$, $p < 0.001$). However, the individual priming effects did not correlate with d-prime values either in the vertical ($t(53) = 1.101$, $p = 0.276$, corr $= 0.15$) or in the lateral condition ($t(53) = 0.662$, $p = 0.511$, corr $= 0.09$). As shown in Fig. 7, the Greenwald regression analysis showed that the priming effect on the vertical axis was not considered to occur entirely outside of awareness since the intercept of the regression line was not significantly above the origin. (The same analysis was conducted for the lateral axis and can be found in the public analysis folder; see the Data availability statement).

This discrepancy with Exp. 1 raises the doubt that both the lack of an effect on the lateral axis in the subliminal condition and the inconsistent regression results may be due to low statistical power. Therefore, since the two experiments presented the same experimental design, we combined the two data sets into a single one to explore more consistently the emergence of priming effects outside of awareness. Results showed that the overall average d-prime value was 0.255 ($SD = 0.357$), which was different from 0 ($t(112) = 7.583$, $p < 0.001$). The individual priming effects did not correlate with the d-prime values either in the linguistically encoded spatial metaphors – namely, the sagittal axis in Exp. 1 and the vertical axis in Exp. 2 ($t(111) = 1.474$, $p = 0.143$, corr $= 0.14$) – or the non-linguistically encoded ones – that is, the lateral axis in both experiments ($t(111) = -0.16$, $p = 0.873$, corr $= -0.02$). As we can observe in Fig. 8, the Greenwald regression methodology showed a significant priming effect on masked linguistically encoded spatial metaphors in the absence of awareness, given that the 95% confidence interval at the intercept lay entirely above the origin.

5.7. Discussion

Similarly to the first experiment, in this second one we investigated which aspects of a word's meaning can be accessed unconsciously by comparing spatial metaphors of numerical operations that can be expressed through language – that is, the metaphorical representation on the vertical axis – with those that are only related conceptually – i.e., the metaphorical mapping on the lateral axis. In line with Exp. 1, our results show that spatial primes activated metaphorically related targets on both the vertical and the lateral axis in the supraliminal condition, while in the subliminal one, this congruence effect was found only on the vertical axis – that is, the spatial mapping entangled in language. However, in this experiment, we found that the priming effect on the lateral axis was less consistent than the one on the vertical axis, independent of the prime's visibility. That is, the effect on the lateral axis, although present in the supraliminal condition, was significantly weaker than the effect on the vertical axis.

We cannot exclude the possibility that the partial awareness of primes contributed to the effect on the vertical axis in this experiment. Although no participant included in the analyses reported having noticed the prime, and the sensitivity index was very low and close to 0, it was not significantly different from 0, and the Greenwald regression did not indicate a significant priming effect at d' = 0. As discussed in more detail in the Limitations section below, the question of whether the effects observed in our experiment and in the existing literature are fully conscious or only partially so remains a challenging issue, and our data have limitations in providing a definitive answer. Nevertheless, we do not believe that this limitation undermines our main finding, namely, that the congruence effect in the subliminal condition was observed only on the metaphorical axis encoded in language. Importantly, when we combined data from Exp. 1 and 2, thus increasing our statistical power, we observed that the priming effect did not correlate with d-prime values and emerged on the linguistically encoded axes at $d' = 0$. This result suggested that, when considering a larger sample size, the significant priming effect did occur outside of awareness. This finding further supports the hypothesis that metaphorical mappings can be processed outside of consciousness only if the mapping between the concrete source domain and the abstract concept is explicitly represented in language use.

[3] m ←lmer(−1000/RT ∼ congruity*axis*PrimeVisibility + (1|subjectNum) + (1|target).

Table 4
Raw reaction times for each condition.

Supraliminal				Subliminal			
Axis	*Congruity*	*Mean RTs*	*SD*	*Axis*	*Congruity*	*Mean RTs*	*SD*
vertical	con	483.8	102.4	vertical	con	506.6	99.7
vertical	inc	501.5	101.4	vertical	inc	509.1	90.9
lateral	con	491.8	101.3	lateral	con	510.9	93.9
lateral	inc	497.5	99.9	lateral	inc	510.4	93.9

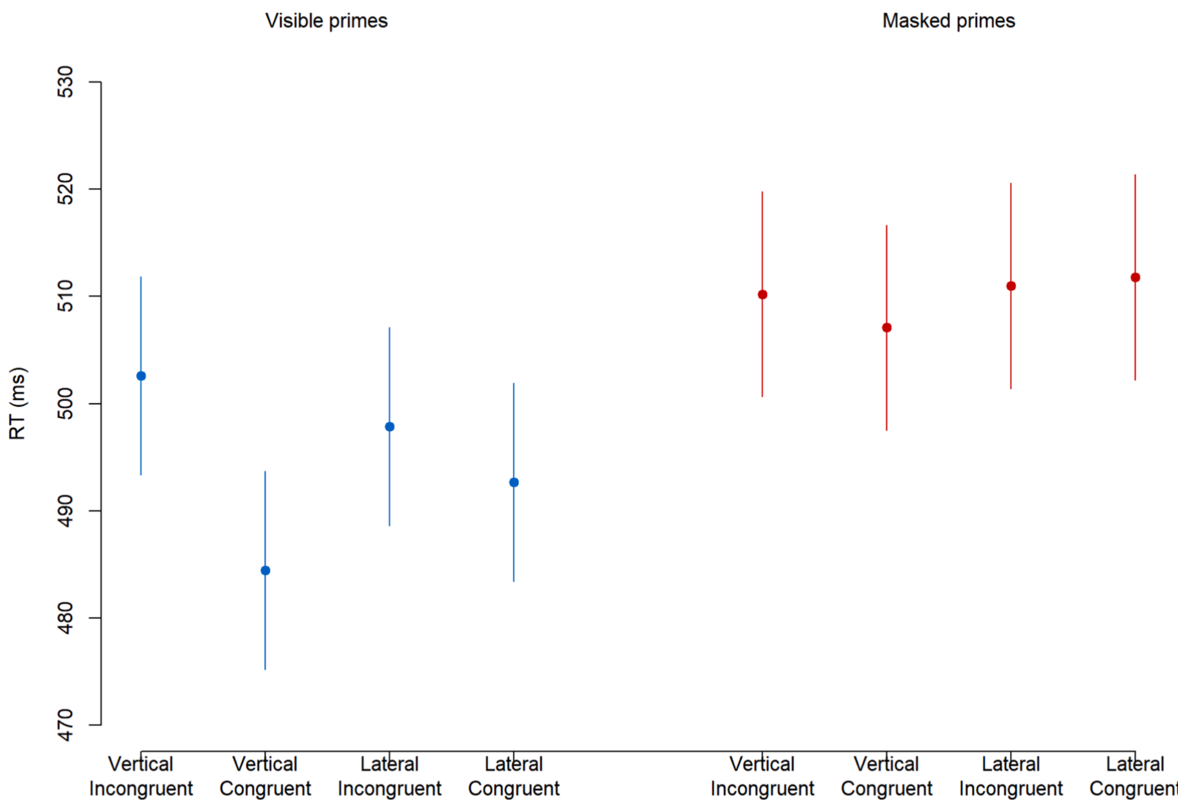

Fig. 6. Estimated reaction times (RTs) from a mixed-effects model including a three-way interaction between Prime Visibility (visible/masked), Congruity (incongruent/congruent), and Axis (vertical/lateral). Points represent model-predicted RTs for each condition, with vertical lines indicating standard errors.

6. General discussion

This study investigated the boundaries of unconscious versus conscious processing in the semantic domain through a masked priming paradigm. Research on unconscious semantic processing has long been polarized: on one side, some studies suggest that words can be processed up to their semantic level even when they are not consciously perceived (e.g., Ansorge et al., 2010; Dehaene et al., 1998; Sklar et al., 2012); on the other side, evidence has been presented against this claim (e.g., Moors & Hesselmann, 2019; Rabagliati et al., 2018; Tal & Mudrik, 2024). However, this dichotomous perspective fails to capture the complexity of existing data and leaves unanswered the question of what types of semantic information can be processed unconsciously – and under which conditions. Here, we investigated in more fine-grained detail which aspects of a word's meaning can be accessed from semantic memory without conscious awareness. Specifically, we tested the SPIW model, which proposes that low-level, simple semantic associations can be processed unconsciously, whereas high-level semantic relationships require conscious access. We used metaphorical relationships as a testbed, because they are widely regarded as prototypical examples of high-level semantic associations (e.g., Chien et al., 2023; Mudrik et al., 2014). More precisely, we focused on conceptual metaphors, as they are often considered a fundamental and largely unconscious aspect of human cognition (e.g., Boroditsky, 2000; Casasanto & Bottini, 2014; Clark, 1973; Dehaene et al., 1993; Gentner et al., 2001; Lakoff & Johnson, 1980; Tversky et al., 1991), a position that partially contrasts with the SPIW model.

Across two experiments, we examined spatial metaphors of time and number. A large body of literature shows that these two abstract concepts are intrinsically linked to spatial representations (e.g., Boroditsky, 2000; Casasanto & Bottini, 2014; Cienki & Müller, 2008; Clark, 1973; Dehaene et al., 1993). Both can be mapped along two spatial axes. Time can be mapped along the sagittal axis (e.g., from behind to front) or the lateral axis (e.g., left to right) (e.g., Boroditsky, 2000; Casasanto & Jasmin, 2012; Saj et al. 2014; Santiago et al., 2007; Tversky et al., 1991), while numbers can be mapped along the vertical axis (e.g., from bottom to top) or the lateral axis (e.g., from left to right) (e.g., Dehaene et al., 1993; Loetscher et al., 2010; Mathieu et al., 2016; Viganò et al, 2024; Zorzi et al., 2002). Consequently, given that we represent numbers on these spatial axes, we can also metaphorically move along them when performing mathematical operations such as addition or subtraction (e.g., Fischer & Shaki, 2014; Knops et al., 2009; McCrink et al., 2007). Importantly, both temporal and numerical representations share a crucial feature: only one spatial mapping – namely, the sagittal axis for temporal metaphors and the vertical axis for numerical metaphors – is encoded in language (e.g., Clark, 1973; Eikmeier et al., 2015;

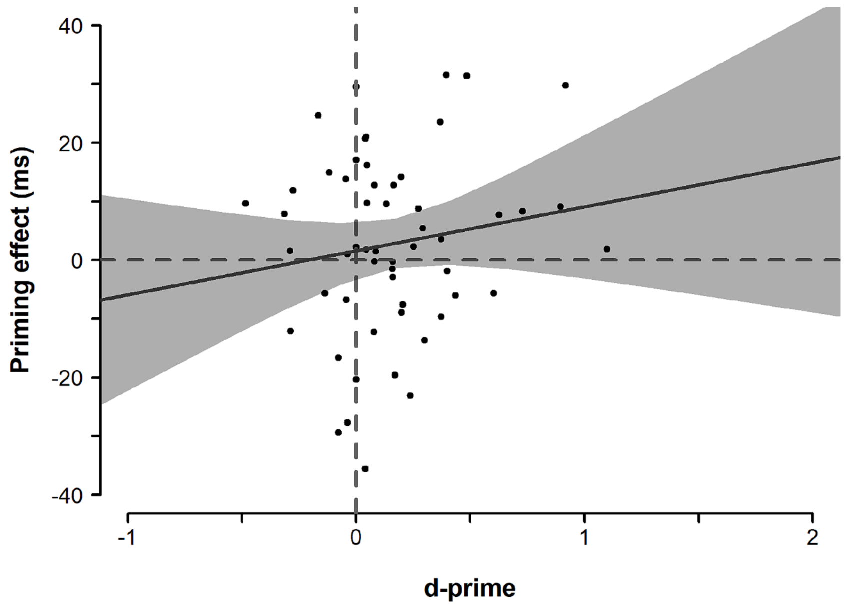

Fig. 7. The Greenwald regression on the masked vertical condition.

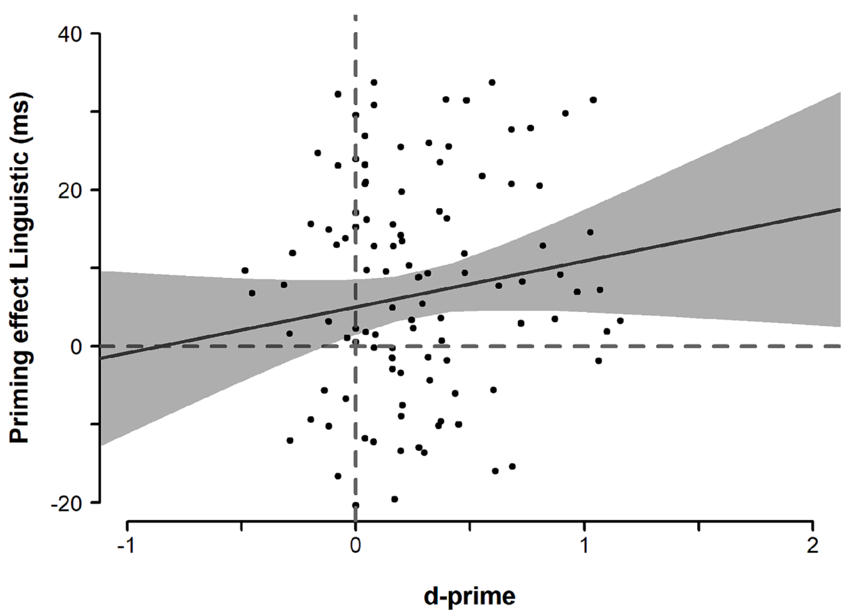

Fig. 8. The Greenwald regression on the masked Linguistically Encoded Metaphors.

Haspelmath, 1997; Pitt & Casasanto, 2022). For example, we can say "I'm looking forward to our next meeting!" or "taxes won't ever go down", but no equivalent linguistic expressions exist for the lateral mapping of either concept.

In the present study, we conducted two priming experiments in which spatial words were used as primes and temporal or numerical terms as targets, and participants performed a semantic categorization task on the targets. In each experiment, we manipulated the visibility of the prime across two groups of participants. Results showed that semantic priming between metaphorically related words emerges when the prime is visible to participants, for both types of metaphors and along both spatial axes. However, under masked priming conditions, priming effects occurred only when the metaphorical associations are expressed in common linguistic patterns – namely, along the sagittal axis for temporal metaphors and the vertical axis for numerical metaphors. In contrast, both temporal and numerical metaphorical relationships along the lateral axis (with a left-to-right orientation) failed to emerge when participants were not fully conscious of the prime.

Our results thus suggest that consciousness may be necessary for high-level conceptual associations such as metaphorical space–time and space-number mappings – unless the relationship between the two words is also expressed in language. That is, even widespread and well-established spatial–temporal and spatial-numerical mappings, which have been robustly reported in countless experiments and seem to emerge spontaneously when people think about time and numbers (e.g., Casasanto & Jasmin, 2012; Mathieu et al., 2016; Werner & Raab, 2014), were not accessible under subliminal conditions if they are not linguistically encoded. In other words, even if in our mind the left is associated with the past and such association emerges spontaneously in our gestures and body or eye movements, when we think about temporal relationships the prime word "left" does not facilitate a temporal judgement on the word "past" when it is masked. This null effect holds even if the priming effect takes place when the prime is visible and even if the corresponding metaphorical mapping on the sagittal axis ("back" – "past") does emerge when the prime is masked.

How to account for this finding? One possibility, in line with the SPIW hypothesis, is that metaphorical mapping does indeed require a larger integration window than simple associative ties in semantic memory and, therefore, needs conscious access. However, strong linguistic links may lead to stronger semantic links, and therefore to a reduction of the integration window needed to process some metaphorical relationships. This interpretation could also explain why, in the supraliminal condition, the priming effect is (at least in the case of numbers) stronger for the linguistically encoded metaphor compared to the non-encoded one. However, if this were the case, most conceptual metaphors should be processed unconsciously, since the large majority of them are represented in language use (Casasanto & Bottini, 2014; Lakoff & Johnson, 1980). Indeed, the lateral spatial–temporal and spatial-numerical mapping is more the exception than the rule, given that one of the characteristics of conceptual metaphors is their quasi-universality and common everyday use across languages (Boroditsky, 2001; Clark, 1973; Gentner et al., 2001). This would call into question the recent findings by Chien et al. (2023) and would require a more precise operationalization of metaphorical relationships (as well as high-level semantic relationships) within the SPIW model and theories of consciousness in general.

Alternatively, we argue that the absence of a subliminal effect for overlearned, culturally ubiquitous, and often spontaneous conceptual associations – such as space–time and space-number mappings that are not represented in language – not only suggests that unconscious semantic processing is limited in scope, but also casts doubt on whether successful priming in language-based associations reflects truly semantic processing, above and beyond metaphorical priming. Indeed, the congruence effect may happen instead at the lexical level, with subliminal words activating statistically related wordforms without activating the related concepts. A comparable effect can be found in experiments testing unconscious semantic priming across different languages: in a neuroimaging experiment, animal and non-animal masked words were presented in Spanish and Basque to bilingual participants (Sheikh et al., 2019). Using a machine learning algorithm, successful categorical classification was found in a network of language-related areas. However, this was true only for within-language decoding, whereas training the classifier in one language and testing it in the other led to a null result. This finding suggests a lexical rather than a semantic effect (see Mudrik & Deouell, 2022, for a similar interpretation). Indeed, a comparable (null) result was obtained by Chien et al. (2023) when primes were temperature-related words and targets were temperature-related pictures (a condition in which the semantic link was not metaphorical): conceptual priming was found only in the supraliminal condition.

Taken together, all these findings suggest that even common linguistic semantic priming (e.g., cat → dog), when unconsciously proven, derives from the activation of wordform-wordform relationships without the activation of conceptual (non-linguistic) representations, a situation akin to the one depicted in the famous "Chinese room" mental experiment (Searle, 1980). In this philosophical experiment, a man sits in a room, receiving messages in Chinese. Though he does not understand the language, he responds by following strict rules that dictate how to combine the characters. His replies seem meaningful, as if he knew Chinese. Yet, he is merely manipulating lexical associations without grasping their meaning. Indeed, if the man was warned of imminent danger and told to leave the room, he might compose an appropriate response, but he would not exit the room, unaware of the message's true significance. Similarly, under unconscious processing, linguistic symbols can be associated with each other if they follow statistical patterns without, however, activating the underlying conceptual structure that is necessary for meaningful language comprehension. Resorting to a more contemporary example, this might be what happens in current Large Language Models (LLMs), but further studies are needed to directly test this hypothesis.

7. Limitations

Our study has some limitations. First of all, we selected a sample size which was larger than the average reported in the previous literature, but we did not conduct a proper a-priori power analysis. Moreover, our results are based only on the use of words as subliminal primes. Hence, we cannot rule out that a positive effect on the lateral axis could be found using pictorial primes instead of linguistic ones. For instance, a masked arrow could be presented as a prime, pointing to the left or the right. The masked arrow, even if subliminal, might cause a shift of attention on one side or the other, which then could bias the response (e.g., future or past). It has indeed been shown that arrows – as well as other attention-capturing items such as stimuli appearing on one side or the other of a fixation cross – can direct attention even when presented masked (e.g., McCormick, 1997; Sumner et al., 2006; Vorberg et al., 2003; Zhang et al., 2012). Furthermore, as we reviewed before, attentional biases can influence tasks related to the Mental Time and Number Lines (e.g., Masson & Pesenti, 2014; Mathieu et al., 2016; Stocker et al., 2015; Werner & Raab, 2014). It may be that words such as "right" and "left" are not enough to shift attention if presented subliminally. Indeed, in a previous study, a masked central word ("left" or "right") did not yield the expected behavioral or electrophysiological signatures for attentional shifts, although an N400 effect suggested that the word was processed (Baier & Ansorge, 2019). If unconscious priming can be achieved with pictorial attention-capturing stimuli, it would reinforce the finding that, when thinking about time, number, or arithmetic, people spontaneously engage spatial-attentional schemas to organize and retrieve such information, along mental lines (Casasanto & Jasmin, 2012; Loetscher et al., 2010; Saj et al., 2014; Viganò et al, 2024), and that a particular attentional state – i.e., attention momentarily shifted to the left or right – can influence this process.

Although this might be an interesting finding, it would not represent a case of semantic integration like the ones reported in the introduction or intended by Mudrik et al. (2014), as well as other scholars reasoning on the limits of unconscious processing (e.g., Chien et al., 2023; Moors & Hesselmann, 2019; Nakamura et al., 2018; Rabagliati et al., 2018; Van den Bussche et al., 2009, 2012; Zher-Wen & Yu, 2023). That is because the integration of different conceptual domains in low-dimensional spatial–temporal or spatial-numerical attentional maps would happen in plain consciousness (i.e., thinking at the target) and would simply be perturbed by subliminally induced attentional shifts. For this reason, we think that our approach based on words is still a better test of the SPIW Hypothesis – and, indeed, of the hypothesis that conceptual knowledge can be activated by unconscious words. Moreover, our positive results on the sagittal MTL and the vertical MNL cannot easily be explained in terms of mere attentional shifting, since there is apparently no reason to predict (and no evidence) that words such as "up" and "down" should be more effective in shifting attention than "left" and "right" when presented subliminally.

Another limitation is that our objective measure of awareness of the prime combined with the priming effect (i.e., the Greenwald regression; Greenwald et al., 1995) indicated unconscious priming in Experiment 1 and when the two experiments were combined, but not in Experiment 2. At best, this could be explained by the lack of power in the two single experiments, which has been overcome with the combined dataset. However, it could be that, even if participants reported not having seen the prime during the experiment, we find ourselves in a case of partial awareness (Kouider & Dupoux, 2004). Importantly, interpretational problems have been raised regarding the Greenwald regression methodology itself (e.g., Goldstein et al., 2022), highlighting that conclusions about unconscious processing based on this approach should be drawn with caution. There is an ongoing debate about the best way to measure awareness, and fully engaging with this discussion goes beyond the scope of this paper, though we recognize it as highly relevant (e.g., Fisk & Haase, 2023; Meyen et al., 2022; Moors et al., 2019; Shanks, 2017; Sklar et al., 2021). At the very least, our data still support the conclusion that ubiquitous and overlearned metaphorical conceptual relationships need full access to consciousness to arise.

Finally, in Experiment 2, but not in Experiment 1, the language-encoded mapping produced a stronger priming effect also in the conscious (unmasked) condition. It is still unclear why this is the case. However, in both experiments, the priming effect for non-language-based mapping was highly significant in the unmasked condition and absent in the masked condition. We tend to exclude the possibility that this null result is due to the fact that the effect is rather small and hard to detect, since it remained undetected even when the two experiments were combined, doubling the sample size.

8. Conclusions

In sum, when placing our results in the current debate on unconscious semantic processing, we can observe that ubiquitous and overlearned metaphorical conceptual relationships need full access to consciousness to arise. This result is in line with the hypothesis that higher-level conceptual integration cannot be implemented outside of consciousness (Chien et al., 2023; Hirschhorn et al., 2021; Mudrik et al., 2014). When such metaphors are presented subliminally, the prime and the target words need not only to be related conceptually but also to be encoded in language for priming to arise. This opens up the possibility that the mere activation of related wordforms (i.e., at the lexical level) underlies this effect as well as all the unconscious semantic priming effects measured with words in the previous literature, without any involvement of genuinely semantic information.

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CRediT authorship contribution statement

Chiara Saponaro: Writing – original draft, Formal analysis, Data curation, Conceptualization. **Andrea Nadalini:** Writing – review & editing, Formal analysis, Data curation, Conceptualization. **Daniel Casasanto:** Writing – review & editing, Conceptualization. **Davide Crepaldi:** Writing – review & editing, Supervision, Formal analysis, Conceptualization. **Roberto Bottini:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization.

Appendix

Table A1
Complete list of the target words by temporal dimension, with the corresponding English translation, length (number of letters), class (N = noun, ADJ = adjective, ADV = adverb, V = verb), Zipf frequency (taken from SUBTLEX_IT, Crepaldi et al., 2016).

Past					Future				
Target	*Eng*	*Length*	*Class*	*Frequency*	*Target*	*Eng*	*Length*	*Class*	*Frequency*
prima	earlier	5	ADV	6.042	dopo	later	4	ADV	5.792
ieri	yesterday	4	ADV	5.239	domani	tomorrow	6	ADV	5.410
passato	past	7	N	5.288	futuro	future	6	N	4.936
scorso	previous	6	ADJ	4.661	successivo	next	10	ADJ	3.848
		5.5		5.308			6.5		5.000

Table A2
Complete list of the target words by numerical operation, with the corresponding English translation, length (number of letters), class (N = noun, ADJ = adjective, ADV = adverb, V = verb), Zipf frequency (taken from SUBTLEX_IT, Crepaldi et al., 2016).

Addition					Subtraction				
Target	*Eng*	*Length*	*Class*	*Frequency*	*Target*	*Eng*	*Length*	*Class*	*Frequency*
addizione	addition	9	N	2.212	riduzione	reduction	9	N	3.414
maggiore	greater	8	ADJ	4.773	minore	minor	6	ADJ	4.082
più	more	3	ADV	6.383	meno	less	4	ADV	5.429
aumentare	to increase	9	V	3.936	diminuire	to diminish	9	V	3.328
sommare	to sum up	7	V	2.094	ridurre	to reduce	7	V	3.813
mettere	to put	7	V	5.066	togliere	to remove	8	V	4.329
aggiungere	to add	10	V	4.133	levare	to remove	6	V	3.291
aumento	increase	7	N	4.113	diminuzione	to decrease	11	N	3.004
		7.5		4.089			7.5		3.836

Data availability

Data and statistical analysis scripts are available at: https://osf.io/4j75s/overview.

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