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RUNNING HEAD: EEG Coherence in Metaphor Comprehension

Conceptual Metaphors and Embodied Cognition: EEG Coherence Reveals Brain Activity

Differences between Primary and Complex Conceptual Metaphors during Comprehension

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Abstract

Because cognitive linguists assert that primary and complex conceptual metaphors are theoretical constructs with a plausible yet uncertain psychological reality, we investigated if and how EEG coherence would differ between these two categories during comprehension. We formalized an algorithm of conceptual metaphor processing for the purpose of hypothesis testing, before collecting EEG data from 50 normal adults, looking for condition-specific EEG coherence patterns. Results confirm the psychological reality of these two metaphor categories. However, they also support alternative conceptions regarding the algorithm and nature of complex metaphors, developed and discussed in this article.

Keywords:

EEG Coherence, Metaphor, Embodiment, Primary, Complex, Semantics

Introduction

Conceptual metaphors everywhere

A central claim within cognitive linguistics (Lakoff & Johnson, 1999) and psychoanalysis (Lacan, 1966) is that our conceptual system relies heavily on conceptual metaphor, a keystone mechanism in meaning elaboration. We use conceptual metaphors continuously, intuitively, and unconsciously, in all possible human activities, including science, literature, and art. As a research topic related to the way we think and communicate, conceptual metaphors therefore represent a node that connects multiple fields, including, but not limited to, cognitive psychology, cognitive linguistics, translatology, neurolinguistics, and logopaedics.

Conceptual metaphors are “mental devices” for thinking and communicating about abstract conceptual domains in terms of concrete, or at least different, conceptual domains (substitution), and for thinking and communicating faster and intuitively through the conflating of semantic features into new conceptual compounds (condensation). Conceptual metaphors are grounded on neural networks’ structure, logics, and properties (Schnitzer & Pedreira, 2005), linking conceptual compounds through their shared semantic features for producing a different and richer meaning.

In the simple sentence “Prices are rising,” for instance, the conceptual metaphor [INCREASING is RISING] locates on the word “rising,” expressing figuratively that prices are increasing rapidly, significantly, and enduringly. This conceptual metaphor establishes semantic connections between a target domain (INCREASING) with another, apparently remote or unrelated source domain (RISING), through shared semantic subcomponents (FROM LOW TO HIGH). Consequently, an abstract conceptual domain (INCREASING an amount) is understood in terms of a tangible conceptual domain (RISING, a bodily action): this is substitution.

Additionally, semantic features from the source domain are added into the picture (RAPIDLY +

SIGNIFICANTLY + ENDURINGLY) for meaning enrichment: this is condensation. The conceptual metaphor device therefore involves a mechanism of substitution plus a usually sought-after mechanism of condensation – on which often relies poetry, humor, colorfulness of expression, and conceptual power.

Mental structures and mechanisms: The algorithm of a conceptual metaphor

The following section introduces a new theoretical development describing, in terms of both structure and functioning, possible and plausible algorithms behind conceptual metaphor processing. This new cognitive model of conceptual metaphor processing adds the theoretical tools required in the current study for understanding and analyzing conceptual metaphors, and for falsifying hypotheses in an experimental setting.

Algorithm components. Technically speaking, a conceptual metaphor involves eight entities linked together in a network.¹ These eight elements can be divided among three sets of components that define a three-level hierarchical structure: (i) **two surface components**, visible in the formulated sentence, that manifest the conceptual metaphor; (ii) **two actualized components**, hidden in the conceptual representations behind the sentence, that anchor the conceptual metaphor in the surface components; and (iii) **four virtual components**, hidden in the conceptual system of the individual who produces or understands the metaphor, that form the conceptual background of the metaphor.

¹ In the case of a standard and frequent metaphor, an idiomatic or lexicalized status is acquired and the figurative meaning may not be processed through the metaphor device described here, but directly accessed as a lexical entry stored in long term memory. See for instance Hillert (2004).

The **two surface components (Level 1)** are a **context**, or subject, traditionally called “topic” (a word, group of words, or, eventually, group of sentences, e.g. PRICES), and a **carrier**, or predicate, traditionally called “vehicle” (a word or group of words, e.g. RISING).

The **two actualized components (Level 2)** are substituted domain and carrier domain. **Substituted domain** is the conceptual components of the context. The actualized context is considered as a substitution, because only through context substitution can the meaning of the carrier shift from literal to figurative. Traditionally, however, the substitution is incorrectly located on the carrier, the metaphor being abusively considered to shift the sentence meaning from literal to figurative instead of the carrier's meaning.. Words expressing the conceptual components usually related to PRICES can be money, work, effort, purchase, goods, food, increase, decrease, etc. **Carrier domain** is the conceptual components of the carrier – depending on their theory, cognitive linguists would refer to this as either the “source domain” (Lakoff & Johnson, 1999) or “input space 1” (Fauconnier, 1994; Fauconnier & Turner, 2002). Words expressing the conceptual components usually related to RISING can be movement, position change, from low to high, rapid, important, lasting, etc.

The **four virtual components (Level 3)** are ghost domain, context domain, common domain, and metaphor synthesis. **Ghost domain** is the conceptual components specific to the literal meaning of the word expected in the given context in place of the carrier currently observed – depending on their theory, cognitive linguists would refer to this as either the “target domain” or “input space 2”. We poetically named this expected literal carrier “ghost,” because it does not manifest its presence at the first two levels but nevertheless exists at Level 3 as a literal representation usually associated to the context via semantic relatedness. Words expressing the conceptual components usually related to INCREASING can be amount, adding, from low to high, etc. **Context domain** is the conceptual components specific to the context normally

expected for the given carrier's literal meaning. In this example, words expressing the conceptual components usually related to PERSON can be alive, animated, body, movements, actions (including rising), positions, etc. **Common domain** is the conceptual components common to the carrier and the "ghost"; traditionally called "ground." Fauconnier and Turner (2002) would refer to this as the "generic space." The common domain, which allows semantic class inclusion to occur, becomes salient during metaphor comprehension due to the simultaneous activation of the carrier and ghost domains. It has been suggested that the content of the common domain determines the degree of metaphoricity: the greater the number of its appropriate semantic features, the better the metaphor (M. G. Johnson & Malgady, 1979; Tourangeau & Rips, 1991). An example from our illustration case is FROM LOW TO HIGH. Finally, **metaphor synthesis** is the inferred meaning combining semantic subcomponents from the carrier and ghost domains to produce an enriched figurative meaning. Examples here would be RAPID, SIGNIFICANT, AND ENDURING INCREASE (carrier domain: rising is a rapid, qualitatively significant, and enduring change of position, but its application domain is human body movement; common domain: from low to high, establishing the necessary link between domains in order to allow for substitution and produce condensation; the resulting enrichment of the literal meaning "increasing" is rapid, significant, and enduring increase). The algorithm of a conceptual metaphor is summarized in Figure 1.

(FIGURE 1 about here)

Functioning of the algorithm. The figurative meaning generated through a conceptual metaphor occurs because of three events: a substitution of the context, making the carrier's literal meaning impossible; a series of semantic conflicts or mismatches triggered by the context substitution; and the existence of a super-ordinate semantic category including both the carrier domain and the ghost domain. Semantic mismatches, represented by red and orange arrows in

Figure 1, occur between Levels 2 and 3 (respectively between the substituted domain and the context domain, on the one hand, and between the carrier domain and the ghost domain on the other hand) as well as within Level 3 (between the context domain and the ghost domain). These semantic mismatches force the system into a compromise, in order to resolve the impossibility of the literal meaning. By taking into account all constraints, both in the linguistic input (stimulus) and in the semantic network structure (the semantic system stored in long-term memory), the emerging meaning of a conceptual metaphor is created. This phenomenon does not occur at Level 2 (behind the sentence), but at Level 3 (within the conceptual system of the individual). For this reason, conceptual metaphor is believed to pertain to the core of human psychology, rather than being a mere rhetorical figure; if the conceptual background is impaired, for instance following a stroke, or insufficiently elaborated, as in the developing conceptual system of a child, the ability to grasp the figurative meaning of a metaphor will be limited or impossible.

Static aspects. In the sentence “Prices are rising,” the substituted domain at Level 2 (AMOUNT) refers to the ghost domain INCREASING at Level 3 (the literal meaning possibly encountered in the given context AMOUNT), whereas the carrier domain at Level 2 refers to the context domain PERSON at Level 3 (the contextual domain more likely associated to the given carrier domain RISING). Both expected conceptual domains at Level 3 (INCREASING and PERSON) are supposed to be automatically activated (at a subliminal level) as a consequence of lexical access and semantic relations existing between words in the mental lexicon. In other words, the literal expectations corresponding to the sentence components are naturally processed in the subconscious as a result of the wiring between semantic representations in long-term memory (see for instance the study of Pynte, Besson, Robichon, and Poli (1996) on the course of metaphor processing). Because prices are not persons, they cannot perform the physical act of rising: this is the first semantic impossibility (i.e. the first mismatch) existing between the

substituted domain and the context domain. Similarly, because rising is a bodily action, it is not supposed to be interchangeable with an increase, which means the augmentation of a quantity (a person does not increase, only his or her attributes can, for instance size, knowledge, age, etc.). This is the second mismatch, occurring between the context domain and the ghost domain. These first two mismatches (red arrows in Figure 1) forcefully constitute a final impossibility to the system: “Prices are rising” cannot be understood literally, i.e. as if “Prices” were “persons.”

Finally, a third semantic mismatch occurs between the carrier and ghost domains (orange arrow in Figure 1). This third mismatch, however, is weakened by the sharing of semantic features (common domain) between the two conflicting domains: FROM LOW TO HIGH (common domain). Therefore, a figurative escape becomes possible thanks to the existence of semantic relatedness between the carrier and ghost domains. If the common domain did not exist, a conceptual metaphor would be impossible, and the figurative sentence would be meaningless, both literally and figuratively (for example, “The spoon died”). With an appropriate context, such as e.g. engine instead of spoon (“The engine died”), the conceptual metaphor [CEASING TO FUNCTION is DYING] becomes possible thanks to the existence of a common domain (an engine and a living being are both mechanisms, with life being possibly understood as the functioning of this mechanism).

Dynamic aspects. The structure described in Figure 1 has its own dynamics, especially during comprehension, which is at least partly constrained by the linear characteristics of language: information processing unfolds according to the sequence of words, starting with the first word and continuing through time with the subsequent words. Consequently, metaphors are oriented. When first understanding the word “prices,” semantic possibilities are ruled out and semantic expectations get privileged. As a result, the ghost domain INCREASING is activated subliminally, “increasing” being more probably associated to its prime “prices” than to the carrier

domain RISING,² normally related to the bodily action of a person. When the word “rising” gets processed, the system needs to actualize its expectations against reality and faces a series of mismatches that need to be resolved. Backward mismatches on the context domain PERSON (red arrows in Figure 1) are qualitatively secondary in the process, because expectations have already been made on the ghost domain during the processing of “Prices.” Although backward mismatches might require additional computing resources if they need to be resolved, it is more likely that they will remain unresolved and simply serve to dynamically reinforce the focus on the forward mismatch between the ghost domain and the carrier domain (orange arrow in Figure 1). Therefore, backward mismatches help inhibit the possibility of a context domain “PERSON.” Thanks to the existence of a common domain linking the ghost and carrier domains, the forward mismatch between these last two domains gets converted into a natural pathway to figurative resolution. Therefore, according to Figure 1, the system is not forced to engage in a literal resolution first (although some literal expectations might be built during the stimulation stage). It privileges the figurative alternative, because the shortest pathways that exist in its internal wiring (literal meaning) are in this situation inhibited by semantic conflicts.

Conceptual metaphor: A device for embodied cognition?

Conceptual connectivity in our mind is not haphazard, but appears rather to be constrained by our bodily experience in the world (Gibbs, Lenz Costa Lima, & Francozo, 2004). This is probably one of the most intriguing and interesting aspects of conceptual metaphors: they help ground our cognition in our body and therefore represent a tool for investigating the representational

² The strength of the relation might be modulated by conventionality. Therefore, conventionality may determine how a linguistic metaphor is being processed: lexically or metaphorically?

structure of our embodied mind. Johnson (1997), for instance, has pointed out that the regular co-occurrence of subjective experiences and sensory-motor experiences in our life naturally produces new connections in our representational system, between the representations of the co-occurring events. Such conceptual connections generated from our experience as embodied beings in the physical world help structure the way we think. In other words, how human beings move their body and perceive and interact with surrounding objects and beings will naturally influence the way they elaborate and understand meaning.

Grady (1997, 2005) coined the term “primary metaphors” for conceptual metaphors directly based on universal bodily experiences. He suggests that such primary conceptual metaphors are atoms or elementary metaphors. They are embodied, i.e. they result from the co-occurrence of everyday subjective and sensory-motor experiences, for example “I see what you mean” [UNDERSTANDING is SEEING], “they have a warm relation” [AFFECTION is HEAT SENSATION], and “my blood froze” [FEAR is COLD SENSATION]. Furthermore, such metaphors are universal, i.e. they can be shared by all humans independently of geographical or cultural origins, due to identical experiences in the physical reality. For instance, the conceptual metaphor behind the sentence “Prices are rising” can be considered as a primary metaphor (rising is a bodily experience shared by all mankind).

Grady (1997, 2005) and Lakoff & Johnson (1999) have suggested that primary metaphors may be combined into complex conceptual metaphors. If primary conceptual metaphors are seen as atoms, complex conceptual metaphors can be understood as molecules. Through integrative processes, possibly similar to semantic blending (Fauconnier & Turner, 2002), complex conceptual metaphors are supposed to combine at least two primary metaphors into a larger conceptual structure (which may additionally include commonplace knowledge such as cultural models and folk theories). Complex conceptual metaphors are therefore believed to be indirectly

embodied through their primary metaphor constituents (Lakoff & Johnson, 1999). The conceptual metaphor behind the sentence “Negotiations are on track” (Figure 2), for instance, can be categorized as complex because it relies on two primary metaphors: Metaphor 1 [PROGRESSING is HEADING TOWARDS A DESTINATION] + Metaphor 2 [PROGRESSING is FOLLOWING A PATH]. Because a possible ghost domain for negotiations is PROGRESSING, and because the two carrier domains (HEADING + FOLLOWING) involve bodily activities, a plausible common domain appears to be MOVEMENT, and a possible metaphor synthesis of this compound structure is “PROGRESSING ON A PATH TOWARDS A DESTINATION.” Compared to the processing of primary conceptual metaphors, complex conceptual metaphors will therefore involve additional steps, namely processing n primary metaphors in parallel instead of one and subsequently integrating the figurative meaning of these n primary metaphors into a semantic synthesis. The algorithm is summarized in Figure 2.

(FIGURE 2 about here)

An alternative to the preceding analysis supposes a direct processing through abstract representations of reality instead of mediation through primary metaphors. In such a case, the complexity of the input concept (carrier domain), manifested in the example “Negotiations are on track” by a dual meaning (“engaged” + “directed”), will be processed within the same metaphor device. In the previous situation, two metaphor devices were required to process separately and in parallel the carrier domain’s two semantic aspects. Though the metaphor synthesis is slightly different (ENGAGED AND DIRECTED PROGRESSION), the overall meaning is preserved. The notions of “progression” (ghost domain) and “trajectory = launch + direction” (carrier domain) both share the notion of “motion” (common domain) instead of “movement.” The concept of motion refers to physical objects evolving in space, while the concept of movement refers to a bodily action; the first concept is abstract, but the second one is embodied. In other

words, the algorithm of an abstract conceptual metaphor would be identical to that of a primary conceptual metaphor, as shown in Figure 3. The nature and complexity of the semantic inputs would however differ (abstract/complex concepts instead of sensory-motor representations).

(FIGURE 3 about here)

This demonstration shows that complex conceptual metaphors could rather be conceived of as *abstract* conceptual metaphors, implying that the pertinent category opposition may not be between simple and complex conceptual structures built of the same materials (primary conceptual metaphors), but between embodied and abstract semantic systems – i.e. between two knowledge systems, one concerned with procedural concepts stored in the form of sensory-motor representations, and the other one concerned with verbal, abstract concepts (Sabsevitz, Medler, Seidenberg, & Binder, 2005).

Psycholinguistic research has shown that conceptual abstractness (also referred to as “concreteness” or “imageability”) influences both recall duration and understanding difficulty (Barry & Gerhand, 2003; Gerhand & Barry, 2000; Parker & Dagnall, 2009). Therefore, equivalent behavioral consequences should be observed with complex processing structures and abstract concepts because increased difficulty is present in both cases. For this reason, it will be difficult to differentiate between the two theoretical alternatives with behavioral tests that probe processing speed and understanding clarity. We can try, however, to reach a conclusion with neuroscience methods that directly probe brain activity, if we accept the premise that processing verbal abstract knowledge and procedural embodied knowledge will result in different brain activity patterns.

The aim of the current study, therefore, is to use experimental data – obtained with advanced technical and methodological tools (EEG coherence analysis, statistics) – to document

theoretical assertions made by cognitive linguists (Grady, 1997, 2005; Lakoff & Johnson, 1999) regarding the processing of complex metaphors through primary metaphor bricks.

About EEG coherence

EEG coherence is the oscillatory coupling between two channels occurring with several oscillations in a narrow frequency band for a given period of time (Lachaux, Rodriguez, Martinerie, & Varela, 1999). Coupling is assumed if oscillations are systematically correlated in amplitude and phase. Therefore, EEG coherence measures electric signal correlation between regions and over trials, as shown in Figure 4. It can be understood as phase stability between two EEG signals, in a given time window and a given frequency band.

(FIGURE 4 about here)

Two types of coherent activity can be detected in oscillatory signals picked up from two brain or scalp areas: synchrony and asynchrony. Synchrony involves systematic phase locking (i.e. phase delay equals 0) between two oscillatory signals during a given period of time (left part of Figure 5). On the other hand, asynchrony involves a systematic time gap (i.e. phase delay is different from 0) between the two oscillatory signals, during a given period of time (right part of Figure 5).

(FIGURE 5 about here)

The specific significance of synchrony and asynchrony is still a matter of investigation. Since the human brain is no longer seen as a computer that simply stores, accesses and combines information, but is viewed rather as a complex system that generates dynamic representations (Friston & Price, 2001) of a few tenth of milliseconds, on which subsequent processing is carried out (Lehmann, Faber, Gianotti, Kochi, & Pascual-Marqui, 2006), the investigation of coherent electric activity in the brain is essential and has enabled a better understanding of human

cognition. Frequency-dependent synchrony could be a code of information processing that functionally and transiently binds remote neuron assemblies involved in a common cognitive processing (Knyazeva & Innocenti, 2001; Weiss & Mueller, 2003). Conversely, frequency-dependent asynchrony could indicate information exchanges between neuron assemblies involved in a common processing (Weiss & Mueller, 2003). Consequently, EEG coherence could be used as a psychophysiological index of experimental condition-specific cognitive processes.

Due to the measurement method of brain electrical signals we adopted in this study (scalp EEG), interpreting EEG coherence patterns in relation to local brain areas can be haphazard, because a widespread surface coherence may result from dipole orientation rather than from local processing in the underlying cortices. Although technical solutions exist to overcome this issue (such as transforming EEG into its second spatial derivative, or creating a virtual source montage that transforms channel space into brain source space), result interpretation remains haphazard concerning localization aspects. Therefore, we chose to restrict our use of EEG coherence to a metric of processing dynamics' differences between experimental conditions, and as a consequence, data related to hemisphere laterality and cerebral lobes, although available, will not be presented.

Method

Hypotheses. Although our daily experience makes it easy and natural for us to produce and understand both primary and complex conceptual metaphors, complex metaphors (Figure 2) should be more difficult to process than primary metaphors (Figure 1) because they integrate simultaneously more than one primary conceptual metaphor into a larger conceptual structure (Lakoff & Johnson, 1999). Consequently, more procedures need to be carried out: n carrier domains are integrated in parallel by n metaphor devices instead of one, and an additional step

occurs at the end of the sequence of events, for merging the outputs of the n primary metaphor devices into the figurative meaning of the complex metaphor. If this hypothesis is true, early EEG coherence patterns should be similar in nature (although possibly varying in amplitude) in the primary and complex metaphor conditions, because the same brain areas and the same neural pathways will be involved in both cases. Additionally, late differences in EEG coherence patterns should also be observed, because more than one primary metaphor needs to be integrated in the conceptual construct after each primary metaphor brick has been processed. Therefore, EEG coherence patterns should be similar first, and different later.

If, instead, complex conceptual metaphors are abstract conceptual metaphors, their processing diagram will be similar to that of a primary conceptual metaphor (Figure 1 and Figure 3). However, the nature of the input (carrier domain) will differ, with procedural or sensory-motor-dependent semantic representations in primary conceptual metaphors, and verbal or abstract semantic representations in complex conceptual metaphors. In this situation, brain activity should always differ between primary and complex metaphors, because different brain areas and neural pathways are likely to be involved.

Experimental design. Two independent variables were manipulated, each having two levels: *metaphoricity*, literal (control) vs. figurative (experimental); and *complexity*, primary vs. complex. These two variables were crossed in a factorial design that defined four experimental conditions (literal primary, literal complex, figurative primary, and figurative complex). Although neither literal condition was supposed to exhibit any processing difference (they are neither primary nor complex, only literal), each one served as a specific control for its corresponding figurative condition, in order to neutralize any bias caused by the use of different word sets in the primary and the complex conditions (see below on experimental material). For the purpose of hypothesis testing, we investigated EEG coherence evolution by defining 10 time

windows of 100 ms each during the period of interest (1 second following the appearance of the experimental word). Furthermore, as EEG coherence also varies in frequency band, we further explored our data depending on this factor (theta, alpha, beta, and gamma bands, respectively corresponding to the frequency ranges of 4-8, 8-12, 12-30, and 30-44 Hz). Consequently, we analyzed quantitatively the EEG coherence pattern differences in synchrony and asynchrony between the figurative and the literal conditions, and separately for the primary condition and for the complex condition, depending on time window and frequency band – on top of overall synchrony and asynchrony. Interpreting the quantitative results consisted in qualitatively comparing between these pattern differences in primary and complex conditions.

Experimental material. The experimental material consisted of isolated sentences, experimental words, and probe words, all written in Norwegian. Each item included a sentence ending with an experimental word and followed by a probe word. This experimental word took a literal or a figurative meaning depending on the sentence in which it was included.

Eighty sentences built for the purpose of the study were used, twenty per condition (see Table 1 for a sample translated in English, and see Table 2 for statistics). The sentences were short and unambiguous, ended systematically with the experimental word (so that the carrier of a metaphor was always one word), contained no other metaphor than on the experimental word, contained only metaphors easy to understand, and were meaningless without the final word (so that it was impossible to guess their meaning before reading the last word). Sentences were paired in such a way that, by slightly changing the part of the sentence corresponding to the context, the experimental word shifted from its literal meaning to a figurative meaning (therefore, each sentence pair ended with the same experimental word). The semantic transformation did not modify grammatical structure. The literal and figurative conditions shared the same average length of sentences within each metaphoricity condition.

(TABLE 1 about here)

Forty experimental words, easily understood by any Norwegian speaker, were selected and controlled across conditions for a series of descriptors: average length; average lexical frequency in Norwegian;³ average lexical frequency of the English translation;⁴ concreteness, familiarity, imageability, and meaningfulness of the English translation;⁵ grammatical category in

³ The index differences between conditions are caused by two items from the primary condition vocabulary, with exceptionally high frequency, namely *tungt*, meaning “heavy” (frequency: 10.2), and *form*, meaning “shape” (9.92). If these two items had been removed, the primary condition vocabulary set would have had characteristics similar to the complex condition vocabulary set: average 1.44, range 0.00003-4.05, SD 1.42. However, these two items were not replaced due to the headache of multiple constraint satisfaction while building the experimental material. Considering all other satisfied constraints, we estimated the plausible impact of this heterogeneity to be too hypothetical on the final results (see the analysis procedure in the “Recording and Processing” section), and preferred to work with a volume of 20 sentences per condition instead of 18.

⁴ Norwegian and English are cousin languages (with Norwegian among the North Germanic languages and English among the West Germanic languages), and indexed databases exist in English, allowing further control. We used the Kuçera & Francis written frequency database included in the MRC psycholinguistic database (Wilson, 1988).

⁵ These four psychological dimensions are logically supposed to be similar for a Norwegian speaker and an English speaker, considering their cultural and historical neighborhood. All ratings were taken from the MRC psycholinguistic database.

the sentence context;⁶ conventionality of the experimental word in its figurative meaning;⁷ and the universality of our metaphors (existence of a similar expression in English and French). The two sets of experimental words appeared to be fairly balanced (see Table 2), implying that any major brain activity difference between conditions will unlikely originate in a vocabulary bias.

(TABLE 2 about here)

Probe words were selected without formal relatedness to the experimental word within an item, and to allow participants to answer without a doubt. Probe word length, lexical frequency in Norwegian,⁸ and lexical frequency of the English translation appeared fairly balanced across experimental conditions (see Table 3).

(TABLE 3 about here)

Sentences, experimental words, and probe words were dispatched into four counterbalanced lists, each list containing the equivalent amount of items for each combination.

⁶ Systematically identical in the literal and figurative conditions within a sentence pair, and on average in a similar range between primary and complex conditions: respectively 9/6 adjectives; 2/0 adverbs; 5/8 substantives; 4/6 verbs.

⁷ Conventionality was computed as a ranking of the specific meaning against all possible meanings, in reference to the amount of times each meaning occurs in a text bank. This ranking was obtained with the Oslo Multilingual Corpus and tools, developed at the Text Laboratory at the University of Oslo's Department of Linguistics and Scandinavian Studies (Johannessen, Nygaard, Priestley, & Nøklestad, 2008).

⁸ The higher average in the literal complex condition was due to one item (VÆR, 8.8. New average without = 1.05). The higher average in the figurative complex condition was due to two items (LEDER, 9.9, and DETALJER, 7.81. New average without = 0.97).

Each participant was tested with two lists, paired for having each experimental word presented in its literal meaning in the first list and in its figurative meaning in the second list. With each list, a participant received the same amount of sentences in the four experimental conditions (literal primary, literal complex, figurative primary, and figurative complex). Finally, in each list, half of the probe words were congruent with the meaning of the preceding completed sentence, and half were not, with the same amount of congruent and incongruent situations in each experimental condition.

Participants and testing procedure. 50 Norwegian native speakers participated; they were all students at the University of Oslo, with high language competency and no known cognitive or visual challenges. Enrolled students were tested during individual sessions in an ERP Lab of Oslo University Hospital, with each session following a standardized protocol (participant reception, connection to the EEG sensors, instruction, training on a training set until performance reached a minimum average speed and accuracy, testing, and hair cleaning).

All components of an item (incomplete sentence, experimental word that completed the sentence, and probe word) were presented visually at 800 x 600 screen resolution and normal pixel density (96 DPI), at the vertical and horizontal center of a high quality 21” cathode ray tube screen with P22 phosphor type (DELL P1130 Trinitron). To ensure a high timing precision, the screen was refreshed at 100 Hz (non-interlaced) and synchronized with stimulus delivery. The distance between the surface of the screen and the subject’s eyes was standardized (70 cm). Words were written with the fixed-width font Courier New, in size 24 (corresponding to 9 mm height per letter, i.e. 0.7° visual angle), with a lower case for the incomplete sentences and the experimental words, and an upper case for the probe words.

Participants first viewed the incomplete sentence for 4 seconds (example: *Dette lyset er veldig*, meaning “This light is very”), immediately followed by the experimental word

completing the sentence, presented in isolation for 2 seconds (example: *hardt*, meaning “hard”). The participants had to read the sentence very cautiously in order to fully understand its meaning, because just after sentence completion they needed to perform a task that probed their comprehension of the sentence.

Finally, a probe word testing their comprehension of the completed sentence was displayed for 2 seconds (example: INTENSITET meaning “intensity,” or KOMPAKTHET meaning “compactness,” depending on the experimental list). During these 2 seconds, participants had to perform a go/no-go semantic decision on the probe word. Half of the participants received instruction to perform a YES answer, i.e. to press the button of a button box if the probe word’s meaning related to the meaning of the sentence they had just read (congruent), and do nothing otherwise. The other half had to perform a NO answer, i.e. to press the button if the probe word’s meaning did not relate to the meaning of the sentence they had just read (incongruent), and do nothing otherwise. In any case, participants had to answer as fast as possible and with a minimum error rate. Two seconds after the probe word disappeared, a new item was automatically displayed, randomly selected until the list was exhausted.

Reading/understanding the experimental word in its sentence context represented the key experimental task of the EEG investigation, because the semantic integration of the whole sentence occurs while processing this word. The go/no-go task produced extra behavioral data on possible conceptual clarity differences between experimental conditions, and kept the participants’ concentration as high as possible on the reading part of the test. Additional instructions were given to participants regarding behavioral constraints with EEG recording (do not move, systematically blink after answering the probe word, systematically rest during the resting periods, and focus intensely) in order to reduce the amount of electrical artifacts.

Recording and processing. Two computers were used. The first computer, piloted with an E-Prime script ("E-Prime," 2008), stimulated the participant and measured his/her answer (pressed key ID and time stamp). The second computer recorded the participant's EEG continuously at 512 Hz with the software ASA ("Advanced Signal Analysis," 2008), through a 64-channel WaveGuardTM (ANT) shielded cap (10-20 international layout montage, 64 sintered Ag/AgCl electrodes, Hirose HD connectors). EEG was time-synchronized with all stimulus events by the E-Prime script through trigger signals sent from the first computer to the second one. A series of pre-tests established and controlled the time accuracy of the equipment, the script, and the communication protocol settings between the two computers.

Signal processing with the software BESA ("Brain Electrical Source Analysis," 2009) consisted of the following sequence of operations, using the procedures implemented in the software: conditioning; rejection of items with electric artifacts on the portion of interest (first second of EEG following the appearance of the experimental word on the screen, plus a reference period of 100 ms before the experimental word appears, this one second corresponding to the period of time when automatic semantic integration of the sentence becomes possible and is carried out); extraction from all participants' EEGs of all accepted portions of interest (EEG signal plus item's ID); and concatenation into a new EEG file. In order to avoid distorting the information in the signal, no band pass filter was used during this or subsequent processing. Therefore, only clean, unartifacted EEG portions were selected and used. A time-frequency analysis (Hoechstetter, et al., 2004) was run over approximately 650 remaining items per condition (65%), separately for each condition, considering a range of frequencies between 6 and 48 Hz by 25 ms time steps over the period of interest (0-1000 ms; reference interval: -100-0 ms). Time-frequency matrices of EEG power increase and decrease (one matrix per channel, 62 matrices total for each condition) served as inputs for the procedure of coherence analysis across

channels, run manually with BESA on 10 periods of 100 ms. The data thus collected formed eight triangular matrices (four conditions by synchrony+asynchrony) of 0s and 1s (1 if synchrony or asynchrony - respectively for synchrony or asynchrony matrices - is detected at a significant level between two channels for a given frequency band and a given time window), sized 1364 (62 channels by 22 frequency bands) by 620 (62 channels by 10 time windows of 100 ms). The content of these matrices was further analyzed with the general linear model using MLwiN (Rasbash, Charlton, Browne, Healy, & Cameron, 2009) in order to quantify the existence of coherent brain activity differences between conditions. This quantitative analyses explored synchrony and asynchrony variations between the literal and the figurative conditions for each metaphoricity condition (overall synchrony and asynchrony), and further decomposed it depending on time window and frequency band. The test statistic was a large sample chi-squared test. Quantitative results were qualitatively compared between primary and complex conditions for interpretation.

Additionally, reaction times from 23 participants for the YES answer (N = 920 measurements) and 27 participants for the NO answer (N = 1080 measurements) were analyzed. Behavioral information was supposed to bring further light on conceptual clarity differences between primary and complex conceptual metaphors. Only the results for the YES answers will be reported because no effects were observed with the more complex, reversed task (the NO answers). Reaction time outliers (N = 257 or 28%) were erased using a median plus and minus 3 median absolute deviation (MAD) filter (Lachaud & Renaud, In press). Two cross-level multilevel models (Hox, 2002; Lachaud & Renaud, In press) served to analyze the odds to get an answer, as well as reaction times, a non-linear logit multilevel model for the answering odds, and a linear multilevel model for the reaction times. Both models included items and subjects as

random parameters, and metaphoricity, complexity, and interaction between metaphoricity and complexity as fixed parameters. Missing reaction times were not replaced.

Results

Reaction times

(FIGURE 6 about here)

Metaphoricity and the interaction between metaphoricity and complexity were non-significant (respectively, $\chi^2_{(1, N = 663)} = 0.5, 0.4$; $p = .48, .53$). Complexity was marginally significant ($\chi^2_{(1, N = 663)} = 2$; $p = .15$), reaction times being 75 ms faster in the complex condition than in the primary condition. Marginal differences of 83 ms between primary and complex metaphors ($\chi^2_{(1, N = 663)} = 2.3$; $p = .13$), and of 84 ms between primary metaphors and literal complex condition ($\chi^2_{(1, N = 663)} = 2.4$; $p = .12$), were also observed.

Answering odds

(FIGURE 7 about here)

Metaphoricity and complexity did not influence the odds for answering YES (respectively, $\chi^2_{(1, N = 920)} = 0.02, 0.67$; $p = .90, .41$). The interaction between metaphoricity and complexity tended to be significant ($\chi^2_{(1, N = 920)} = 3.38$, $p = .066$). The odds to answer YES with a primary conceptual metaphor tended to be greater than the odds to answer YES with a complex conceptual metaphor, as compared to the respective literal controls.

Overall EEG asynchrony

(FIGURE 8 about here)

Compared to respective literal conditions, primary metaphor comprehension decreased overall asynchrony by 0.011 units ($\chi^2_{(1, N = 54560)} = 5.5, p = .019$), but complex metaphor comprehension increased it by 0.093 units ($\chi^2_{(1, N = 54560)} = 423.5, p = 4E-94$).

Overall EEG synchrony

(FIGURE 9 about here)

Compared to respective literal conditions, primary metaphor comprehension increased overall synchrony by 0.085 units ($\chi^2_{(1, N = 54560)} = 45.4, p = 2E-11$), but complex metaphor comprehension decreased it by 0.045 units ($\chi^2_{(1, N = 54560)} = 12.6, p = 4E-04$).

Time asynchrony

(FIGURE 10 about here)

Compared to respective literal conditions, primary metaphor comprehension decreased asynchrony during the first (0.072 units), fifth (0.067 units), and sixth (0.043 units) time windows (respectively, $\chi^2_{(1, N = 54560)} = 26, 22.9, 9.1, p = 3E-07, 2E-06, .0025$), but increased it during the second (0.022 units) and eighth (0.066 units) time windows (respectively, $\chi^2_{(1, N = 54560)} = 5.2, 21.9, p = .022, 3E-06$). Complex metaphor comprehension increased asynchrony on all time windows but the ninth (respectively by 0.056, 0.145, 0.120, 0.088, 0.126, 0.085, 0.072, 0.194, 0.067; respectively, $\chi^2_{(1, N = 54560)} = 15.6, 106.1, 72.8, 39, 80.1, 36.4, 26, 188.7, 22.9, p = 8E-05, 7E-25, 1E-17, 4E-10, 4E-19, 2E-09, 3E-07, 6E-43, 2E-06$), decreasing asynchrony by 0.028 units during this ninth time window ($\chi^2_{(1, N = 54560)} = 0.03, p = .048$).

Time synchrony

(FIGURE 11 about here)

Compared to respective literal conditions, primary metaphor comprehension decreased synchrony by 0.144 units during the third time window ($\chi^2_{(1, N = 54560)} = 13, p = 3E-04$), but

increased it during the second (0.185 units), fifth (0.183 units), seventh (0.258 units), and ninth (0.243 units) time windows (respectively, $\chi^2_{(1, N = 54560)} = 21.5, 21.2, 42, 37.4, p = 3E-06, 4E-06, 9E-11, 1E-09$). Complex metaphor comprehension increased synchrony during the second (0.101 units) and seventh (0.091 units) time windows (respectively, $\chi^2_{(1, N = 54560)} = 6.5, 5.2, p = .011, .022$), but decreased it during the fourth (0.191 units), fifth (0.110 units), eighth (0.169 units), ninth (0.145 units), and tenth (0.180 units) time windows (respectively, $\chi^2_{(1, N = 54560)} = 22.9, 7.631, 17.9, 13.3, 20.5, p = 2E-06, .0057, 2E-05, 3E-04, 6E-06$).

Frequency band asynchrony

(FIGURE 12 about here)

Compared to respective literal conditions, primary metaphor comprehension marginally decreased theta asynchrony by 0.035 units ($\chi^2_{(1, N = 54560)} = 3, p = .082$), decreased beta asynchrony by 0.014 units and gamma asynchrony by 0.015 units (respectively, $\chi^2_{(1, N = 54560)} = 4.4, 4.9, p = .035, .027$), and marginally increased alpha asynchrony by 0.023 units ($\chi^2_{(1, N = 54560)} = 3.7, p = .056$). Complex metaphor comprehension only increased asynchrony, in theta (0.235 units), alpha (0.242 units), beta (0.096 units), and gamma (0.024 units) bands (respectively, $\chi^2_{(1, N = 54560)} = 132.9, 420.9, 197.5, 12.1, p = 9E-31, 2E-93, 7E-45, 5E-04$).

Frequency band synchrony

(FIGURE 13 about here)

Compared to respective literal conditions, primary metaphor comprehension only increased synchrony, in theta (0.242 units), alpha (0.132 units), beta (0.103 units), and gamma (0.035 units) bands (respectively, $\chi^2_{(1, N = 54560)} = 20, 17.9, 32.3, 3.9, p = 8E-06, 2E-05, 1E-08, .049$). Complex metaphor comprehension only decreased synchrony, in alpha (0.071 units) and beta (0.076 units) bands only (respectively, $\chi^2_{(1, N = 54560)} = 5.2, 17.9, p = .023, 2E-05$).

Synthetic summary

Table 4 summarizes significant results ($p < .05$), showing at a glance how coherent activity differences between literal and figurative conditions follow primary-specific and complex-specific patterns.

(TABLE 4 about here)

Discussion

Two operational hypotheses were opposed in the experimental setting: (i) if complex conceptual metaphors were made out of primary metaphor bricks, coherent activity variations in primary and complex conditions would be similar at the beginning of the semantic integration but would differ later; and (ii) on the contrary, if complex conceptual metaphors were based on verbal abstract concepts instead of procedural sensory-motor representations, coherent activity variations would more probably differ from the very beginning of the semantic integration.

Depending on the time window, coherent activity variation showed a pattern compatible with the second hypothesis (see Figure 10 and Figure 11). Additionally, coherent brain activity differed radically between primary and complex conditions (see Figure 8 and Figure 9), involving all frequency bands (see Figure 12 and Figure 13): an overall synchrony increase characterized primary metaphor comprehension (compared to the control condition), but an overall asynchrony increase characterized complex metaphor comprehension (compared to the control condition).

Considering the importance and dynamics of coherent brain activity differences between primary and complex conditions, the two categories of metaphors theorized by cognitive linguists are likely to have a cognitive reality. The brain does not appear to process primary conceptual metaphors as it processes complex conceptual metaphors. Understanding primary conceptual metaphors seems to involve greater binding of neuron assemblies, whereas understanding

complex conceptual metaphors seems to rely on increased information exchange between neuron assemblies.

The go/no-go task revealed slight behavioral differences between the two metaphor categories (see Figure 6 and Figure 7), possibly suggesting conceptual clarity and cognitive effort differences during the mental manipulating of concepts involved in both cases. Comparing probe words' meaning to the figurative meaning of complex conceptual metaphors seems to have been less straightforward than it was with primary conceptual metaphors, resulting in a smaller certitude to answer YES (smaller odds). This fact does not necessarily imply that a complex conceptual metaphor is a complex structure built of primary metaphors, because the go/no-go task probed the by-product characteristics of the metaphor processing (i.e. the figurative meaning) and not the metaphor processing itself (contrary to the EEG). Nevertheless, this fact probably indicates greater conceptual elaboration or abstractness in the figurative complex condition than in the figurative primary condition. Despite the answering odds' pattern, the task tended to be carried out faster with complex conceptual metaphors (marginal significance), possibly indicating a faster conscious access to abstract concepts than to concepts closer to our biological life. Indeed, because the semantics of primary conceptual metaphors is closer to our sensory-motor activity, it may also locate at a deeper, more automatic level of our psyche than abstract concepts, and hence be slightly less accessible to mental tasks involving verbal objects.

Asserting that complex conceptual metaphors are processed through primary conceptual metaphor bricks can, however, still be questioned in light of these results. Both metaphor categories probably share common processing aspects, traces of which were detected in our data (for instance, asynchrony increase occurring in the second and eighth time windows, or synchrony increase occurring in the second and seventh time windows, in both primary and complex conditions – see Figure 10 and Figure 11, respectively). EEG coherence closeness

between primary and complex conditions at around 100-200 ms and 600-800 ms, may, however, only reveal common stages in figurative meaning integration – for instance lexical access during the second time window, and semantics integration during the seventh and eighth time windows – rather than a signature of primary metaphor processing.

It is likely that both categories of metaphors undergo different mental processes, considering (i) the nature of predominant coherent activity for each (synchrony with primary metaphor, asynchrony with complex metaphor – see Figure 8 and Figure 9); (ii) condition-specific patterns of coherence through time (slow oscillations of asynchrony increase/decrease and fast oscillations of synchrony increase/decrease with primary metaphors, stable asynchrony increase and slow oscillations of synchrony increase/decrease with complex metaphors – see Figure 10 and Figure 11); and (iii) coherent activity distribution across frequency bands (weak asynchrony variations but strong synchrony variations in all frequency bands with primary metaphors, strong asynchrony variations in all frequency bands and synchrony variations in alpha and beta bands with complex metaphors – see Figure 12 and Figure 13).

Massive increase of synchrony during primary conceptual metaphor comprehension might be a manifestation of automatic and unconscious figurative meaning integration based on embodied semantics, with synchrony possibly indicating how preexisting wiring in the brain might for instance be involved to link sensory-motor-based representations to the abstract semantic system. Because this pattern is absent with complex conceptual metaphors, the processing of such metaphors may not be carried out through pre-existing links between sensory-motor representations and the semantic system – in other words, the processing may not be carried out through primary metaphors. Massive increase of asynchrony during complex conceptual metaphor comprehension possibly indicates greater information exchange between brain areas, greater amount of brain areas involved, and/or the involvement of brain areas

unrelated to embodied semantics. An algorithm such as the one described in Figure 3 could fit the data, if both primary and complex conceptual metaphors had the same logical processing organization but involved semantic inputs of different nature, such as procedural (or sensory-motor) representations in primary metaphors and verbal (or abstract) representations in complex metaphors. It is likely that each type of input would not involve the same combination of brain areas and the same dynamics to be processed. If this were true, complex conceptual metaphors should be rebaptized “abstract conceptual metaphors,” and be opposed to “sensory-motor conceptual metaphors,” the previously named primary conceptual metaphors. Therefore, the pertinent dimension opposing the two types of metaphors would not be structure (i.e. primary metaphors are bricks used for building complex semantics in complex metaphors). It would rather be the very nature of the representational inputs, i.e. the knowledge system involved: embodied/sensory-motor/procedural knowledge vs. abstract/conceptual/verbal knowledge.

Conclusion

This investigation enriches the fields of psycholinguistics, cognitive linguistics, and potentially many more disciplines, with a new theoretical framework designed for understanding the structure and the cognitive mechanisms behind conceptual metaphors. Additionally, with highly complex and expensive means to produce brain facts, it validates experimentally the psychological reality of two conceptual metaphor categories asserted by cognitive linguists. Finally, it suggests, with experimental data supporting the relevance of this new understanding, an alternative reading of the metaphor theory regarding primary and complex conceptual metaphor: these metaphors do not differ by the structure of their algorithms, but by the very nature of their semantic inputs. Future investigations involving neuroscience imagery techniques

will clarify which representational systems are specifically involved in primary and complex conceptual metaphors.

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References

- . Advanced Signal Analysis (Version 4.6) (2008). Enschede, Netherlands: Advanced Neuro Technology Software BV (ANT).
- Barry, C., & Gerhand, S. (2003). Both concreteness and age-of-acquisition affect reading accuracy but only concreteness affects comprehension in a deep dyslexic patient. *Brain and Language*, 84(1), 84-104.
- . Brain Electrical Source Analysis (Version 5.2.4.48) (2009). Gräfelting, Germany: MEGIS Software GmbH.
- . E-Prime (Version 2.0.1.119) (2008). Pittsburgh, PA, USA: Psychology Software Tools, Inc.
- Fauconnier, G. (1994). *Mental Spaces*. New York: Cambridge University Press.
- Fauconnier, G., & Turner, M. (2002). *The way we think: Conceptual blending and the mind's hidden complexities*. New York: Basic Books.
- Friston, K. J., & Price, C. J. (2001). Dynamic representations and generative models of brain function. *Brain Research Bulletin*, 54(3), 275-285.
- Gerhand, S., & Barry, C. (2000). When does a deep dyslexic make a semantic error? The roles of age-of-acquisition, concreteness, and frequency. *Brain and Language*, 74(1), 26-47.
- Gibbs, R. W., Lenz Costa Lima, P., & Francozo, E. (2004). Metaphor is grounded in embodied experience. *Journal of Pragmatics*, 36, 1189-1210.
- Grady, J. (1997). THEORIES ARE BUILDING revisited. *Cognitive Linguistics*, 8, 267-290.
- Grady, J. (2005). Primary metaphors as inputs to conceptual integration. *Journal of Pragmatics*, 37, 1595-1614.
- Hillert, D. G. (2004). Spared access to idiomatic and literal meanings: A single-case approach. *Brain and Language*, 89, 207-215.

- Hoechstetter, K., Bornfleth, H., Weckesser, D., Ille, N., Berg, P., & Scherg, M. (2004). BESA source coherence: A new method to study cortical oscillatory coupling. *Brain Topography*, 16, 233-238.
- Hox, J. (2002). *Multilevel analysis: techniques and applications*. London: Lawrence Erlbaum Associates.
- Johannessen, J. B., Nygaard, L., Priestley, J., & Nøklestad, A. (2008). *Glossa: a Multilingual, Multimodal, Configurable User Interface*. Paper presented at the Sixth International Language Resources and Evaluation (LREC'08), Paris.
- Johnson, C. (1997). Metaphor vs Conflation in the Acquisition of Polysemy : the Case of SEE. . In M. K. Hiraga, Sinha, C. & Wilcox, S (Ed.), *Cultural, Typological and Psychological Issues of Cognitive Linguistics*. Amsterdam John Benjamins.
- Johnson, M. G., & Malgady, R. G. (1979). Some cognitive aspects of figurative language: Association and metaphor. *Journal of Psycholinguistic Research*, 8, 249-265.
- Knyazeva, M. G., & Innocenti, G. M. (2001). EEG coherence studies in the normal brain and after early-onset cortical pathologies. *Brain Research Reviews*, 36, 119-128.
- Lacan, J. (Ed.). (1966). *Ecrits* (Vol. 2): Editions du Seuil.
- Lachaud, C. M., & Renaud, O. (In press). A tutorial for analyzing Human reaction times: How to filter data, manage missing values, and choose a statistical model. *Applied Psycholinguistics*.
- Lachaux, J.-P., Rodriguez, E., Martinerie, J., & Varela, F. J. (1999). Measuring Phase Synchrony in Brain Signals. *Human Brain Mapping*, 8, 194-208.
- Lakoff, G., & Johnson, M. (1999). *Philosophy in the flesh: The embodied mind and its challenge to western thought*. New York: Basic Books.

- Lehmann, D., Faber, P. L., Gianotti, L. R. R., Kochi, K., & Pascual-Marqui, R. D. (2006). Coherence and phase locking in the scalp EEG and between LORETA model sources, and microstates as putative mechanisms of brain temporo-spatial functional organization. *Journal of Physiology - Paris*, 99, 29-36.
- Parker, A., & Dagnall, N. (2009). Concreteness effects revisited: The influence of dynamic visual noise on memory for concrete and abstract words. *Memory*, 17(4), 397-410.
- Pynte, J., Besson, M., Robichon, F.-H., & Poli, J. (1996). The time-course of metaphor comprehension: An event-related potential study. *Brain and Language*, 55, 293-316.
- Rasbash, J., Charlton, C., Browne, W. J., Healy, M., & Cameron, B. (2009). MLwiN (Version 2.1). Bristol, UK: Centre for Multilevel Modelling, University of Bristol.
- Sabsevitz, D. S., Medler, D. A., Seidenberg, M., & Binder, J. R. (2005). Modulation of the semantic system by word imageability. *NeuroImage*, 27(188-200).
- Scherg, M., Berg, P., & Hoechstetter, K. (2010). BESA Research Tutorial 6: Time-Frequency Analysis and Source Coherence.
- Schnitzer, M. L., & Pedreira, M. A. (2005). A neuropsychological theory of metaphor. *Language Sciences*, 27, 31-49.
- Tourangeau, R., & Rips, L. (1991). Interpreting and evaluating metaphors. *Journal of Memory and Language*, 30, 452-472.
- Weiss, S., & Mueller, H. M. (2003). The contribution of EEG coherence to the investigation of language. *Brain and Language*, 85, 325-343.
- Wilson, M. D. (1988). The MRC Psycholinguistic Database: Machine Readable Dictionary, Version 2. *Behavioural Research Methods, Instruments and Computers*, 20, 6-11.

TABLES

Table 1

Sample of sentences (English translation) for each condition

		Metaphoricity	
		Literal	Figurative
Complexity	Primary	This wood is very <u>hard</u> .	This light is very <u>hard</u> .
	Complex	His goldfish is <u>dead</u> .	His phone is <u>dead</u> . ⁹

Note. Bold: context. Underlined: carrier.

⁹ Since death is not an embodied, procedural, sensory-motor activity of our daily life, it cannot be considered as a possible experience grounding primary conceptual metaphors, even though it relates to the body.

Table 2

Descriptors for the experimental words

		Primary	Complex
Length (n letters)	Average	5.05	6.25
	Range (SD)	3-8 (1.3)	3-10 (1.9)
Lexical frequency (Norwegian)	Average	2.3	1
	Range (SD)	0.00003-10.2 (2.9)	0.016-5.6 (1.6)
English translation Lexical frequency	Average	71.6	66.4
	Range (SD)	3-202 (93)	1-395 (94.5)
Concreteness	Average	431.3	488.8
	Range (SD)	292-595 (89.9)	336-600 (76)
Familiarity	Average	572.9	545.4
	Range (SD)	521, 613 (33.9)	474-583 (31)
Imageability	Average	477.1	538.9
	Range (SD)	376-634 (70.5)	435-612 (56.3)
Meaningfulness	Average	463.5	466.4
	Range (SD)	393-548 (51.3)	376-524 (47)
Conventionality of figurative meaning	Average	0.9	0.75
	Range (SD)	0-1 (0.44)	0-1 (0.43)
Universality of the metaphor	Average	0.8	0.9
	Range (SD)	0-1 (0.34)	0-1 (0.3)

Note. SD Standard deviation. Lexical frequency in Norwegian is computed from the Google search engine (in millions of Norwegian pages containing the exact orthography and located in Norway). The Kuçera & Francis ratings in the MRC psycholinguistic database provided lexical

frequency for the English translation. Conventionality rating: 0 unconventional/1 conventional.

Universality rating: 0 specific/1 universal.

Table 3

Descriptors for the sentence and probe words

		Literal		Figurative	
		Primary	Complex	Primary	Complex
Sentence	Average	4.15	4.4	4.15	4.4
length	Range	2-7	3-8	3-7	3-6
(words)					
Probe word	Average	7.1	6.85	9.1	8
length	Range (SD)	3-14 (2.8)	3-11 (2.4)	5-13 (2.2)	5-11 (2.2)
(letters)					
Probe word	Average	1.07	1.44	0.9	1.76
frequency	Range (SD)	0.000002-	0.000019-8.8	0.000032-	0.0017-9.9
(Norwegian)		7.33 (1.9)	(2.5)	11.6 (2.5)	(2.8)
Probe word	Average	0.36	0.34	0.33	0.9
frequency	Range (SD)	0.000008-2.5	0.000003-2.7	0.000001-3.9	0.0007-6.4
(Eng. transl.)		(0.6)	(0.7)	(0.8)	(1.9)

Note. SD Standard deviation. Lexical frequency in Norwegian is computed from the Google search engine (in millions of Norwegian pages containing the exact orthography and located in Norway). The Kuçera & Francis ratings in the MRC psycholinguistic database provided lexical frequency for the English translation.

Table 4

Results synthesis: significant asynchrony or synchrony decrease or increase between literal and figurative conditions, for primary and complex conditions, depending on time window and frequency band, or overall activity

		Asynchrony		Synchrony	
		Primary	Complex	Primary	Complex
Time	↘	1, 5, 6	9	3	4, 5, 8, 9, 10
Window	↗	2, 8	all but 9	2, 5, 7, 9	2, 7
Frequency	↘	β , γ			α , β
Band	↗		θ , α , β , γ	θ , α , β , γ	
Overall		↘	↗	↗	↘

Note. ↘ decrease, ↗ increase. θ 4-8, α 8-12, β 12-30, γ 30-44 Hz

FIGURE CAPTIONS

Figure 1. Algorithm of a conceptual metaphor

Figure 2. Algorithm of a complex conceptual metaphor (*Cd* means carrier domain)

Figure 3. Algorithm of an abstract conceptual metaphor

Figure 4. Example of coherent and incoherent EEG signals across trials over two regions (Scherg, Berg, & Hoechstetter, 2010)

Figure 5. Example of synchronous oscillations on the left, and asynchronous oscillations on the right (Scherg, et al., 2010)

Figure 6. Reaction time (ms) distribution per condition for the YES answers (error bars: 95% confidence interval)

Figure 7. Odds for answering YES: Difference between the figurative and the literal conditions, for the primary and complex conditions (error bars: 95% confidence interval)

Figure 8. Overall asynchrony in the figurative condition, compared to the literal control, for primary and complex conditions (Y-axis: average count difference (units) between figurative and literal conditions in the 0-1 matrix. Error bars: 95% confidence interval)

Figure 9. Overall synchrony in the figurative condition, compared to the literal control, for primary and complex conditions (Y-axis: average count difference (units) between figurative and literal conditions in the 0-1 matrix. Error bars: 95% confidence interval)

Figure 10. Asynchrony evolution during 1000 ms in the figurative condition, compared to the literal control, for primary and complex conditions (X-axis: time

windows (ms). Y-axis: average count difference (units) between figurative and literal conditions in the 0-1 matrix. Error bars: 95% confidence interval)

Figure 11. Synchrony evolution during 1000 ms in the figurative condition, compared to the literal control, for primary and complex conditions (X-axis: time windows (ms). Y-axis: average count difference (units) between figurative and literal conditions in the 0-1 matrix. Error bars: 95% confidence interval)

Figure 12. Asynchrony across frequency bands in the figurative condition compared to the literal control, for primary and complex conditions (X-axis: frequency band. Y-axis: average count difference (units) between figurative and literal conditions in the 0-1 matrix. Error bars: 95% confidence interval)

Figure 13. Synchrony across frequency bands in the figurative condition compared to the literal control, for primary and complex conditions (X-axis: frequency band. Y-axis: average count difference (units) between figurative and literal conditions in the 0-1 matrix. Error bars: 95% confidence interval)