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Heating up or *cooling up* the brain?

MEG evidence that phrasal verbs are lexical units

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Abstract

There is a considerable linguistic debate on whether phrasal verbs (e.g., *turn up*, *break down*) are processed as two separate words connected by a syntactic rule or whether they form a single lexical unit. Moreover, views differ on whether meaning (transparency vs. opacity) plays a role in determining their syntactically-connected or lexical status. As linguistic arguments could not settle these issues, we used neurophysiological brain imaging to address them. Applying a multi-feature Mismatch Negativity (MMN) design with subjects instructed to ignore speech stimuli, we recorded magnetic brain responses to particles (*up*, *down*) auditorily presented as infrequent "deviant" stimuli in the context of frequently occurring verb "standard" stimuli. Already at latencies below 200 ms, magnetic brain responses were larger to particles appearing in existing phrasal verbs as context (e.g. *rise up*) than when they occurred in non-existing combinations (e.g. **fall up*), regardless of whether particles carried a literal or metaphorical sense (e.g. *rise up*, *heat up*). Previous research found an enhanced MMN response to morphemes in existing (as opposed to non-existing) words but a reduced MMN to words in grammatically acceptable (as opposed to unacceptable) combinations. The increased brain activation to particles in real phrasal verbs reported here is consistent with the lexical enhancement but inconsistent with the syntactic reduction of the MMN, thus providing neurophysiological support that a congruous verb-particle sequence is not assembled syntactically but rather accessed as a single lexical chunk.

Keywords: lexicon; syntax; phrasal verbs (verb-particle combinations); semantic transparency; metaphor; linguistic theories; MEG; Mismatch Negativity (MMN); lexical enhancement; redundant lexical storage

1. Introduction

Verb-particle combinations, also known as 'phrasal verbs', 'particle verbs' **or** 'separable verbs', such as *show off*, *try out*, or *wake up*, are common in English and do not seem to put much demand on the human comprehension system. However, despite their familiarity and apparent simplicity, they have been the subject of much debate in linguistic theory and description. No consensus has been reached yet with respect to two basic and related questions, which, in their simplest terms, can be formulated as follows: (1) are phrasal verbs 'words' or 'phrases', and (2) does this depend on their meaning? To put these questions differently: are phrasal verbs unitary lexical units all by themselves or are they syntactically assembled combinations of two independent lexical units? And should or shouldn't we make the answer to this question dependent on whether we are dealing with clear, uncontroversial cases of phrasal verbs – those that appear in dictionaries because of their partly or fully idiomatic meaning, like *show off* ('brag') or *make out* ('kiss in a sexual way') – rather than with ordinary sequences of a verb and a spatial particle, like *walk in* or *swim back*, in which the particle literally refers to location or direction?[1] As linguistic arguments have so far not led to a consensus, we here for the first time use neurophysiology to probe the brain signatures of verb-particle combinations and compare these responses to brain activation patterns typically elicited by lexical units and by syntactic combinations. Before going into the details of the experiment, we explain the linguistic controversies (1.1), the neurophysiological background (1.2) and hypotheses generated by the competing theoretical approaches (1.3.).

[1] At the end of *Aspects of the Theory of Syntax*, Chomsky (1965, p. 190) already mentioned verb-particle combinations as one class of linguistic objects which pose "a variety of ... problems": "To some extent, the Particle is a fairly free "Adverbial" element, as in "I brought the book (in, out, up, down)." Often, however, the Verb-Particle construction is (distributionally as well as semantically) a unique lexical item (such as "look up," "bring off," "look over"). In all cases, however, the syntactic structure is apparently the same,

1.1. Linguistic controversies about the status of phrasal verbs

As regards the first question – are phrasal verbs words or phrases? – the situation is nicely summed up by the grammarian Declerck (1991, p. 11): "Some grammars treat phrasal verbs as single words ('two-part verbs'), others as combinations of words ('two-word verbs')" (Declerck, 1991, p. 11).[2] There are some obvious arguments for a morphological (i.e. word-level) analysis. One argument is the possibility to use phrasal verbs as input for morphological derivation (e.g. *a show-off, a passer-by, a fixer-upper, an unputdownable book*) (Farrell, 2005; Los, 2004; for discussion of the double *-er* type, see Cappelle, 2010). Derivational processes typically operate on words but not on syntactic phrases (cf. the *No Phrase Constraint*, Botha, 1981), so phrasal verb derivations could be argued to provide evidence that phrasal verbs are words. Moreover, phrasal verbs have been detected in grammatical environments where simplex words but not syntactic combinations of a verb and a free adverb can be used, e.g. *"Get lost," {shouted out / exclaimed / *shouted loudly} Daisy* (Cappelle, 2005; McIntyre 2007; Toivonen, 2003).

However, there are equally strong linguistic arguments that speak in favour of duplex representation and syntactic linkage. The most obvious such argument hinges on the well-known fact that the verb and the particle can be separated from each other, thereby displaying a phrasal manifestation. For instance, a transitive phrasal verb generally allows the option to put the direct object between the verb and the particle – a word order which is even required if the object is an unstressed pronoun (e.g. *She {threw 'em away / *threw away 'em}*). Similarly, the intensifying adverb *right* can be inserted before the particle (e.g. *I gave right up*). If a verb and a particle really formed a lexical *word* together, such

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with respect to the possibility of applying familiar transformational rules. I see no way, for the present, to give a thoroughly satisfactory treatment of this general question."

[2] A similar controversy exists for counterparts of phrasal verbs in other Germanic languages, e.g. for so-called separable complex verbs in Dutch: just like phrasal verbs they are "combinations of a verb and some other word which have both word-like properties and properties of a combination of words" (Booij, 2002, p. 203-204).

disruptions of their contiguity would be in violation of the *Lexical Integrity Principle* (Chomsky, 1970; Di Sciullo & Williams, 1987; Lapointe, 1985). Indeed, a direct object or the adverb *right* obviously cannot be allowed to intervene between parts of a single word structure (e.g. **She dis-'em-carded*; **I sur-right-rendered*).

As regards the second question, there are strong linguistic arguments in favour of a critical role of semantics for the linguistic analysis of phrasal verbs. A combination like *walk in* can be paraphrased as 'do something, namely walking, so that you are/get *in*', but such a causative-resultative paraphrase works for semantically transparent phrasal verbs with a motion verb and a spatial particle, not for the many idiomatic verb-particle combinations which learners of English have a hard time mastering. For example, *give up* is not equivalent to 'do something, namely giving, so that you are/get up' but has a more unpredictable, 'fused-together' meaning ('stop doing something'). This difference in paraphrase possibilities suggests that literal phrasal verbs as in *She walked in* or *I pulled off the tablecloth* ('I yanked it from the table') and idiomatic ones as in *He gave up* or *They pulled off a stunning victory* ('They succeeded in accomplishing one') "are not instances of the same phenomenon" (Fraser, 1976, p. 3), the former being loose, syntactically assembled sequences of a verb and a free adverb functioning as a so-called 'secondary predicate', the latter being tight, lexical verb-particle units which are inserted into syntax as complex verbs, i.e. as 'wholes' (Aarts, 1989; Dehé, 2002; Fraser, 1976; Ishikawa, 2000; Williams, 1997; Wurmbrand, 2000).[3] Despite Chomsky's (1965) assumption that semantically transparent and idiomatic phrasal verbs are structurally identical (cf. footnote 1), a number of arguments based on differences in syntactic properties have been adduced for a structural distinction between these two kinds of phrasal verbs (Fraser, 1965; 1976). For instance, so-called free adverbs can often be

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[3] This position might be conveniently referred to as a Generative Grammar position. It should be noted, though, that there is considerable variation in individual proposals within the generative literature (for overviews, see, *inter alia*, Dehé et al. 2002; Haiden, 2006; Elenbaas, 2008). Quite a few generative linguists

coordinated (e.g. *walk in and out*; *jump up and down*; *pull clothes on and off*), while supposedly true verb particles cannot (e.g. **freak in and out*; **give up and down*; **pull the deal on and off*).

However, there are again equally compelling counterarguments against postulating a structural difference between semantically transparent and opaque phrasal verbs. To begin with, a clear semantic dividing line between these two kinds of verb-particle combinations cannot be drawn, making a dichotomous structural distinction based on semantics impossible. For instance, in combinations such as *figure out* or *slow down*, the particle does not refer to physical space but may nonetheless appear motivated in the light of Lakoff & Johnson's (1980; 1999) conceptual metaphors; thus, drawing on the KNOWING IS SEEING metaphor, one can elucidate *figure out* in terms of a solution to a problem being first 'locked' up in a metaphorical 'box' or 'container' and then being 'calculated' out of it and so becoming 'visible', i.e. mentally accessible (e.g. Lindner, 1981; Morgan, 1997; Tyler and Evans, 2003). Another problem for the view that only idiomatic verb-particle combinations are lexically listed is that completely transparent combinations can be very common in use; this common status has been invoked to argue that they are stored in the lexicon from which they are retrieved 'ready-made', rather than being assembled by a rule whenever they are used (Bolinger, 1971; Hampe, 2002; Diessel & Tomassello, 2005). Finally, differences in syntactic behaviour alluded to above (Fraser, 1965; 1976) do not neatly distinguish phrasal verbs which refer to motion in space and those which do not, as certain non-spatial particles can also be coordinated (e.g. *switch the computer on and off*), and, moreover, there are far more similarities than differences in syntactic behaviour between (clearly) transparent and (clearly) idiomatic phrasal verbs (Declerck, 1976), leading Lindner (1981, p. 31) to conclude that *walk in* and *give up* should really be seen "as instances of the same phenomenon differing only in terms of semantic

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consider *all* verb-particle combinations to be syntactically generated (den Dikken, 1995; Guéron, 1990;

characteristics".[4] In sum, the answer to question (2) could just as well be "no", that is, the semantic status of phrasal verbs could be irrelevant to their grammatical analysis as essentially 'words' or 'phrases'.

As is demonstrated by our review above, questions about the linguistic status of particle verbs have not been answered conclusively by theoretical linguistics.[5]

1.2. A neurophysiological perspective on linguistic linkage

Previous research has shown that recordings of the neurophysiological brain response can be informative about the linguistic status of a spoken or written word and word combinations. One such response, the Mismatch Negativity or MMN, which can be recorded using electro- and magnetoencephalography (EEG, MEG), is relatively *enhanced* if speech is linked into *a single word*, but relatively *reduced* in case of a syntactic and semantic match between *two words* linked by phrase structure rules. We will briefly elaborate on and explain both of these opposing effects.

Hoekstra, 1988; Kayne, 1985; Svenonius, 1994).

[4] Both the view that idiomatic combinations may be metaphorically motivated and the view that frequently used combinations (whether idiomatic or not) may be lexically stored can most straightforwardly be associated with the paradigm of Cognitive Linguistics (established by Lakoff, 1987; Langacker, 1987; for recent overviews, see Evans, Bergen, & Zinken, 2007; Geeraerts & Cuyckens, 2007). However, the present claim that there is no structural difference between transparent and non-transparent combinations is not an exclusively Cognitive-Linguistic one, as it was in fact also made by the founding father of Generative Grammar, Noam Chomsky (cf. again footnote 1) and has since been adopted by a great many generative linguists (cf. footnote 3). Likewise, for Jackendoff (2002a, p. 92), who does not unequivocally belong to either theoretical camp, the syntactic similarities between semantic types prevail: "careful description reveals a wide range of English particle constructions that are syntactically uniform".

[5] More recently, behavioural psycholinguistic experiments addressed the possible processing differences between *up* (/ʌp/) as a part of words (e.g. *cup*, *puppy*, *upholstery*) and as a particle in phrasal verbs (e.g. *go up*, *keep up*, *line up*). The experiments revealed a reduced ability to detect *up* within frequent words but speeded recognition in frequent verb-particle contexts; only for extremely frequent verb-particle combinations could a behavioural pattern be observed similar to that seen for single words (i.e., difficulty to detect a part within the whole, Kapatsinski & Radicke, 2009). These psycholinguistic results suggest that the large majority of verb-particle combinations are processed differently from single words, except for a few extremely frequent combinations, such as *go up* or *set up* (1531 and 8483 occurrences, respectively, in the 100 million word British National Corpus). It should be noted that these behavioural results are subject to the criticism that it cannot be decided whether the response time differences, which are usually seen at rather long latencies (in this particular study, >700 ms), are due to lexical access processes, including word recognition, parsing and semantic understanding, or rather to post-understanding inferences and other post-lexical processes. To distinguish between early psycholinguistic processes and later ones following comprehension, it is necessary to use fast experimental techniques, ideally observing the work of the underlying neuronal machinery itself.

Sounds or syllables critical for recognizing words trigger *larger* MMNs than when the same, identical stimuli appear in the context of unfamiliar and meaningless pseudowords (Pulvermüller et al., 2001; Shtyrov & Pulvermüller, 2002). Thus, the *t*-sound occasionally following upon the standard stimulus *bi* (/baɪ/) thus producing the existing word *bite*, elicited a larger amplitude of the MMN compared with the same *t*-sound appearing after the standard stimulus *pi* (/paɪ/), where it yields a non-existing meaningless pseudoword (**pite*) (Shtyrov & Pulvermüller, 2002). The MMN is also enhanced to affixes embedded in existing complex words, relative to affixes embedded in pseudowords (Shtyrov, Pihko, & Pulvermüller, 2005).[6] The relative response enhancement evoked by lexical units of speech is explained by strong reciprocal connections holding together the memory circuits storing these lexical elements. Memory circuit activation leads to amplification of sensory-evoked activity in the temporal cortex and to additional activity in brain areas housing neurons of the memory circuit (Näätänen, Paavilainen, Rinne, & Alho, 2007; Pulvermüller, 1999; Pulvermüller & Shtyrov, 2006; Shtyrov & Pulvermüller, 2007b). Interestingly, the cortical generators of the MMN to words reflect aspects of the meaning of the words eliciting it (Pulvermüller & Shtyrov, 2006; Pulvermüller, Shtyrov, & Ilmoniemi, 2005; Shtyrov, Hauk, & Pulvermüller, 2004). Neuronal network simulations using realistic neuroanatomical architectures underpin these statements and document the non-linear activation-enhancing effect of strongly interconnected distributed memory circuits for words in the human brain (Garagnani, Wennekers, & Pulvermüller, 2008; 2009).

In sharp contrast to this lexical pattern, a grammatically acceptable *string of words* elicits a relatively small MMN but an unacceptable string a much larger 'syntactic

[6] This lexical enhancement of the Mismatch Negativity was confirmed repeatedly using electroencephalography (EEG), MEG and functional magnetic resonance imaging (fMRI) in a variety of languages, including English (e.g. Shtyrov & Pulvermüller, 2008), German (e.g. Endrass, Mohr, & Pulvermüller, 2004), Finnish (e.g. Korpilahti, Krause, Holopainen, & Lang, 2001; Shtyrov, Pihko, & Pulvermüller, 2005), Thai (e.g. Sittiprapaporn, Chindaduangratn, Tervaniemi, & Khotchabhakdi, 2003) and other languages.

MMN'. The syntactic MMN has the same latency and left-anterior topography as the early left-anterior negativity also elicited by syntactic violations (Friederici, Pfeifer, & Hahne, 1993; Hahne & Friederici, 1999; Isel, Hahne, Maess, & Friederici, 2007; Neville, Nicol, Barss, Forster, & Garrett, 1991), but is automatic, persisting even when subjects are heavily distracted (Pulvermüller, Shtyrov, Hasting, & Carlyon, 2008; Shtyrov, Pulvermüller, Näätänen, & Ilmoniemi, 2003), and, critically, reflects the grammatical status of a string but not its sequential probability (Pulvermüller & Assadollahi, 2007).[7] The explanation of the enhanced brain activation to grammatically incorrect word strings builds upon the syntactic priming effect some grammar models postulate between a sentence fragment and categories of possible successor words (Pickering & Branigan, 1999; Pulvermüller, 2003; Pulvermüller, 2010). As a grammatical string member is syntactically primed by the syntactic context, its representation is already primed when it appears and, therefore, the activation this critical item elicits is reduced relative to its pre-stimulus baseline. However, in ungrammatical conditions, such syntactic priming is not available thus making the syntactically misplaced lexical unit elicit a relatively enhanced brain response (for discussion, see Pulvermüller, 2003; Pulvermüller & Knoblauch, 2009; Pulvermüller & Shtyrov, 2003; Shtyrov, Pulvermüller, Näätänen, & Ilmoniemi, 2003).

1.3. Using MEG to test predictions made by alternative linguistic theories

Here, we take advantage of the opposing patterns of lexical and syntactic-semantic event-related potential or field (ERP/ERF) effects to address question (1) about the lexical or syntactic status of the link between verb and particle. Spoken existing and infelicitous

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[7] The stronger response to ungrammatical phrases (Hasting, Kotz, & Friederici, 2007; Menning et al., 2005; Pulvermüller, Shtyrov, Hasting, & Carlyon, 2008; Shtyrov, Pulvermüller, Näätänen, & Ilmoniemi, 2003) was repeatedly shown by a number of studies using different languages (including English, Finnish, German). For instance, the German sequence *der Mut* ('the courage') is allowed by the language, but not **die Mut*, where the gender of the article (female) disagrees with the gender of the noun (male), and the MMN response to the stimulus *Mut* is lower when preceded by *der* than it is when preceded by *die* (Pulvermüller & Assadollahi, 2007). Similarly, a larger MMN response was seen when words did not match the preceding context semantically (Menning et al., 2005; Shtyrov & Pulvermüller, 2007a).

combinations of verb and particle (*rise up* vs. **fall up*) were presented to native speakers and their brain responses recorded in an MMN experiment using magnetoencephalography, with the aim of finding out whether the particle triggered a reduced or an enhanced brain response in the region of ~200 ms after its onset, depending on the preceding verb context in which it is presented. A theoretical position postulating a syntactic link between verb and particle predicts, on the background of pre-existing MMN evidence, a large response to the incongruent strings compared with the congruent ones. By contrast, an alternative theoretical position assuming lexical representation or storage of a (common) phrasal verb as a complex unit predicts, on the background of the lexical enhancement of the MMN, an increased response to the congruent form compared with the infelicitous one.

Possible meaning dependence (question (2)) was addressed by including both fully transparent (e.g. *rise up*) and idiomatic (but metaphorically motivated) combinations (e.g. *heat up*). The hypothesis, held by many generative linguists (see 1.1), that the meaning of phrasal verbs is critical for their linguistic status, predicts that *if* there is a lexical effect, this will *only* show up, in the form of enhanced brain activity in the relevant region, for non-transparent combinations, because fully transparent ones are produced by syntax. By contrast, other linguistic views (in both generative and cognitive schools, see 1.1) postulate the same status for transparent and idiomatic verb-particle combination, thus implying similar brain responses.[8]

In an MEG experiment, we observed, in orthogonalised conditions, the effects of Congruency (existing vs. infelicitous context), Transparency (spatial vs. metaphorical meaning) and Stimulus Word (*up* vs. *down*) on the brain response to identical particles (i.e. to the same instance of *up* after different verbs and to the same instance of *down* after

[8] No theoretical linguistic position predicts that individual particles behave radically differently with respect to their embedding in congruent vs. incongruent combinations or in fully vs. less fully transparent ones.

different verbs).[9] Table 1 presents a brief overview of the conflicting predictions discussed.

Please insert Table 1 about here.

2. Experimental procedure

2.1. Subjects

Twenty one healthy right-handed (handedness assessed according to Oldfield, 1971, no left-handed family members) native British English speakers (age 19-40) with normal hearing and no record of neurological diseases were presented with four sets of auditory stimuli in four separate experimental conditions.

All subjects gave their written informed consent to participate in the experiments and were paid for their participation. The experiments were performed in accordance with the Helsinki Declaration. Ethical permission for the experiments was issued by the Cambridge Psychology Research Ethics Committee (Cambridge University; CPREC 2006.33).

2.2. Design

As the present experiment addresses questions about linguistic processes at the lexical-morphological and syntactic levels, it was important to exclude any confounding of experimental results by acoustic, phonetic and phonological differences between stimuli. To this end, *identical recordings* of the particles were used in different experimental

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Therefore, if an enhancement or reduction is found depending on one or both of these factors, as predicted by a linguistic theory, it should be found for both particles tested in the present experiment, *up* and *down*.

9 We made sure that the congruent combinations had also sufficient frequency, so that they could at least in principle be eligible for lexical storage, under the Cognitive-Linguistics view. The congruent items were however not ultra-frequent, enabling us to test Kapatskinski & Radicke's (2009) hypothesis that only extremely frequent verb-particle combinations are stored as lexical units (cf. section 1.1, note 5).

condition, where they were placed in the context of different verb stems. To rule out the possibility that differences between stimulus words (verb stems or particles) could *per se* explain the results, an orthogonal design (see figure 1) was used. That is, we selected four existing verb-particle combinations in English (*rise up*, *fall down*, *heat up*, *cool down*) and four non-existing ones (**rise down*, **fall up*, **heat down*, **cool up*). The verbs functioned as frequently presented standard stimuli, which set the context for the particles. The particle and other linguistic materials were presented only infrequently, as so-called "deviant" stimuli. In this Mismatch Negativity design (see table 2), the brain effects of differences between critical words (i.e., *up* vs. *down*) and context words (e.g., *rise* vs. *fall*) are orthogonal (i.e. statistically unrelated) to those of congruency (i.e. the factor whether or not a standard and a subsequent particle together form an existing combination). Orthogonal designs of this sort are important in psychophysics and psychoacoustics and in neurophysiological investigations of language processing, because they allow one to separate the influence of stimulus properties from context effects (for discussion, see Carlyon, 2004; Pulvermüller & Shtyrov, 2006).[10]

Notably, the four standard stimuli allow a subdivision between a pair which refers to motion (*rise* and *fall*) and a pair which refers to a non-motion change (*heat* and *cool*), therefore commanding respectively literal or metaphorical use of the two critical stimuli *up* and *down*.

Please insert figure 1 and table 2 about here.

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[10] Note that if one critical stimulus (e.g. the particle *up*) formed an existing verb-particle combination with one of the standard stimuli from each pair (e.g. *rise up*), it formed an infelicitous combination with the other standard (e.g. **fall up*). The opposite was true for the other critical stimulus (*down*) which, in this case, formed an unacceptable combination with the former standard stimulus (e.g. **rise down*) and an acceptable one with the latter (e.g. *fall down*). Note furthermore that any difference in the brain response to the stimulus word *down* can, in this design, not be related to the makeup of this item: as identical instances of the word are presented in different contexts, it must be the word-to-context relationship that is manifest in any difference between conditions. The same argument also applies to responses related to the context, as also each context (verb stem) is presented together with both particles. It is for this reason that the orthogonal design controls for purely acoustic, phonetic and phonological effects, as well as psycholinguistic effects stemming from e.g. frequency differences between stimuli, on evoked responses.

2.3. Stimuli

For stimulus preparation, we recorded multiple repetitions of each word uttered by a male native speaker of British English. Verb stimuli and particle stimuli were recorded separately from each other so as to avoid co-articulation cues from the verb to its matching particle (e.g. from *rise* to *up*). When uttering the verbs, the speaker was instructed to have them followed by (but not connected with) the 'dummy' particle *pack*, whose voiceless plosive onset (i) resembles the onset of neither *up* or *down*, thus preventing co-articulation biases, (ii) allowed the coda of the preceding verb to be pronounced without any phonological reduction and (iii) allowed the verb stimuli to be clipped at a non-arbitrary point. The particles were preceded by (but briefly set off from) the verb *wake*, whose voiceless plosive coda (a) is non-identical to the coda of either *rise*, *fall*, *heat* or *cool*, thus again preventing co-articulation cues to the onset of the particles *down* and *up*, and (b) allowed isolation of the particle stimuli. The utterance frames 'verb+*pack*' and '*wake*+particle' used in recording the stimuli ensured that when the selected verbs and particles were then fed to the stimulation programme (E-prime) for splicing (more on which below), this led to a natural prosodic pattern associated with phrasal verbs, where the verb has a weaker accent and hence lower pitch than the particle – in contrast to prepositional verbs; compare, e.g., *dream ON* and *dePEND on something*, where *on* is a particle and a preposition, respectively (on the prosody of phrasal verbs, see Bolinger, 1971; Dehé, 2002).

With great care we selected a set of verb stem recordings whose vowels matched in their fundamental frequency (F0) and whose overall length and maximal sound energy were maximally similar. The particles were also matched for sound energy and F0. F0 frequencies of the particles and other deviant stimuli were higher (11%) than those of verb stems to create natural perception as potential phrasal verbs (see explanation above;

Figure 1).[11] All stimuli were normalized to have the same mean sound energy by matching the root-mean-square (RMS) power of the acoustic signal. For the analysis and production of the stimuli, we used the Cool Edit 96 program (Syntrillium Software Corp., AZ).

The splicing respected the presence of a brief pause in intonation which the speaker had inserted between the verbs and the 'dummy' particle and between *wake* and the particles. Thus, between *rise* and either *up* or *down*, there was a 145 ms. break in the stimulation stream. This was necessary because if the verbs and the particles had been spliced without such a pause, the absence of any co-articulation effects would have been unnatural. The resulting verb+particle splices sounded as emphatically pronounced real or potential phrasal verbs would sound in natural language production in cases where a speaker prefers to render the verb and the particle as unconnected words, a possibility which is allowed in speech and which is sometimes reflected even in writing (e.g., *shut up* can be pronounced with co-articulation of verb and particle, as when it is spelled *shuddup*, but it can also be pronounced with pauses, as in the second instance in this title of a web article: *Shut up, Lane. Just ... shut ... up*). There was a break in all verb+particle combinations, existing and non-existing ones, transparent and non-transparent ones, and those with *up* and *down*. Note also that such a pause was not at odds with but certainly did not *favour* the perception of the phrasal verb as a lexical unit rather than as a combination of isolated words.

Word frequencies of all relevant standard and deviant stimuli used in the experiment are given in Table 3 along with the frequencies and normalised sequential probabilities of the word pair sequences.[12] The latter measure, which is similar to Shannon's mutual information (Shannon & Weaver, 1949), indicates how common a word sequence is given

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[11] This difference matches that of verbs and particles in natural sentences such as *I want it to cool down*.
[12] Frequencies of combinations which we consider as "non-existent" in our experiment should be expected to be zero. Yet, the BNC did yield a few occurrences. On closer investigation, they do not constitute valid

the likelihood of the component words (for further elaboration, see Pulvermüller & Assadollahi, 2007). Note that NSP values are substantially higher for existing combinations than for infelicitous ones. Note furthermore that fully transparent and not fully transparent pairs have comparable NSPs: the NSPs for *rise up* and for *heat up* are very similar to each other and they are both, incidentally, three to four times lower than the NSPs for *fall down* and *cool down*, which are therefore also similar to each other. The differences in NSPs between the existing combinations with *up* on one hand and the existing combinations with *down* on the other, as well as pure acoustic differences between the particles, are taken into account by the counterbalanced design in which the same particles appear in different contexts, but could become manifest in a main effect of the particle factor.

Please insert table 3 about here.

2.4. Acoustic stimulation

During the stimulation, the subjects were seated in a magnetically-shielded chamber and asked to watch a DVD of their own choice. Films did not include text and were played without sound. Subjects were instructed to focus their attention on the video film and to pay no attention to sounds or speech. All experimental conditions ('blocks') were performed with every subject, their order being counter-balanced across the subject group. The stimuli were binaurally presented at 88 dB SPL (determined using 1 kHz tone) via non-magnetic earpieces connected to an E-Prime set-up (Psychology Software Tools, PA). The inter-stimulus (stimulus onset asynchrony, SOA) interval between any two consecutive words was 835 ms. In each condition, all word combinations were equiprobable in an otherwise random sequence of presentation in which the standard stimulus alternated with any of the deviant stimuli.

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counterexamples to our judgements. For instance, in the sentence *How many feet does the tide rise down at*

For stimulus presentation, we adopted the so-called ‘optimium’ or ‘multi-feature’ paradigm for eliciting the Mismatch Negativity (Kujala, Tervaniemi, & Schroger, 2007; Näätänen, Pakarinen, Rinne, & Takegata, 2004), which can accommodate multiple deviant stimuli in a time-efficient manner. In this design, every second stimulus is recommended to be the standard sound, whereas the remaining stimulus locations are randomly distributed between the different types of deviants.

In addition to the critical deviant stimuli – the particles *up* and *down* – we added additional deviants to increase the level of uncertainty about upcoming speech stimuli (see again Table 2). In the MMN paradigm with only one or two deviant stimuli, the normal uncertainty about the identity of upcoming words is reduced so that the word recognition process may be speeded. To compensate for this, one can include additional stimuli with word onsets similar to the critical deviants. Thus, the infrequent deviant stimuli in our experiment were the particles *up* and *down*, and four additional syllables, two words and two pseudowords, with the same onset phoneme(s) (*us*, **ut*; *doubt*, **douge*). Recording of these items followed the same procedure as that described above for the critical stimuli. Each deviant occurred with a probability of 8.33% in a given block and the standard stimulus with a 50% probability.

2.5. Magnetoencephalographic recording

The evoked magnetic fields were recorded continuously (passband 0.03-330 Hz, sampling rate 1000 Hz) with 204 planar gradiometer and 102 magnetometer channels of a whole-head Neuromag Vectorview MEG system (Elekta Neuromag, Helsinki) during the auditory stimulation. To enable the removal of artefacts introduced by head movements, the position of the subject’s head with respect to the recording device was tracked throughout the session. In order to do so, magnetic coils were attached to the head and

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this dock?, the word *down* is not a verb particle but a modifier within the adjunct *down at this dock*.

their position (with respect to a system of reference determined by three standard points: nasion, left and right pre-auricular) was digitized using the Polhemus Isotrak digital tracker system (Polhemus, Colchester, VT). To allow the off-line reconstruction of the head model, an additional set of points randomly distributed over the scalp was also digitized. During the recording, the position of the magnetic coils was continuously tracked (continuous HPI, 5Hz sampling rate), providing information on the exact position of the head in the dewar.

2.6. MEG data processing

The continuous raw data from the 306 channels were pre-processed off-line using MaxFilter software (Elekta Neuromag, Helsinki), which minimises possible effects of magnetic sources outside the head as well as sensor artefacts using a Signal Space Separation (SSS) method (Taulu et al., 2004, 2006). SSS was applied with spatio-temporal filtering and head-movement compensation, which corrected for between-block motion artefacts and re-corrected the head position to the middle of the dewar to avoid any laterality biases. Using the MNE Suite (Martinos Center for Biomedical Imaging, MA), stimulus-triggered event-related fields (ERFs) starting at 100 ms before stimulus onset and ending 650 ms thereafter were computed from the pre-processed data for each stimulus of interest. Epochs with voltage variation exceeding 150 μV at either of two bipolar electrooculogram (EOG) electrodes or with magnetic-field gradient variation exceeding 2000 femtotesla per centimeter (fT/cm) at any gradiometer channel were excluded from averaging. Only ERFs calculated from 100 (83.3%) or more accepted trials of a given condition were used. If the data from a given subject and condition did not reach this criterion, the subject's data was excluded from further analysis. The responses to filler deviant items were excluded from the analysis. The averaged responses were filtered (passband 1-20 Hz) and baseline corrected relative to the 100 ms of silence before onset of the particle.

To quantify the event-related magnetic field gradients, vector sums of recordings from two orthogonal sensors in each pair of planar gradiometers were produced by computing the square root of the sum of squares of the two orthogonal planar gradiometers in each pair, i.e. computing the absolute field gradient amplitude from the two orthogonal components. The resulting vector's absolute magnitude was used in further analysis. For quantifying global activation unbiased by sensor topographic location, a root-mean square (RMS) was computed across all gradiometer pairs in the sensor array by taking the square root of the sum of squared amplitudes divided by the total number of gradiometers (204). Matlab 6.5 programming environment (MathWorks, Boston, MA) was used for the procedures described above.

2.7. Statistical analysis

The data were subjected to analyses of variance (ANOVAs). Parameters of Event-related magnetic-field responses for each region of interest were entered into analysis separately. We compared them between conditions using factors Congruence (existing vs. infelicitous verb-particle combination), Transparency (literal vs. metaphoric use of the particle, as e.g. for *up* in *rise up* vs. *heat up*) and Stimulus (*up* vs. *down*).

3. Results

Event-related magnetic-field responses (ERFs) were elicited by all types of stimuli. Deviant responses to the critical stimuli (i.e. the particles) presented in both legal and infelicitous contexts were successfully calculated and Mismatch Negativity responses were also additionally obtained by subtracting the responses to the standard stimuli (i.e. the verb stems) from these deviant responses (see Figure 2). Initial inspection indicated a clear difference between brain responses to the existing and infelicitous verb-particle combinations, suggesting an advantage of the former over the latter developing at ~100 ms, peaking at ~190 ms and sustained over the entire epoch (Figure 2). To determine the general size of the neurophysiological brain response to particles in their different contexts, global root mean square (RMS, Brown, Lehmann, & Marsh, 1980) values were calculated across all gradiometer channels over the entire recording array and compared between conditions. Calculating the RMS is a standard analysis procedure providing an estimate of the overall magnitude of the brain response and an unbiased data-reduction technique for assessing temporal signal dynamics (Hamburger & Wexler, 1975). We chose to analyse RMS of the magnetic field gradients around the time point of the strongest magnetic brain response. This is advantageous because at that time point, the largest signal to noise ratio is present in the recording, yielding the best chance to find significant effects. The choice of time window was also consistent with pre-existing data (for review, see Pulvermüller & Shtyrov, 2006) and, importantly, with the present data, which showed the first divergence of magnetic gradients between conditions at that very interval (see Figure 2). As the differences between the contexts peaked at around 190 ms in both ERF and RMS, we extracted average global RMS amplitudes for each condition and participant in one 20-ms window centred at this latency and submitted these RMS values to statistical analysis.

Please insert Figure 2 about here.

The statistical results demonstrated stronger magnetic brain responses to existing verb-particle combinations compared with infelicitous ones ($F(1,20)=4.67$; $p<0.043$) and this effect of the Congruence factor was present in the same way for verbs of motion (*rise*, *fall*) and for verbs of non-motion change (*heat*, *cool*); no significant effect of the

Transparency factor was present, nor an interaction involving this factor and the factor Congruence, or any other interaction (Figure 3).

Please insert Figure 3 about here.

Magnetic brain responses to particles appeared to have bilateral distribution and no significant laterality differences was found when comparing local vector sum values between the hemispheres. Further topographic analyses of the difference between legal and infelicitous context suggested that the enhancement of the MEG signal in the former mainly arose from sensors mapping local magnetic field gradients in superior temporal and, most prominently, parietal areas (Figure 4).

Please insert Figure 4 about here.

4. Discussion

We recorded, in a passive multi-feature MMN paradigm, the brain's magnetic responses to verb-particle combinations and found that the same particles, when embedded in an existing verb-particle context, elicit a larger response than when placed in a context of an infelicitous, non-existing verb-particle combination. This difference peaked at 180-200 ms and did not depend on the exact stimulus or the combination's degree of transparency (i.e. literal vs. figurative use of the particle). Effects were primarily present at temporoparietal planar gradiometer recordings. Below, we will discuss these findings in light of questions asked in the Introduction and with regard to their broader implications for linguistic theory. First, however, we comment on the nature of the observed brain response and its location in time and space.

4.1 Brain signatures of verb particles in space and time

The dependent measure used in the present experiment was the magnetic brain response – quantified as global and local RMS recorded with 204 planar gradiometers. These were responses to the critical deviant stimuli in an MMN design, where these deviant stimuli are considered to elicit the magnetic correlate of the MMN response together with other responses in the N1-P2/P3a family. The MMN can be isolated by recording the brain response to the same stimulus (used as deviant in the MMN design) but now presented on its own, outside the context of an MMN design, and by subtracting that response from the deviant response to the same stimulus (so-called "identity MMN", for discussion see Pulvermüller & Shtyrov, 2006). However, these subtractions are identical for all particles of the same kind. Observe that the response difference between the conditions *heat up*-minus-*cool up* are identical to the MMN differences (*heat up*-minus-*up*) – minus – (*cool up*-minus-*up*), as the same value is subtracted in both brackets. And it is this context difference, the relatively enhanced response to the same particle in congruous contexts, which we interpret here. On the background of the MMN literature summarized in the introduction, especially the match between the lexical MMN enhancement and the enhanced brain responses to existing verb-particle combinations, we attribute this context difference to the MMN. In future, it will be fruitful to explore whether a similar difference could possibly be obtained outside MMN paradigms.[13]

At around 180-200 ms after critical stimulus information was present, MEG recordings suggested profound comparatively strong activation of the temporal and especially parietal cortex by particles presented in a felicitous context (Figure 4). This finding is of interest, as the temporal cortex houses an area especially sensitive to movement (the human homologue of area MT) and the parietal cortex includes the WHERE stream of visual processing (Ungerleider & Haxby, 1994). The topographical data, which suggest

[13] An additional experiment could compare N1 responses to repeatedly presented sequences of *heat up*, *cool up* etc. We have experimented with this kind of design, but could not find correlates of the MMN signatures of lexical processing in the N1-P2/P3a complex.

activation of both movement and WHERE systems of the brain, therefore provide a possible neurophysiological correlate of aspects of the meaning of particles, which, similar to prepositions, can convey information on direction of movement and location. These results are consistent with data from neurological patients with lesions involving the temporoparietal cortex (especially angular gyrus) who have difficulty in the use of locative prepositions (Tranel & Kemmerer, 2004). In the present study, the temporoparietal activation was independent of semantic type, thus suggesting that features of the locative meaning of verb particles (and their homophonous prepositions) were accessed when these items appeared in their spatial sense (*rise up*), but also when their use was metaphorical or abstract (*heat up*) in nature (but see Noordzij, 2008 for somewhat different results on prepositions). WHERE and movement system activations were however reduced in infelicitous contexts.

The fact that the neurophysiological difference between congruous and incongruous verb-particle combinations emerged already 180-200 ms after onset of the particle could be taken as neurophysiological evidence in support for early lexical processing, as it has been revealed in a range of earlier studies (Hauk, Davis, Ford, Pulvermüller, & Marslen-Wilson, 2006; Hauk, Pulvermüller, Ford, Marslen-Wilson, & Davis, 2009; Kissler, Herbert, Winkler, & Junghofer, 2008; Martin-Loeches, 2007; Martin-Loeches, Hinojosa, Gomez-Jarabo, & Rubia, 1999; Pulvermüller, Lutzenberger, & Birbaumer, 1995; Pulvermüller & Shtyrov, 2006; Scott, O'Donnell, Leuthold, & Sereno, 2008; Sereno, Rayner, & Posner, 1998; Shtyrov & Pulvermüller, 2007b). In spite of its consistency with these earlier reports, our early context-related differentiation was found with repeated (deviant) stimuli presented in a restricted context. In principle, one can argue that this kind of experimental setup might lead to a speeding of psycholinguistic processes. Having said this, we must, however, emphasize the by now frequently replicated finding that lexical and also context-related effects in the neurophysiological brain response emerge within 100-250 ms, regardless of whether written or spoken stimuli are being repeated or not (Pulvermüller, Shtyrov, & Hauk, 2009).

One may argue that the present results should be replicated in designs avoiding stimulus repetition; however, we here have to face the natural limits of psycholinguistic and neurophysiological research: as we have pointed out previously in the context of the investigation of inflectional affixes (Pulvermüller & Shtyrov, 2009), some types of linguistic elements only have a small number of members (e.g., four inflectional affixes in English, few particles allowing either a 'match' or a 'mismatch' with a motion verb) so that neurophysiological experiments such as the present one which require 50 or more single neurophysiological response traces for averaging, *cannot, in principle, avoid stimulus repetition*. Therefore, the general validation of results of studies using MMN designs, including their latency and topography, relies on language mechanisms that can be investigated using designs with and without stimulus repetition (see, for example, Pulvermüller, 2005), but some specific linguistic questions need to take advantage of designs that include repetitions.

We will now turn to the findings about the impact, or lack thereof, of the factors congruence and transparency, and their theoretical implications (sections 4.2 to 4.5). We will then discuss the findings from a neurophysiological point of view (section 4.6).

4.2. The link between verb and particle is lexical, not syntactic, in nature

With respect to the first question in the Introduction, the results provide neurophysiological evidence that *phrasal verbs are lexical items*. Indeed, the increased activation that we found for existing phrasal verbs, as compared to infelicitous combinations, suggests that a verb and its particle together form one single lexical representation, i.e. a single lexeme, and that a unified cortical memory circuit exists for it, similar to that encoding a single word. Note that the unbiased stimuli recording and disconnected splicing described in Section 2.3, together with the orthogonal design applied, means that we can exclude the possibility that the observed effect is, in fact, a phonetic-prosodic rather than a lexical effect. Indeed, the way we prepared our stimuli guarantees that the combinations *rise up*, *heat up*, *fall down* and *cool down* do not sound more natural, in terms of their phonetic-prosodic properties, than the combinations **rise down*, **heat down*, **fall up* and **cool up*.

As the postulate that phrasal verbs are lexical units (see Assumption A sub (1) in Table 1), together with pre-existing observations of a lexical enhancement of the MMN, led us to accurately predict the observed pattern of results, the present results now support this lexical hypothesis. In previous work, an inflectional affix attached to a verb stem similarly led to an enhancement of the MMN response relative to the same affix appearing in an incoherent context (Shtyrov, Pihko, & Pulvermüller, 2005). If syllables or phonemes combine into monomorphemic words, there is again an enhancement of the MMN brain response compared with incoherent syllable/phoneme combinations (Pulvermüller et al., 2001; Shtyrov & Pulvermüller, 2002). The parallel increase of the brain response to existing verb-particle combinations is consistent with these earlier findings and supports theories postulating a *lexical link* within the phrasal verb. In the language of the brain, the two morphemes do indeed seem to form one single lexical item.

The neurophysiological pattern observed is contrary to that accompanying words linked by way of grammar rules (‘syntax’). Words correctly linked by a grammar rule produce a reduced brain response compared with grammatically infelicitous combinations. This inconsistency of the results with a pattern of syntactic linkage above the word level further strengthens the conclusion that the connection holding together verb and particle is lexical in nature, and not syntactic. Similar to the syntactic effect, a word appearing in a context where it is semantically unexpected also leads to an enhanced brain response relative to a congruent context. This observation, which has been made in a range of paradigms, the MMN paradigm included (Kutas & Federmeier, 2000; Kutas & Hillyard, 1980; Shtyrov & Pulvermüller, 2007), suggests that any between-word linkage – be it syntactic or semantic in nature – would lead to a brain signature different from the one observed for verb-particle combinations in the present study.

The congruent verb-particle combinations used in our experiment are rather common in English but definitely not ultra-high-frequent: compare the BNC frequencies given in Table 3 (*rise up*: 125; *heat up*: 78; *fall down*: 207; *cool down*: 90) with those for *set up* (8379), *pick up* (2697), *go down* (1967) or *sit down* (1892). Our finding that the medium-frequency phrasal verbs in our experiment produced a lexical effect contests the hypothesis that only ultra-high-frequent word combinations can be lexically stored (Kapatsinski & Radicke, 2009).

4.3. Some implications of the lexical effect for linguistic theories

The lexical status of phrasal verbs supports what Jackendoff (2002b, p. 154) claims about lexical items (i.e. “unit[s] stored in long-term memory”): they “may be larger or smaller than grammatical words”. Our first main finding thus ties in with a basic tenet of constructionist theories of language (Goldberg, 1995, 2003, 2006; Lakoff, 1987), namely that stored form-function pairings can differ considerably in size and level of complexity and abstractness, ranging from single morphemes and words, over recurrent phrasal units of words, to very schematic but still meaningful patterns, traditionally known as ‘constructions’, and including mixed cases or “constructional idioms”, that is, patterns which contain one or more open slots yet to be filled in as well as one or more pre-installed lexical elements (e.g. verb *one’s {head/ass/butt/...} off* = ‘verb very intensely’). So, in constructionist frameworks, no distinction is made between lexicon and syntax; rather, there is one single storage space for listed items: an extended lexicon or ‘construct-i-con’.

We would not like, however, to present our data as an unambiguous support for the constructionist account. In fact, the constructionist abolition of a distinction between lexical and syntactic phenomena does not appear to be supported by previous neuroscience evidence. As we stated above, our experiment hinges precisely on the fact that grammatically correct phrases and lexically appropriate items exhibit a reverse pattern of responses in comparison to their ill-shaped counterparts. Consider the German sequence *der Mut* (‘the courage’). This word combination has very high usage frequency: in German-language websites searched by Google, over 400.000 hits were found for it. Yet, as we noted in the Introduction, it appears that this sequence fails to trigger the same kind of stronger early brain response as single existing words. This fact is damaging to the constructionist belief that words and frequent phrases are stored alike, for if they were really both treated as lexical units on a par, we should expect to find that both of these units trigger an enhanced brain response. Given the opposite neurophysiological signatures of lexical and syntactic combinations of linguistic materials (Pulvermüller & Shtyrov, 2006), it appears well-motivated to maintain a linguistic distinction between word-level and phrase-level units. A neurobiological model attributes the two effects to two fundamentally different processes at the nerve cell circuit level, the amplification of activity related to the full “ignition” of a lexical nerve cell circuit (Garagnani, Wennekers, & Pulvermüller, 2008) and the priming and subsequent reduced activation (“primed ignition”) of such circuits provided by the grammar network (Pulvermüller, 2003; Pulvermüller & Knoblauch, 2009).

We should complement this critical remark on constructionist approaches to grammar by a similar one on generative approaches: In reporting neurophysiological evidence for the lexicality of phrasal verbs, which are allowed to be broken apart by syntactic operations (e.g. *right*-insertion, cf. the Introduction), we here provide proof that potentially separable multi-word items can nonetheless be words themselves, and thus against the validity of a once well-established linguistic principle, the *Lexical Integrity Principle* (Chomsky, 1970; Lapointe, 1985; Di Sciullo & Williams, 1987).

4.4. Both semantically opaque and transparent phrasal verbs are lexically listed

A second theoretically relevant conclusion (question (2), see Introduction) is that the lexical brain signature of phrasal verbs emerges not just for partly opaque phrasal verbs (*heat up*, *cool down*) but for fully transparent ones as well (*rise up*, *fall down*). Thus, semantics does not seem to be relevant and, if our logic is flawless, both kinds of phrasal verbs should be listed in the lexicon (supporting Assumption B sub (2) in Table 1).

Apart from fully transparent and metaphorically motivated phrasal verbs, there are also quasi-fully idiomatic phrasal verbs such as *make out* and *give up*, where any semantic motivation of the constituent parts is hard to find. Since the link between the form and the meaning of these latter combinations is so unpredictable, there is no other option for them than to be stored in the lexicon. Given that we found evidence of lexical storage for combinations whose status as listed items is more controversial (transparent and partly motivated ones), we can conclude – based on the present findings and their interpretations along with linguistic observations about the lexical unity of idiomatic combinations – that idiomatic phrasal verbs are indeed stored as well.

The lexical listing of *transparent* combinations is an interesting finding, since these combinations in fact *need not* be stored. As stated in the Introduction, they can be linguistically analyzed as combinations of a motional verb and a 'free' adverbial element joined together by the same syntactic rule which can be used to combine, say, *crawl* and *towards the edge of the water*, and there is nothing, in principle, which prevents transparent combinations to be constructed this way. Insofar as the transparent phrasal verbs used in our experiment are indeed 'rule-abiding', their lexical storage can be described as *redundant*. The fact that the lexical pattern predominates in the brain response means that the retrieval of the phrasal verb as a prefabricated lexical ‘chunk’ seems to have priority over its rule-governed construction – at least in the present experimental context.

Future research may focus on the role of the frequency (and associated NSP value) of verb-particle combinations and its influence on the neurophysiological effects they elicit. In the present study, we found the same lexical pattern responses to semantically transparent and more opaque items with high frequencies: Though there were inevitably frequency differences between the items, all of them occurred more than 50 times in the BNC (cf. again Table 3). It remains to be explored whether our results generalize to less frequently occurring items.

4.5. Redundant storage and the relationship between lexicon and grammar

That there are memory traces even for transparent (and therefore ‘rule-abiding’) multi-word items has important implications for how we should conceive of the lexicon and of its relation to (the rest of) grammar.

The lexicon has long been seen as a repository of all and only idiosyncratic facts of language. According to Sweet (1877, p. 480), “The real distinction is that grammar deals with the general facts of language, lexicology with the special facts”. Likewise, Bloomfield (1933, p. 274) described the lexicon as “really an appendix of the grammar, a list of basic irregularities”. This traditional view has been echoed by later linguists, like Di Sciullo & Williams (1987, p. 3), for whom “[t]he lexicon is like a prison—it contains only the lawless, and the only thing that its inmates have in common is lawlessness.” Chomsky, too, adheres to a conception of the lexicon as containing only exceptions to the rules of grammar: “Consider the way an item is represented in the lexicon, with no redundancy, including just what is not predictable by rule” (Chomsky, 2002, p. 118).

Meanwhile, an alternative view of the lexicon is emerging. Some linguists argue that language users do not only store idiosyncratic forms in language memory but also high-frequent regular ones. For instance, Langacker (1987) rejects the idea, referred to by him as the 'rule/list fallacy', that forms which can be constructed by rule cannot also be listed separately in the lexicon. According to him, non-redundant storage is merely a dictate of descriptive economy, as there is no factual ground to assume that language users do not employ the brain's vast storage capacity to commit to long-term memory some of the frequently occurring instantiations of constructional schemas. Moreover, redundant storage may be more efficient than non-redundant storage, since frequently used combinations can be quickly retrieved as pre-assembled chunks without having to be constructed or processed anew on each usage occasion. It is now generally accepted by cognitive linguists that complex pairings can become *cognitive routines* or *units* if they are used with sufficient frequency. Accordingly, even some fully transparent combinations, which in principle *could* be built compositionally by the combinatorial language system, are thought to be stored and accessed as wholes rather than produced 'from scratch'. Similarly, in Goldberg's (2006) formulation of a constructionist outlook on grammar, any frequently occurring combination of words is assumed to be stored, whether that combination is idiosyncratic or not. Frequency of use and cognitive entrenchment are also fundamental in usage-based approaches to language (learning): multiple, concrete instances of language use are claimed to lie at the basis of speakers' mental grammar: a grammar rule is not 'innate' but is extracted from its regular instantiations – it gradually emerges from learned exemplars (e.g. Barlow & Kemmer, 2000; Tomasello, 2003; Bybee, 2006). In a neurobiological framework, syntactic rule formation has been related as an emergent property of the learning and storage of word strings and the substitutions between string members normally encountered (Pulvermüller & Knoblauch, 2009).

There is a growing body of experimental evidence that redundant storage of regular forms does indeed occur. With respect to word inflection, for example, several researchers have proved psycholinguistically that full inflectional forms with a sufficiently high rate of actual occurrence are stored as units even if they can also be derived by rule (e.g. Sereno & Jongman, 1997; Baayen et al., 1997, 2002; Alegre & Gordon, 1999). Even strong proponents of the dual route theory, according to which "irregular and regular inflection, and words and rules more generally, depend on different systems in the brain" (Pinker, 1999, p. 255), recognize that medium- and high-frequent regular forms can also have stored representations (Pinker & Ullman, 2002, p. 458). Our second finding is in consonance with these studies, in that we have provided evidence that common phrasal verbs appear to be lexically listed, *even in cases where they could just as well have been put together from their parts by the grammar system*. Moreover, the brain responses indicate that lexical access processes have priority over rule-based decomposition in the case of common verb-particle combinations.

4.6. Neurophysiological explanation

As our first main finding indicates that the neurobiological links between the constituents of a multi-word unit can be of a similar kind as the links between morphemes, syllables or sounds within a single word, it follows that the lexicon-syntax distinction (which is needed; cf. section 4.3) does not coincide with the distinction between single words and assemblies of multiple words, as they appear in written text. This raises the question about the brain mechanisms underlying the lexical enhancement of the brain response to phrasal verbs and the reverse effect, the reduced brain responses to common syntactic word sequences (relative to ungrammatical word sequences), such as a noun preceded by its grammatically agreeing determiner (e.g. German *der Mut*).

As explained above, a neurobiological model of language relates the two opposed effects to two distinct processes at the level of neural circuits: "full ignition" and "primed ignition". The former may reflect the amplification of activity when a lexical nerve cell circuit activates (Garagnani, Wennekers, & Pulvermüller, 2008). The latter is grammatical in nature, occurring when a given lexical circuit primes, by way of a link through the grammar network, a second one, whose own full activation amplitude is thereby reduced compared to its full activation amplitude when ignited from rest (Pulvermüller, 2003; Pulvermüller & Knoblauch, 2009). Accordingly, then, the 'matching' verbs and particles in our experiment are instantiated in the brain as complex, higher-order lexical nerve cell circuits which ignite as wholes.

Consider the basic lexical nerve cell circuit corresponding to, for instance, *up*. This circuit ignites upon acoustic presentation of *up*, but when *up* follows *rise* or *heat*, there is added brain activity caused by the ignition of the higher-order nerve cell circuit corresponding to the compounds, the phrasal verbs *rise up* or *heat up*; such added activity is absent when *up* is presented after the verbs *fall* or *cool*, whose corresponding nerve cell circuits at the brain level do not form a complex lexical nerve cell circuit with that of *up*. This model accounts for the lexical enhancement effect of the former combinations compared to the latter.

What a determiner does, by contrast, is raise the expectation of the presence of a noun *of the right type* – not a *particular* noun with which it might form a complex lexical item. In the case of the German determiner *der*, one legal possibility is for the following noun to be singular, masculine and in the nominative case. The word *Mut* meets these expectations and, at the level of brain mechanics, the activation of its corresponding nerve cell circuit is then less pronounced than when *Mut* were presented in a context where it would not be anticipated. The likely reason for this is that *Mut*'s nerve cell circuit had already been pre-activated ('primed') by the nerve cell circuit of *der* – due to connections with additional circuits processing combinatorial grammatical information about word strings – and is therefore not enhanced so much any longer in its activation upon *Mut*'s presentation. In contrast, such priming and subsequent reduced activation of (a part of) *Mut*'s nerve cell circuit would not happen if *Mut* appeared in a grammatical context which is alien to it.

Of course, it could be surmised that the nerve cell circuits of *rise* and *heat*, which are lexical items in their own right, must also prime and thus reduce the full activation of the nerve cell circuit of *up*, but such primed ignition of *up*'s circuit, if it occurs, appears to be outweighed by the explosion-like ignition of the strongly interconnected nerve cell circuits of the larger lexical items, *rise up* and *heat up* (see Garagnani, Wennekers, & Pulvermüller, 2008 for relevant simulation results). The fact that lexical enhancement of *der Mut* compared to, say, the ungrammatical **die Mut* does *not* occur can be explained on the basis of a qualitatively different neuronal link, which does support priming between lexical nodes, but not the simultaneous ignition of competing lexical circuits. A formal model of a neuronal grammar along the lines indicated here has been elaborated in an earlier publication (Pulvermüller, 2003). We haste to add that the treatment of particle verbs in that publication was, however, based on syntactic linkage between verb stem and particle, a feature which, after our present results, now needs to be revised.

Irrespective of the ultimate neurophysiological explanation of the opposite effects of lexical and syntactic coherence, it remains important to note that the opposite effects for phrasal verbs such as *rise up* and *cool down* on the one hand and for grammatical sequences like *der Mut* or *he comes* on the other correspond to a wide-spread and strong intuition that the former but not the latter kind of sequences are lexical items in the usual sense. Observe, as evidence for this intuitive distinction, that the former but not the latter take the form of entries in dictionaries. Therefore, it should not come as a surprise that phrasal verbs, unlike frequently heard determiner-noun or subject-verb sequences, trigger word-like responses. The above neurophysiological mechanisms might provide an explanation for this intuition and the resulting lexicographical convention.

5. Conclusion

The MEG experiment on the cognitive and neurophysiological status of common verb-particle combinations reported here is the first to provide support, using data directly taken from the brain, for the position that language users store prefabricated chunks of lexical material (1) which consist of more than one word and which can potentially be separated (e.g. *heat the room up*) and (2) which make metaphorical sense (e.g. *heat up*) or which are even semantically fully compositional (e.g. *rise up*). Our findings support a conception of the mental lexicon as including common, but not necessarily ultra-frequent, multi-word items that allow a discontinuous manifestation as well as the idea that there are even semantically predictable word combinations which are not assembled 'on-line' from their parts, but which are stored and retrieved as wholes instead.

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Table titles and legends

Table 1. Summary of the main competing linguistic positions on the status of phrasal verbs and the role of semantics, and the associated conflicting experimental predictions about neurophysiological correlates, on the background of pre-existing Mismatch Negativity research.

Table 2. Experimental design. Standard and deviant stimuli are given for each of the four experimental conditions (‘blocks’). The probability with which each stimulus occurred within a block is indicated at the top of the column (in percent). At the bottom, a short example sequence containing standard and deviant stimuli is given for experimental block 1. Note that block order was counterbalanced between subjects.

Table 3. Word frequencies and normalised sequential probabilities (NSP) for all standard and critical deviant stimulus words and word combinations, based on the 100 million word British National Corpus (BNC), accessed via Davies’s (2004) interface.

[1] Frequencies given for *up* and *down* (in isolation and in combination with the standard stimuli) are for their use as particles, since *up* and *down* were recorded with the intonation of a particle (rather than that of a preposition) vis-à-vis the preceding word.

[2] NSP values are multiplied by 10^9 for ease of presentation and interpretation.

Figure legends

Fig. 1. The stimuli were presented in counterbalanced fashion, in which the particle renders the whole standard-deviant combination pair as an existing phrasal verb or as an infelicitous verb-particle combination. Additional filler items were included in order to keep the percentage of the critical combinations low (maintaining the requirements of optimum oddball paradigm for responses elicitation), and to provide competitive environment for the particles.

Fig. 2. Shown are data from the channel with maximum response amplitude in the grand-average data (MEG0242, after SS and realignment). Note the divergence (highlighted in yellow) between the responses to physically identical items presented in different contexts. This difference was maximal at ~190 ms. Note also that the dynamics shown by the MMNm (shown in (a)) is identical to that seen in oddball ERFs before the subtraction (shown in (b)). Other gradiometer recordings showed similar enhancement of the magnetic brain response to congruent verb-particle combinations, especially over temporal and parietal areas (Figures 3 and 4).

Fig. 3. RMS values were calculated from all 204 gradiometer channels. Note that event-related magnetic brain responses were larger to particles presented in congruous contexts than responses to the same items placed in infelicitous contexts. Furthermore, note the absence of significant differences between metaphorical combinations (with a non-spatial use of the particle) and transparent combinations (with a spatial use of the particle).

Fig. 4. Each local field gradient value is calculated as the RMS of two orthogonal gradiometer recordings and differences between RMS values are shown (congruent minus incongruent). Note the bilateral distribution of the effects suggesting contributions of temporal and parietal cortex.

Figure Titles

Fig 1. Spectrograms of spoken verb-particle stimuli and illustration of experimental design.

Fig. 2. (a) Magnetic mismatch negativity (MMNm, i.e. deviant response – standard response) and (b) ‘oddball’ (i.e. deviant response) event-related magnetic fields elicited by critical particles in context of legal and illegal verb stems.

Fig 3. Mean values of RMS amplitudes (+/- standard errors of mean) produced by the same particles in existing phrasal verbs and in infelicitous contexts.

Fig. 4. Topographical maps of field gradient amplitude difference between responses to the same critical stimuli (particles) presented in felicitous and infelicitous contexts in left and right hemispheres.