Psicológica (2013), 34, 253-271.

Temporal constraints on the comprehension of motor language. An embodied semantics approach

Eduardo Santana* and Manuel de Vega

University of La Laguna (Spain)

This paper investigates how language comprehension is modulated by temporal information, marked by time adverbs, and bodily constraints imposed by motor actions. The experiment used a paradigm similar to that employed by de Vega, Robertson, Glenberg, Kaschak and Rinck (2004), but included significant refinements in the materials and the procedure, allowing for stronger theoretical conclusions. Participants read sentences describing two manual actions as simultaneous or consecutive by means of the adverbs *while* or *after*, respectively (e.g., *While [After] cleaning the wound he unrolled the bandage*). Comprehension was more difficult (longer reading times and lower sensibility rates) when actions were described as simultaneous. This indicates that the semantics of time marked by temporal adverbs is not an independent dimension, but interacts with the motor properties of the described actions. These results cannot be easily explained by the temporal iconicity assumption, but they are consistent with embodied theories of language such as the indexical hypothesis.

This paper explores the semantics of temporal constructions in a particular case: when sentences describe an agent performing two motor actions either simultaneously or successively using the adverb *while* or *after*, respectively. We are concerned with how embodied constraints, under the grammar guidelines, modulate the comprehension of these temporal constructions. Thus we hypothesize that *while*-sentences only demand more cognitive resources than *after*-sentences when the two simultaneous actions

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* This research was supported by the Spanish Ministry of Science and Innovation (Grant SEJ2011-28679), the Canary Agency for Research, Innovation and Information Society (NEUROCOG project), and the European Regional Development Fund. We thank Víctor Romeo and the SAI of the Faculty of Psychology for their help in preparing the experimental software. Corresponding author: Eduardo Santana. Departamento de Psicología Cognitiva, Facultad de Psicología. Universidad de la Laguna, Campus de Guajara, 38205 La Laguna, Tenerife (Spain). Tel.: +34 922317511. Fax: +34 922317461. E-mail address: esangal@gobiernodecanarias.org

referred to in the sentence share effectors and therefore cannot be easily simulated at the same time.

Temporal information is an important dimension of language. In fact, it is practically impossible to produce an utterance without placing the described events in time (Madden & Ferretti, 2009). Temporality is marked, in some languages mandatorily, by means of different linguistic resources (Zwaan, 1996). Grammatical tense is the first and most general linguistic temporal marker, and exists in almost every language in the world (Comrie, 1985). However, the information provided by tense morphemes is scarce, indicating only if the event is in the past, present or future with reference to the moment of the utterance, and in some cases whether it occurs continuously or one time only. To increase the temporal resolution, language repertoires include time adverbs and phrases, which allow speakers to locate events more accurately in temporal frameworks (e.g., yesterday, next week, in January 2010, etc.).

Sometimes, language users are primarily concerned with explicitly expressing the temporal relation between two or more events, relating them as either consecutive or simultaneous by means of adverbial constructions like *before, after, while*, etc. However, these markers are absent in many cases, because temporal relations are sometimes implicit in the text or discourse. According to some linguists, to communicate temporal relations, both speakers and addressees are guided by the temporal iconicity assumption; namely, the order of the clauses or sentences usually matches the order of the events being referred to (Chafe, 1979; Comrie, 1985; DeClerck, 1991; Dowty, 1986; Fleischman, 1990; Givón, 1992; Hopper, 1979). Thus, in the sentence “the mechanic tightened the screw and cut the cable”, despite the absence of an adverbial temporal marker, the reader would interpret that the mechanic first tightened the screw and then cut the cable. One possible psychological explanation for the iconicity assumption is that events in everyday life access consciousness in a chronological and sequential manner (Zwaan & Radvansky, 1998). Some authors even postulate a strong version of the iconicity assumption (Zwaan, 1996). They claim that not only does the sequence of clauses or sentences preserve the order of the events, but it also supports the assumption that the events occur continuously, without any disruption (e.g., Dowty, 1986). Thus, in “the *mechanic”* example, the reader would assume that the two actions occurred contiguously in time, and without any pause between them. According to the strong iconicity assumption, only when the speakers want to express a mismatch between the iconic order of the clauses and the order of events in the world or a break of continuity between them will they rely on adverbial markers. For instance, "the mechanic went into the garage and *one hour later* cut the cable; *before* he had found the pliers".

Some evidence exists about the psychological reality of the iconicity assumption. Most refers to the analysis of the cognitive cost of the markers. As mentioned above, the iconicity assumption posits that readers follow the mention order of the text units to represent the order of the events, unless a linguistic marker specifies otherwise. The use of these markers, such as time adverbs or phrases, to reconstruct the order of the events from non-iconic discourse would involve additional cognitive cost. Evidence of such cognitive cost exists. For example, Münte, Schiltz and Kutas (1998), in an ERP study, presented sentences with two clauses where independent actions could be preceded by the adverbs *after* or *before* (e.g., *Before/after the psychologist submitted the paper, the journal changed its policy*). Thus, in some versions (*after*), the chronological order of the actions matched the order in which they appeared in the sentence, whereas in the other versions (*before*), the order was altered. They found that there was a larger negativity with a left anterior focus in versions starting with *before* than in versions starting with *after*. These differences were greater in participants with a larger memory span. This finding was interpreted as an evidence of greater working memory load in *before* versions, that is to say, versions where the mention order does not match the chronological order.

It must be said, however, that although the iconicity assumption is useful in explaining how readers represent certain temporal aspects during text comprehension, it treats time as an additive factor that is independent of other types of information. Therefore, it fails to explain certain phenomena, such as the interaction of time with other dimensions like space or causality. For example, Radvansky, Zwaan, Federico and Franklin (1998) used sentences that described a character as performing one or three actions which were either integratable, i.e. they could all be performed by the same person in the same place (*The engineer was folding a towel / biting his lip / listening to the radio*), or non-integratable, i.e. unlikely to be performed by the same person in the same situation (*The teacher was reading a novel / playing pinball / playing the piano*). They found a sentence fan effect (the larger the number of associations a concept has, the longer its retrieval time is; Anderson, 1974) in a recognition task only for the non-integratable sentences, which were associated with longer response times than integratable sentences. This suggests that to integrate actions into a temporal situation model, the described actions must be consistent with that situation. In another study, de Vega et al. (2004) employed sentences describing a character performing two actions either simultaneously or successively, by means of the adverbs *while* and *after*, respectively. The two actions involved either the same motor effectors (e.g., *While [After] chopping wood with his large axe, he painted the fence white*) or different motor effectors (e.g., *While [After] whistling a lively folk melody, he painted the fence white*). They found longer reading times and lower coherence ratings when both actions relied on the same effectors and were described as simultaneous rather than successive. By contrast, when the actions employed different effectors, no differences were found between a simultaneous or successive timing. Finally, when one of the same-effector actions was presented as a mental plan (e.g., *While [After] chopping wood with his large axe, he thought of painting the fence white*) again no differences were reported between the simultaneous and successive conditions. In other words, the difficulty of *while*-constructions only arises when the events being referred to are two motor actions that are difficult to perform at the same time.

A strong iconicity assumption would predict that *while*-constructions are always difficult to process, because of the fact that the simultaneous events are described by means of successive clauses. Namely, the iconicity assumption claims that temporal information is an additive and independent parameter that is used to place events in time, regardless of the nature of other information conveyed by the sentences. The aforementioned experiments clearly conflict with this assumption, because they demonstrate that the understanding of temporal information is modulated by other parameters (i.e. situational, motor) that might determine the plausibility of placing the events in a particular chronological order. The embodied cognition approach offers a possible explanation for these facts: the temporal cues and other sources of information in the text prompt the reader to perform sensory-motor grounded simulations of the events, subject to environmental and bodily constraints. Embodied cognition theories assume that information processing involves brain systems for action, perception or emotion and, in this sense, is grounded or embodied (e.g., Barsalou, 1999; Kaschak & Glenberg, 2000; Lakoff & Johnson, 1980; Pulvermüller, 2005). Thus, de Vega et al.'s (2004) findings can be interpreted in the framework of embodied theories such as the indexical hypothesis (Glenberg & Robertson, 1999, 2000). The indexical hypothesis posits that sentence comprehension requires three processes: first, words and phrases are *indexed* to their referents, then, the *affordances* of these referents are derived and, finally, guided by the grammatical cues in the sentence, these affordances are *meshed* according to physical and biological constraints. Consider a sentence like "*The mechanic took the pliers and cut the cable*". According to the indexical hypothesis, words like *pliers* or *cable* would be indexed to their referents in the reader's memory. Then, their affordances would be derived; for instance, pliers can afford cutting a cable, screwing a nut or tightening a screw, but not peeling an apple. Finally, the sentence grammar would guide a mental simulation that attributes to the "mechanic" the role of agent for the cutting action, and combines the affordances of *pliers* and *cable*. If the affordances do not fit into a feasible mental simulation of the action (such as in the sentence *The mechanic cut the cable with an apple*), comprehension would be impaired, even thought the sentence is syntactically correct.

The starting point of our investigation is the aforementioned work by de Vega et al. (2004), where motor coherence, as implied by the adverbs *while* and *after*, was found to determine comprehension. In de Vega et al.'s study, the simultaneity conditions were made sensible or non-sensible by using pairs of actions involving either different effectors (e.g., mouth and hands/arms) or the same effectors (e.g., hands/arms in both actions). However, as the authors recognized, the description of simultaneous same-effector actions does not always determine a non-sensible sentence. First, in some cases, same-effector actions could be compatible and executable at the same time (as in *snapping one's fingers while conducting a band*), and therefore the corresponding sentences would be sensible. Second, the relative duration (long vs. short) of two same-effector actions could make them interpretable as compatible, exhibiting a figure-ground temporal effect (Talmy, 2001). Thus, de Vega, Rinck, Díaz and León (2007) found that *while*-sentences were read faster and judged as more sensible when the long-duration event was placed in the adverbial clause, playing the role of *ground*, and the short-duration event was in the main clause as the *figure* (e.g., *While John was writing a letter, Mary came into the room*) than vice versa (*While Mary was coming into the room, John wrote a letter*). This fact could also be applicable to the current case of simultaneous same-effector actions performed by a single agent. For example, in the sentence *While he was painting the wall he switched on the radio*, the reader could interpret that the character momentarily interrupted the long-duration action (*painting the wall*), to perform the short-duration action (*switching on the radio*). Finally, de Vega et al. (2004) did not control that pairs of actions involving different effectors were not incompatible due to situational or spatial restrictions (e.g.: *While he was running, he served a cup of tea*).

This paper tried to study motor coherence effects as modulated by temporal adverbs. As in de Vega et al.'s (2004) study, participants read pairs of actions described as simultaneous or consecutive by means of the adverbs *while* or *after*, respectively. However, the materials were controlled in several ways to overcome the aforementioned limitations in their study. Firstly, we only employed materials describing same-effector actions.

Specifically, we selected manual actions forming part of the ordinary human repertoire, because they have wider range of variety and complexity and involve larger neural networks than actions involving the legs or mouth (Pulvermüller, 2002). Secondly, we chose pairs of actions with similar duration. This was done to avoid situations where *while*-sentences might be accepted as sensible due to the varying duration of the actions, as may happen (de Vega et al., 2007). Finally, we employed pairs of actions belonging to the same situation to avoid cases in which *after*-paragraphs could be interpreted as non-sensible for belonging to different spatial-temporal frameworks (Johnson-Laird, 1983; Radvansky et al., 1998).

According to embodiment theories such as the indexical hypothesis, readers of action-related paragraphs mentally simulate the events described. In this study, each paragraph describes two manual actions performed by an agent and we predict that their simulation will be more difficult to perform, due to bodily constraints, when they are described as simultaneous than when they are described as successive. Consequently, comprehension will be impaired in *while*-paragraphs, slowing reading times and leading to the sentence being judged as less sensible than in *after*-paragraphs. It is not clear what predictions might be derived from the strong iconicity assumption, a disembodied approach (de Vega et al., 2004). One might expect that understanding *after*-paragraphs would be easier than understanding *while*-paragraphs, because the former match the iconicity assumption: what was mentioned first, occurred first. If so, this prediction would be indistinguishable from the embodied simulation prediction. To overcome this difficulty, this experiment included additional control materials, which reversed the sensibility values of the *while*- and *after*-paragraphs, as will be explained later. In the case of the control materials, the predictions from the embodied approach and the iconicity assumption diverge. For the iconicity proposal, *while*-paragraphs will be still more difficult to understand than *after*-paragraphs, because the temporal parameters conveyed by the adverbs are the same as in the homologous experimental sentences. By contrast, for the embodiment approach, the reading times will be larger for the *after*-paragraphs (events described in a non-canonical order) than for the *while*-paragraphs (events that do not violate embodied constraints). An additional function of these control sentences, as explained in the method below, was to avoid having participants employ a superficial strategy to produce sensibility responses.

METHOD

Participants. Thirty-seven students of psychology of the University of La Laguna (29 women), with ages ranging from 18 to 31 (M = 19.3; SD = 2.8) took part voluntarily in exchange for academic credit. They all were native Spanish speakers and had normal or corrected vision.

Design and Materials. The experiment included only a within-participant manipulation of the two temporal adverbs (*while* vs. *after*) placed in the first clause of each experimental paragraph. In Spanish this manipulation involves some formal differences between the two adverbial constructions: the *after* clause uses two words (*después de*) and the infinitive verb, whereas *while* clause employs only one adverbial word (*mientras*) and the imperfect past tense verb. Forty experimental paragraphs were created, each consisting of a title, a first clause containing the adverb and a manual action, a second clause including another manual action, and a third clause describing the purpose of the second action. The intention was for the second clauses to be sensible in the context of *after* and non-sensible in the context of *while*.

In addition, 40 control paragraphs were written with the same *while*/*after* structure as the experimental ones, but with reversed sensibility values in the second clause. Sensible *while*-paragraphs included either a non-motor or a long-duration (interruptible) motor action in the first adverbial clause and a manual action in the second clause. These combinations of events should make the second clause sensible in the context of the previous one. On the other hand, non-sensible *after*-paragraphs included a change in the canonical order of the two actions, creating an absurd or impossible sequence of events. The *while*/*after* control materials tried to ensure participants would not rely on superficial processing by employing simple rules of thumb: "if *while* → non-sensible", and "if *after* → sensible". For the same reason, the third clause was made incongruent in seven experimental *after*-paragraphs and in seven control *while*-paragraphs to discourage readers from simply focusing on the second-clause sensibility. With respect to the second critical clause, participants thus received a total of 20 non-sensible *while*-paragraphs, 20 sensible *while*-paragraphs, 20 sensible *after*-paragraphs and 20 non-sensible *after*-paragraphs. Finally, 40 filler paragraphs with varied linguistic structures (except *while*- and *after*-constructions) were also written; 34 fillers were sensible and 6 were non-sensible, to correct for the imbalance resulting from the fact that 7 experimental and 7 control paragraphs were inconsistent in the third clause. Thus, the whole set of materials included 60 sensible paragraphs and 60 non-sensible paragraphs. Five practice items were also created. Examples of each type of item are shown in Table 1.

All paragraphs were followed by a YES/NO sensibility judgment task and by a probe word that may (positive probes) or may not (negative probes) have been present in the paragraph. Positive probes were presented in half of the paragraphs, and belonged with the same probability to any of the three clauses. Two counterbalance conditions were created, resulting from the assignment of the adverbs to the experimental paragraphs. Namely, for half of the participants a set of 20 experimental paragraphs was presented in the *while* version and another set of 20 paragraphs was presented in the *after* version, and for the other half of the participants, the *while/after* versions were reversed for the two sets of paragraphs.

Normative studies. To avoid the aforementioned limitations in de Vega et al. (2004), we conducted three normative studies, aimed at improving the experimental materials. The studies involved a total of 234 students from the University of La Laguna, none of whom participated in the main experiment. The objective of the first study was to select pairs of manual actions with equivalent duration, to avoid having readers infer that the longer action was momentarily interrupted to carry out the shorter one. A group of 108 participants were given booklets with 20 pairs of actions each presented randomly, with instructions to estimate the duration of each action in seconds, minutes or hours. These estimations were standardized (mean duration, in seconds) and the duration of each pair of actions was contrasted. Pairs with different durations were reformulated and once again evaluated, following the same procedure, until all pairs were judged as of similar duration (first action in the pairs: M = 211 seconds, SD = 411; second action in the pairs: M = 295 seconds, SD = 618.79, (t (39) = 1.29; $p > .05$).

The second study aimed to know how people usually represented the actions, either as visual or as motor events. A group 104 students were asked to estimate whether, when thinking about an action, they imagined themselves *doing* it or *seeing* themselves or someone else doing it. Participants received a booklet with 40 sentences, and were asked to define their representation in a bipolar scale ranging from -5 (totally visual) to +5 (totally motor). To be sure that the full range of the scale was used, 10% of the actions included in the booklets corresponded to particularly unfamiliar actions (e.g., *loading a gun*) that served as contrast elements. Participants judged only 5.5% of the actions as more visual than motor. These actions were modified and once again submitted to evaluation. At the end, all actions were judged to elicit preferably motor images (M = 2.97; SD = 1.12).

Table 1. Examples of the original Spanish material and their English translation. Self-paced segments are separated by a slash.

Experimental paragraphs (40)
ARAÑAZO / Mientras limpiaba (Después de limpiar) la herida / desenrolló el esparadrapo / para ponérselo en la rodilla. Prueba: ***ensuciaba*** *SCRATCH / While (After) cleaning the wound / he unrolled the bandage / to put it over the knee.* *Probe: ***dirty****
Control *while* sensible paragraph (20)
BARRENDERO / Mientras barría el suelo / recogió una lata / para meterla en la papelera. Prueba: ***barría*** *SWEEPER / While sweeping the floor / he picked up a can / to put it into the litter bin.* *Probe: ***sweeping****
Control *after* non-sensible paragraph (20)
CONDUCTOR / Después de ponerse el cinturón / entró en el coche / para ir al trabajo. Prueba: ***ir*** *DRIVER / After putting the seatbelt on / she got into the car / to go to work.* *Probe: ***go****
Filler sensible paragraph (34)
ARTISTA / El escultor empezó a tallar / el mármol / y pronto acabó su obra. Prueba: ***profecía*** *ARTIST / The sculptor began to carve / the marble / and soon finished his work.* *Probe: ***prophecy****
Filler non-sensible paragraph (6)
FELIZ / La niña era muy alegre / por lo que rara vez hablaba / y solía estar deprimida. Prueba: ***deprimida*** *HAPPY / The girl was very joyful / so she rarely talked / and was frequently depressed.* *Probe: ***depressed****

Finally, the third normative study aimed to ensure that the pairs of actions belonged to the same spatial-temporal context or situation (Johnson-Laird, 1983; Zwaan & Radvansky, 1998). This was to avoid any discontinuity, which could make it difficult to integrate them into the same situation (Radvansky et al., 1998). An online survey was completed by 22 voluntary participants, who were asked to estimate on a five-point scale how often pairs of actions occurred in the same situation (1: actions never happen in the same situation; 5: actions very often happen in the same situation); we included 80 pairs of experimental actions as well as 15 non-experimental pairs referring to clearly discontinuous actions (e.g.," *throwing a Frisbee* and *playing piano")* to ensure that participants used the full scale. Virtually all the experimental pairs were judged as happening in the same situation very frequently (M = 3.91, SD = .59), unlike the fillers (M = .46, SD = .32).

Lexical controls. We were interested in contrasting *after*- and *while*-control materials, but unlike in the experimental paragraphs, they differed in the second clause. Thus, it was necessary to control for their lexical variables. Word frequency, obtained from Alameda and Cuetos' (1995) dictionary, and word length (in number of syllables) in the second-clause verb and noun were statistically matched between after- and while- control materials (see Table 2).

Table 2. Word frequency (in words per million) and length (in syllables) at the second clause in the control materials. SDs in parentheses.

	Sensible *while*	Non-sensible *after*
Frequency	254 (296)	343 (594)
Length	6.85 (.67)	6.95 (.99)

Procedure. Participants were randomly assigned to one of the two counterbalanced conditions. They first read the instructions on the computer screen. Then they received the five training paragraphs, to become familiar with the task. Feedback was provided to the responses. Finally, they received the complete set of paragraphs (experimental, control and fillers) in random order, and were asked to read them for comprehension.

Participants self-paced the four segments of each paragraph by pressing the keyboard spacebar. Then they were prompted to judge whether or not the paragraph was sensible (*Is this coherent?*). Finally, participants were required to indicate whether a probe word had been present in the text or not. The responses for both the sensibility judgment and the probe word were made with the keys of the mouse, labeled as *yes* and *no*, and speed and accuracy were equally emphasized. No feedback was provided. All response times were registered by the computer.

RESULTS

Experimental paragraphs and control paragraphs were analyzed separately, by means of the Student's t-tests, both for participants (t_1) and for items (t_2). The analyses were conducted on reading times for the first (adverbial) clause, the second critical clause, and the third clause. We also analyzed the reaction times and rates (percent of yes responses) in the sensibility judgment task, and the reaction times and errors in the probe word task. The most important measure was the reading time for the second clause, where the motor congruence/incongruence occurs for the experimental paragraphs. Outlying data two standard deviations above or below the mean were discarded (about 2.7% of the data). One experimental paragraph was also discarded from the analyses for being judged as not sensible in both the *while* and the *after* versions by most participants. Non-sensible third-clause items (seven *after* experimental paragraphs and seven *while* control paragraphs) were excluded from the analysis of sensibility rates, third-clause reading times, and probe word performance, because we were only interested in the sensibility effects located in the second clause.

First-clause reading time. *While* and *after* adverbs did not produce any significant difference in reading times for either the experimental or the control paragraphs ($t_1(36) = .41$, $p > .05$; $t_2(38) = .06$, $p > .05$) . In other words, *while* and *after* adverbs did not have any impact on the processing of the adverbial clause itself, in spite of the formal differences between the two adverbial constructions mentioned before.

Second-clause reading time. The second clause was read 101 ms faster in the experimental *after*-paragraphs than in the experimental *while*-paragraphs ($t_2(38) = 2.39$, $p \leq .022$). By contrast, in the control paragraphs, involving reversed sensibility values, the second clause was read 205 ms faster in the *while*-paragraphs than in the *after*-paragraphs ($t_1(36) = 3.74$; $p \leq .001$). All these effects are illustrated in the Figure 1.

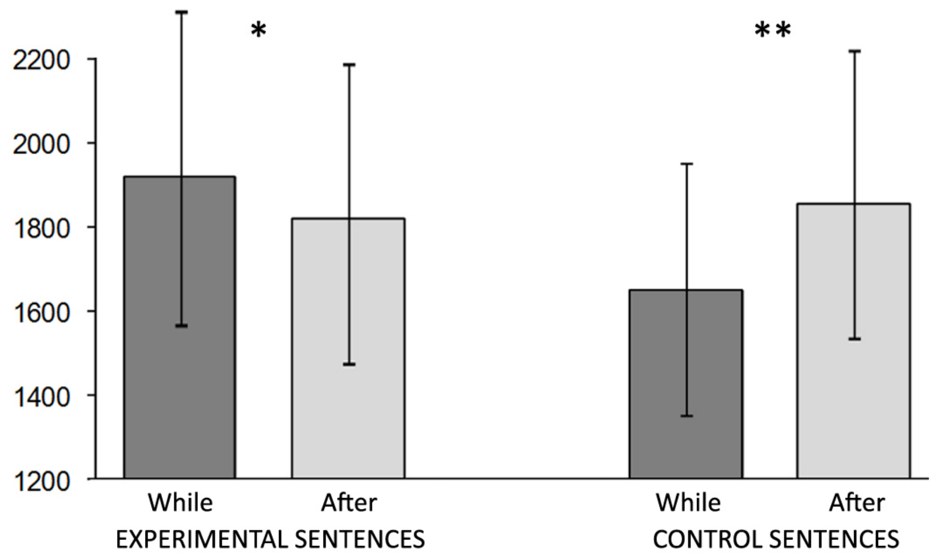

Figure 1: Mean reading time in the second clause. The vertical lines indicate the SDs and the asterisks (*) correspond to significant pairwise comparisons (*p ≤ .05; **p ≤ .01).

Third-clause reading time. As Figure 2 shows, this clause was read 156 ms faster in experimental *after*-paragraphs than in experimental *while*-paragraphs ($t_1(36) = 2.38$, $p \leq .022$). No differences were obtained in this clause between *after*- and *while*-paragraphs in the control materials.

Sensibility judgments. As shown in Table 3, reaction times were 128 ms faster in experimental *after*-paragraphs than in experimental *while*-paragraphs ($t_1(36) = 2.49$, $p \leq .017$;). Furthermore, *after*-paragraphs were associated with higher sensibility rates than *while*-paragraphs ($t_1(36) = 33.55$; $p \leq .0001$). Reaction times were also 78 ms faster in control *after*-paragraphs than in control *while*-paragraphs ($t_1(36) = 2.17$; $p \leq .037$). However, unlike in the experimental materials, control *while*-paragraphs were associated with higher sensibility rates than control *after*-paragraphs ($t_1(36) = 96.52$; $p \leq .0001$).

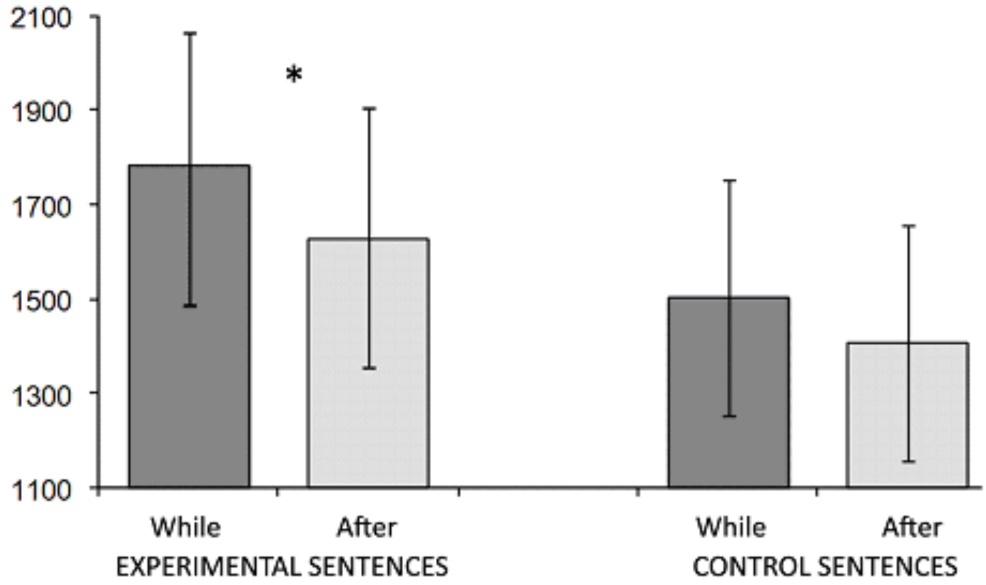

Figure 2: Mean reading time in the third clause. The vertical lines indicate the SDs and the asterisks (*) correspond to significant pairwise comparisons ($p \leq .05$).

Table 3: Reaction times (in milliseconds) and percent of yes responses in the sensibility judgment. SDs in parentheses. Asterisks (*) correspond to significant pairwise comparisons (*$p \leq .05$; **$p \leq .01$).

	Experimental		Control	
	Time	Sensibility (% yes)	Time	Sensibility (% yes)
While (W)	1224 (369)	6.2 (5.9)	1047 (317)	99.3 (1.6)
After (A)	1096 (358)	97.5 (0.4)	969 (335)	3.9 (5.4)
W-A	128 *	-91.3 **	78*	95.4 **

Probe word errors and reaction times. The experimental *after*-paragraphs were associated with more errors than the experimental *while*-paragraphs ($t_1(36) = 2.05$; $p \leq .047$). By contrast, the control *while*-paragraphs produced more errors than the control *after*-paragraphs ($t_1(36) = 2.93$; $p \leq .006$). No differences between *while*- and *after*-versions were found when analyzing reaction times (see Table 4).

Table 4: Reaction times (in milliseconds) and percentage error (%) in the probe word. *SD*s in parentheses. Asterisks (*) correspond to significant pairwise comparisons (*p ≤ .05; **p ≤ .01).

	Experimental		Control	
	Time	Errors	Time	Errors
While (W)	1168 (191)	4.9 (5.6)	1122 (169)	6.4 (8.1)
After (A)	1151 (191)	8.1 (4.9)	1150 (176)	2.2 (3.5)
W-A	17	-3.2*	-28	4.2 **

DISCUSSION

As expected, the experimental paragraphs describing two manual actions performed by an agent at the same time were more difficult to understand than the experimental paragraphs describing the same actions performed successively. The difficulty of the simultaneity condition was evidenced by the longer reading times in the second and third clauses. Furthermore, simultaneous manual actions were judged as less sensible than successive manual actions, indicating that readers are aware of the motor incongruence produced by the simultaneity condition. These results cannot be attributed to any lexical factor, because the second and third clauses tested for reading times were exactly the same in the simultaneous and the successive conditions, nor can they be attributed to the use of superficial rules of thumb such as: "if *while* then non-sensible", because the presence of control paragraphs with reversed *while*/*after* sensibility values and the fact that some experimental *after*-paragraphs become incongruent in the third clause make this kind of response strategy unsuitable. The analysis of the control paragraphs confirmed that, unlike in the experimental materials, *while*-paragraphs were judged as more sensible than *after*-paragraphs.

This study validates and extends de Vega et al.'s (2004) findings, involving a stricter control of materials and procedure, as explained before. De Vega et al. employed relatively heterogeneous materials, involving factors besides embodied constraints that could affect comprehension, such as using pairs of actions with different duration, or using actions that belong to different situations. These uncontrolled factors could introduce noise in the results, because they could determine sensibility rates conflicting with the prediction of the indexical hypothesis. In fact, in de Vega et al. (2004) the sensibility rates for their experimental action *while*-paragraphs were fairly high (33% of Yes responses in Experiment 1A and 45% in Experiment 1B), in contrast with the sensibility rates obtained here for the experimental *while*-paragraphs (only 6% of Yes responses). This indicates that we have been successful in reducing the influence of other factors, and that the observed results mostly derive from the temporal constraints imposed by the adverbs *while* and *after* and the embodied constraints of manual actions.

The most important result obtained here was the difference between *while*- and *after*-paragraphs in the second clause, which was the locus of the motor incoherence. Readers exhibited difficulties in understanding two simultaneous manual actions, as shown by the increase in reading times; this effect was so powerful that it was carried over to the next clause's reading time. In other words, readers have trouble integrating two simultaneous manual actions in the same situation model. This is exactly what might be expected from the indexical hypothesis, according to which temporal adverbs are used as grammatical guides for the process of *meshing* affordances, following bodily constraints. According to this hypothesis, the adverb *while* prompts a simultaneous simulation of the incoming actions, but as both actions depend on the hand and forearm muscles, the simulation fails and hence comprehension is impaired. Notice that it is possible that some readers may try to make a bizarre simulation of the two simultaneous actions in some *while*-paragraphs. For instance, one could think of a way to *clean a wound* while *unrolling a bandage*, using the teeth to hold the bandage and one hand for each action. In any case, this sort of non-standard simulation might take longer than simulating the successive manual actions. These bizarre simulations were probably infrequent in this study given the fact that *while*-paragraphs were judged as non-sensible in 94% of the cases.

The results are not explained as well by the iconicity assumption. If time is an independent and non-interactive dimension of language, as the iconicity assumption claims, then *while*-paragraphs could have been expected to be more difficult to understand than *after*-paragraphs both in the experimental and control materials, because the *while*-construction violates the iconicity assumption. This prediction is similar to the prediction derived from the embodiment approach, but only for the experimental paragraphs. By contrast, for the control paragraphs, the data showed that reading sensible *while*-paragraphs took lesser time than reading non-sensible *after*-paragraphs, which conflicts with the iconicity assumption that always predicts longer reading time for the non-iconic *while*-construction. Moreover, the control paragraph results are consistent with the embodiment approach. Particularly, the control *while*-paragraphs are easy to understand, because there is no conflict in simulating a non-motor and a motor action performed at once, or a short-duration action embedded in a long-duration action (de Vega et al., 2007). A different explanation is required to deal with the difficulty in understanding the control *after*-paragraphs. Their incongruence derives from violating the canonical order of the events in the world, rather than for their motor incompatibility, as in the sentence: *After putting the seatbelt on she got in the car*.

Could these results reflect just a case of general semantic incongruence? We don't think so, because in the experimental sentences, the materials were created with strict sensorimotor and temporal criteria, while matched in lexical and semantic features. Thus, in *while*-paragraphs a single agent was described as performing two same-effectors actions of analogous duration. Consequently, there was a violation of temporal and embodied constraints and the comprehension was impaired. By contrast, when these constraints were relaxed, normal comprehension occurred. This was the case in the experimental *after*-contexts (temporal compatibility) and in the control *while*-contexts (motor compatibility).

A result that seems at odds with the main results was the fact that probes were better recognized following non-sensible *while*-paragraphs than sensible *after*-paragraphs. However, similar results have been reported in the literature: performance in recognition tasks could be better in the context of incongruent sentences than in the context of congruent sentences, as a consequence of the additional elaborative effort expended by the reader to try to extract meaning (O'Brien & Myers, 1985; Waddill, & McDaniel 1998). This explanation is appropriate here, because for the control materials, probes were better recognized following non-sensible *after*-paragraphs than sensible *while*-paragraphs, confirming that the critical factor improving memory retrieval was the extra elaboration demanded by incongruent materials.

In conclusion, this study suggests that temporality cannot be considered as an isolated or additive dimension of language. Specifically, when interpreting temporal information in texts, readers are sensitive to temporal markers such as tense morphemes, time adverbs and phrases, but this information interacts with the motor properties of the described actions. In other words, the representation of meaning derives from meshing the temporality, marked by the adverb, and the bodily constraints of the motor actions. This study confirms previous findings by de Vega et al. (2004), while avoiding the possible confounding factors reported in the previous study. Our experiment's control on materials permits us to more clearly attribute the effects to the motor incompatibility between actions marked as simultaneous by the adverb. Moreover, the study validates the motor incoherence paradigm as a means to study embodied constraints to action language comprehension at the discourse level. Simulation is a central concept for embodied theories of cognition, and a paradigm like the one used here allows us to create conditions, with minimal manipulation of the linguistic materials, in which the simulation of motor actions becomes either feasible or unfeasible.

RESUMEN

Restricciones temporales a la comprensión del lenguaje de acción. Una aproximación desde la semántica corpórea. Este artículo investiga cómo la información temporal establecida mediante adverbios de tiempo y las restricciones corpóreas impuestas por las acciones motoras modulan la comprensión del lenguaje. El experimento emplea un paradigma similar al utilizado por de Vega, Robertson, Glenberg, Kaschak y Rinck (2004), aunque incluye importantes mejoras del material y del procedimiento, permitiendo así establecer conclusiones teóricas más sólidas. Los participantes leyeron oraciones que describían dos acciones manuales como simultáneas o consecutivas por medio de los adverbios *mientras* y *después*, respectivamente (v.g., *Mientras limpiaba [Después de limpiar] la herida desenrolló la venda*). La comprensión fue más difícil (mayores tiempos de lectura y menores puntuaciones de coherencia) cuando las acciones se describían como simultáneas. Esto indica que la semántica del tiempo guiada por los adverbios no es una dimensión independiente, sino que interactúa con las propiedades motoras de las acciones descritas. Estos resultados no pueden explicarse fácilmente a partir de la hipótesis de iconcidad temporal, pero apoyan las teorías corpóreas del lenguaje, como la hipótesis de indexación.

REFERENCES

Alameda, J.M., & Cuetos, F. (1995). *Diccionario de frecuencias de las unidades lingüísticas del castellano* [Frequency Dictionary of Linguistic Units in Spanish]. Oviedo: Servicio de publicaciones de la Universidad de Oviedo.

Anderson, J. R. (1974). Retrieval of propositional information from long-term memory. *Cognitive Psychology, 6*, 451-474.

Barsalou, L.W. (1999). Perceptual symbol systems. *Behavioral & Brain Sciences*, 22, 577-660.

Chafe, W.L. (1979). The flow of thought and the flow of language. In T. Givón (Ed.), *Syntax and semantics: Vol. 12. Discourse and syntax* (pp. 159-181). New York: Academic Press.

Comrie, B. (1985). *Tense*. Cambridge: Cambridge University Press.

de Vega, M., Rinck, M., Díaz, J.M., & León, E. (2007). Figure and Ground in temporal sentences: The role of the adverbs When and While. *Discourse Processes, 43*, 1-23.

de Vega, M., Robertson, D.A., Glenberg, A.M., Kaschak, M.P., & Rinck, M. (2004). On doing two things at once: Temporal constraints on actions in language comprehension. *Memory & Cognition, 32*, 1033-1043.

DeClerck, R. (1991). *Tense in English: Its structure and use in discourse*. London: Routledge.

Dowty, D. (1986). The effects of aspectual class on the temporal structure of discourse: Semantics or pragmatics? *Linguistics & Philosophy, 9*, 37-61.

Fleischman, S. (1990). *Tense and narrativity*. Austin, TX: University of Texas Press.

Givón, T. (1992). The grammar of referential coherence as mental processing instructions. *Linguistics*, *30*, 5-55.

Glenberg, A.M., & Robertson, D.A. (1999). Indexical understanding of instructions. *Discourse Processes*, *28*, 1-26.

Glenberg, A.M., & Robertson, D.A. (2000). Symbol grounding and meaning: A comparison of high-dimensional and embodied theories of meaning. *Journal of Memory & Language*, *43*, 379-401.

Hopper, P.J. (1979). Aspect and foregrounding in discourse. In T. Givón (Ed.), *Syntax and semantics: Vol. 12. Discourse and syntax* (pp. 213-241). New York: Academic Press.

Johnson-Laird, P.N. (1983). *Mental models: Towards a cognitive science of language, inference and consciousness*. Cambridge, MA: Harvard University Press.

Kaschak, M.P., & Glenberg, A.M. (2000). Constructing meaning: The role of affordances and grammatical constructions in sentence comprehension. *Journal of Memory & Language, 43*, 508-529.

Lakoff, G., & Johnson, M. (1980). *Metaphors We Live By*. Chicago: University of Chicago Press.

Madden, C.J., & Ferretti, T.R. (2009). Verb Aspect and the Mental Representation of Situations. In W. Klein & P. Li (Eds.) *The Expression of Time* (pp. 217-240). Berlin & New York: Mouton de Gruyter.

Münte, T.F., Schiltz, K., & Kutas, M. (1998). When temporal terms belie conceptual order. *Nature*, *395*, 71-73.

O'Brien, E.J., & Myers, J.L. (1985). When comprehension difficulty improves memory for text. *Journal of Experimental Psychology*: *Learning, Memory, and Cognition*, *11*, 12-21.

Pulvermüller, F. (2002). *The Neuroscience of Language. On Brain Circuits of Words and Serial Order*. Cambridge: Cambridge University Press.

Pulvermüller, F. (2005). Brain mechanisms linking language and action. *Nature Reviews Neuroscience, 6*, 576-582.

Radvansky, G.S., Zwaan, R.A., Federico, T., & Franklin, N. (1998). Retrieval from temporally organized situation models. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, *24*, 1224-1237.

Talmy, L. (2001). *Toward a cognitive semantics. Vol. 1: Concept structuring systems*. Cambridge, MA: The MIT Press.

Waddill, P.J., & McDaniel, M.A. (1998). Distinctiveness effects in recall: Differential processing or privileged retrieval? *Memory and Cognition*, *26*, 108-120.

Zwaan, R.A. (1996). Processing narrative time shifts. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *22*, 1196-1207.

Zwaan, R.A., & Radvansky, G.A. (1998). Situation models in language comprehension and memory. *Psychological Bulletin*, *123*, 162-185.

(Manuscript received: 10 October 2012; accepted: 5 December 2012)