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Event representations constrain the structure of language: Sign language as a window into universally accessible linguistic biases

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According to a theoretical tradition dating back to Aristotle, verbs can be classified into two broad categories. Telic verbs (e.g., "decide," "sell," "die") encode a logical endpoint, whereas atelic verbs (e.g., "think," "negotiate," "run") do not, and the denoted event could therefore logically continue indefinitely. Here we show that sign languages encode telicity in a seemingly universal way and moreover that even nonsigners lacking any prior experience with sign language understand these encodings. In experiments 1–5, nonsigning English speakers accurately distinguished between telic (e.g., "decide") and atelic (e.g., "think") signs from (the historically unrelated) Italian Sign Language, Sign Language of the Netherlands, and Turkish Sign Language. These results were not due to participants' inferring that the sign merely imitated the action in question. In experiment 6, we used pseudosigns to show that the presence of a salient visual boundary at the end of a gesture was sufficient to elicit telic interpretations, whereas repeated movement without salient boundaries elicited atelic interpretations. Experiments 7–10 confirmed that these visual cues were used by all of the sign languages studied here. Together, these results suggest that signers and nonsigners share universally accessible notions of telicity as well as universally accessible "mapping biases" between telicity and visual form.

language universals | sign language | cognitive biases | telicity

It is well established that human languages are shaped by both cultural and biological constraints (1). On the biological side, sensorimotor restrictions on the production and comprehension of language (2, 3) as well as higher level phonological constraints (4) may systematically shape natural languages. However, the existence of universally accessible properties of meaning remains controversial (5).

In the study of spoken language, it is generally difficult to find compelling evidence for universally accessible units of meaning because although such elements may be present, they may also lack an overt morphological marking that would provide visible proof of their existence (6–9).

Sign languages can potentially offer a unique window into this issue. Sign languages have much in common with spoken languages in that they are complex, diverse, and rich in their morphosyntactic structure (10), and their use is supported by similar neural circuitry to that used in spoken languages (11, 12). In at least some cases, sign languages overtly mark certain elements of meaning that can be morphologically hidden in spoken language (8, 9, 13, 14). Here we exploit this tendency of sign languages to ask whether knowledge of how to map "event telicity" (explained further below) into visual signs may be universal and therefore (i) be encoded similarly across a range of sign languages with diverse historical origins and (ii) be accessible even by non-signers lacking experience with sign languages.

Telicity

According to a theoretical tradition dating back to Aristotle's metaphysics (15), verbs (and more generally predicates) describing dynamic events can be classified into two broad grammatical categories: telic and atelic (16–20). Telic verbs logically entail a culmination of the events denoted (e.g., "to decide," "to sell"). On the other hand, atelic verbs require no such endpoint (and thus could logically continue indefinitely), and the events denoted are conceived of as containing homogenous subparts (e.g., "to ponder," "to negotiate").

Evidence that English makes this distinction comes from a series of linguistic tests. For example, the "how long did it take" test distinguishes atelic from telic verbs (21).

1) How long did it take for John to "think"? (atelic)
2) How long did it take for John to "close" the door? (telic)
3) How long did it take for John to "decide"? (telic)

Despite the fact that each of these sentences has a nearly identical syntactic structure, sentences 2 and 3 are acceptable but not sentence 1, as only telic verbs are allowed to appear with the "how long did it take" construction. Similar to the English examples above, other spoken languages often incorporate telicity into the restrictions on the selection of adverbial phrases or modifiers (22–25). However, spoken languages also differ in important ways in how telicity is expressed, and it is not usually overtly marked in morphology or phonology (26).

On the other hand, there is reason to suspect that sign languages may make telicity visible in a universally accessible way. In some cases, sign languages make certain elements of verb meaning visible. One way in which this occurs is via processes of "holistic imitation." For example, the sign for "eat" often imitates the action of putting something in the mouth. However,

Significance

One key issue in the study of human language is understanding what, if any, features of individual languages may be universally accessible. Sign languages offer a privileged perspective on this issue because the visual modality can help implement and detect certain properties that may be present but unmarked in spoken languages. The current work finds that fine-grained aspects of verb meanings visibly emerge across unrelated sign languages using identical mappings between meaning and visual form. Moreover, nonsigners lacking prior exposure to sign languages can intuit these meanings from entirely unfamiliar signs. This is highly suggestive that signers and nonsigners share universally accessible notions of telicity as well as universally accessible "mapping biases" between telicity and visual form.

meaning visibility can also encompass more subtle elements of meaning (7, 8). For example, recent sign language research has proposed that sign languages sometimes use systems of "structural iconicity," in which properties of denotations are preserved by geometric properties of signs (8, 9, 13, 14).

With regards to the telic/atelic distinction, using detailed linguistic analyses of American Sign Language (ASL) and Croatian Sign Language (HZJ), Wilbur (13) has proposed an "event visibility hypothesis." This hypothesis states that telicity may be marked at the morpho-phonological level by mappings between geometric elements in the visible form of signs and telicity. Wilbur (13) and Malaia and Wilbur (27) argued that in ASL and HZJ telic meanings are made visible by salient gestural or event boundaries (see also ref. 28), whereas atelic meanings were made visible by a lack of such salient boundaries and the presence of repetition. This hypothesis comes in at least two varieties. One is that the use of mappings between telicity and visible geometric properties are universal but that languages vary widely in the precise way that such mappings are realized. The second is that the precise nature of the mappings is a linguistic universal. This might be the case, for instance, if the mappings between the telic conceptual boundary and gestural boundary (on the one hand) and atelic homogenous subparts and gestural repetition (on the other hand) were examples of universally understood structurally iconic mappings.

Here we examine this question empirically. Specifically, we ask to what extent mappings between telicity and the phonological form of signs are stable across historically unrelated sign languages and, second, whether nonsigners lacking prior exposure to sign language(s) can access such mappings, thus potentially strengthening claims of highly specific linguistic universals.

Results

In experiment 1 a native Italian signer produced 18 signs, each corresponding to a single verb in Italian Sign Language (LIS). Nine of these were telic in LIS (e.g., "decide," "leave," "sell") and nine were atelic in LIS (e.g., "think," "run," "negotiate") (see Fig. 2 for examples).

The stimuli came from three conceptual domains: mental state verbs (e.g., "decide"/"think"), physical events (e.g., "leave"/ "run"), and social exchanges (e.g., "sell"/"negotiate"). Video recordings of these signs were then shown in a random order to 24 online participants on Amazon's Mechanical Turk (29). Importantly, all participants reported having no significant prior experience with sign language and were predominantly native English speakers. Participants viewed the video of each of the 18 signs as many times as needed in their web browser and were asked to guess the meaning of the sign. They were presented with two possible answer choices, one of which was the actual meaning of the sign and a second that had a different telicity and was from a different conceptual domain. So if the participants saw, for example, the sign for "forget" (telic), they might see the English words "forget" and "negotiate" (atelic) at the bottom of the screen. A by-item analysis revealed accuracy of 90.51%, which was significantly better than chance according to a Wilcoxon Signed Rank Test ($P < 0.001$). (Here we report only by-item analyses, but patterns of significance across all experiments are similar for by-participant analyses.) A second Wilcoxon Signed Rank Test revealed that participants also correctly provided more

Fig. 1. Results summary for experiments 1–6.

telic responses for telic verbs than for atelic verbs (93.06% vs. 12.04%, $P < 0.01$). See Fig. 1 for a summary of all results.

Although the fact that nonsigning participants could correctly pick the meanings of entirely unfamiliar signs is perhaps surprising, it is not clear that they accomplished this by correctly interpreting verb telicity per se. For example, it could be that the effects were driven entirely by the similarity in conceptual domain as opposed to telicity because these two factors were (intentionally) conflated, as our goal in experiment 1 was initially to assess whether participants could perform well at all in a task like this. In experiment 2 we ran a similar experiment on a new set of participants ($n = 24$) that used virtually identical stimuli and methods. The only difference was that in the answer choices, the second (wrong) choice came from the same conceptual domain as the correct choice but was again not matched on telicity. So for example, if the participants were presented with the sign meaning "forget" (telic), they might now be presented with the (English) meaning choices of "forget" and "ponder" (atelic), which are both mental state verbs. Participants in this task again showed high levels of success, with an overall accuracy of 84.72%, which was significantly better than chance ($P < 0.001$). Again participants correctly provided more telic responses for telic verbs than for atelic verbs (81.94% vs. 12.5%, $P < 0.01$).

The results of experiment 2 are suggestive that participants are capable of extracting verb telicity from unfamiliar signs, even when presented with two conceptually similar meaning choices (e.g., "forget" vs. "ponder"). However, it is still possible that, given the fact that one of the meaning choices was actually correct, some form of imitation relating the meaning to the sign guided participants toward the correct meaning. To address this possibility, in experiment 3 we ran an identical study to those in experiments 1 and 2, with the exception that neither of the meaning choices was correct, whereas one was matched on verb telicity. Both meaning choices were from the same conceptual domain, which was different from the conceptual domain of the sign. So for example, if participants saw the sign for "forget" (telic), they were presented with the meaning choices of "die" (telic) and "run" (atelic). Overall, participants chose a meaning matching the telicity of the sign 65.40% of the time, which was significantly better than chance ($P < 0.05$). Participants again

gave (marginally) more telic responses for telic than atelic signs (66.16% vs. 35.35%, $P = 0.058$).

Experiments 4 and 5 asked if the patterns we had observed in LIS would extend to two other historically unrelated sign languages, thus strengthening the possibility that the mapping system between sign phonology and telicity is universally accessible. Experiments 4 and 5 were identical to experiment 3, except that they used signs from Sign Language of the Netherlands (NGT) and Turkish Sign Language (TİD), respectively, on two new sets of nonsigning participants ($n = 21$ and $n = 22$). We observed a broadly similar pattern as with LIS. When presented with NGT signs, nonsigning participants chose a meaning with matched telicity 71.96% of the time, which was significantly better than chance ($P < 0.001$) (see also experiment 11 in *Methods and Additional Information* for a replication of these results). Participants provided more telic responses for telic than atelic signs (71.96% vs. 28.04%, $P < 0.01$). Similarly for TİD signs, nonsigning participants chose a meaning with matched telicity 72.22% of the time, which was significantly better than chance ($P < 0.01$), and participants provided more telic responses for telic than atelic signs (75.25% vs. 30.81%, $P < 0.05$).

In experiment 6 we asked whether it would be possible to recreate the above pattern of results using artificially created nonsigns that possess visual properties that are likely candidates for the expression of telicity. In analyzing the signs from LIS, NGT, and TİD, one common feature for telic signs is that they are likely to possess a visually salient "boundary" in the gesture, which can be manifest as an abrupt stop in movement, contact, and/or a sudden change of hand shape (as originally stated in Wilbur's event visibility hypothesis). This feature has also been independently postulated to be responsible for the expression of telicity in ASL and HZJ (27, 30). On the other hand, a salient feature of atelic signs is rapid, repeated motion or "trilled movement" (27, 30) that lacks a salient gestural boundary at the end (Fig. 2).

Here we created artificial stimuli possessing these characteristics, with nine artificial telic signs and nine artificial atelic signs. All other aspects of the design were identical to those used in experiments 1–5. We observed that participants provided "correct" responses (i.e., responses that matched the expected telicity of
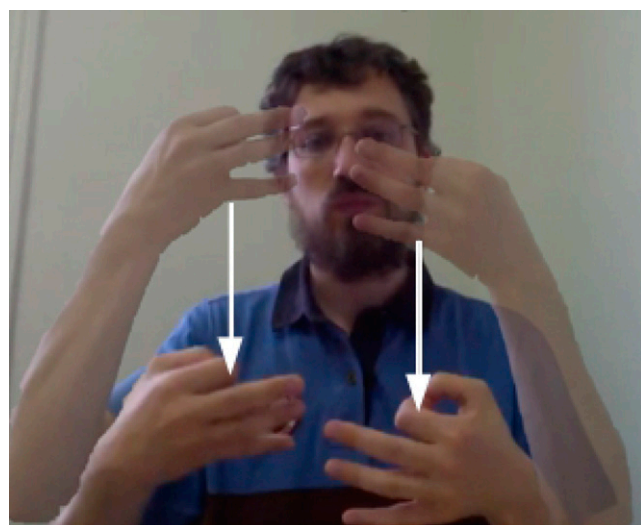
Decide

Think

Fig. 2. Depictions of the signs for "decide" (telic) and "think" (atelic) in LIS.

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the sign) 64.29% of the time, which was better than chance performance ($P < 0.05$). Participants again provided more telic responses for telic than atelic signs (65.08% vs. 36.51%, $P < 0.05$).

These findings suggest that the presence/absence of a gestural boundary as well as trilled movement are two important phonological features across sign languages in conveying verb telicity. To ensure that this was indeed the case, in experiments 7–10 participants viewed the stimuli from LIS, NGT, and TİD as well as our artificial stimuli. For each sign, participants were asked to rate, on a scale of 1–7, the degree to which they perceived a "gestural boundary," which (following ref. 26) was defined as a sudden deceleration, change in hand shape, and/or contact at the end of the gesture. They were also asked to rate the degree of perceived repetitive motion.

For all groups, we found that telic signs were rated as having more boundaries than repeated movement whereas atelic signs were rated as having more repeated movement than boundaries. Results are presented in Table 1. These results thus confirm that our artificial stimuli recreated the mappings between visual form and telicity that are used across natural sign languages.

Finally, we ran two linear regressions asking whether the ratings for perceived boundaries and for repeated motion significantly predicted the percentage of telic responses across items for experiments 3–6. Both analyses revealed significant effects. Thus, higher boundary ratings explained a significant proportion of the variance in telic meaning choices ($R^2 = 0.45$), $F(1,71) = 56.82$, $P < 0.001$, and higher ratings of repetition also explained a significant proportion of the variance in telic meaning choices ($R^2 = 0.47$), $F(1,71) = 62.46$, $P < 0.001$. This further suggests that participants in our tasks were sensitive to these properties of the stimuli in intuiting whether a given sign was telic or atelic.

Discussion

The current results support three conclusions. First, signers and nonsigners make similar distinctions between telic and atelic events. Second, sign languages have a likely universal tendency to use a single set of mapping biases between meaning (i.e., verb telicity) and visual form. We draw this conclusion from the fact that consistent mappings have now been documented for ASL (26), HZJ (27), Austrian Sign Language (ÖGS) (30), LIS, NGT, and TİD. Historically, these sign languages are related to various degrees. LIS and ASL can be considered cousins in that they were both heavily influenced by the Abée de l'Epée method but also developed independently through local influences (31, 32). However, neither shares a strong historical relationship with NGT, TİD, HZJ, or ÖGS, and none of the latter four share a documented historical relationship between themselves (with perhaps the exception of HZJ/ÖGS, according to ref. 33). [Note that although Anderson (34) grouped NGT in the French Sign Language family, more recent work argues that only the Groningen variant from the north, which is not used here, has been influenced by the Abée de l'Epée method (35, 36).] Given their diverse historical origins, the inference to the best explanation is that their use of common telicity/visual mapping biases is not due to a historical accident but instead reflects universal biases in human language.

Third and finally, our results show that these mapping biases are universally accessible and thus interpretable even by nonsigning subjects lacking prior exposure to sign language(s).

What accounts for such universally accessible mappings? One hypothesis is that it results from structural iconicity (8). On this view, there may be a universal way of mentally representing events as containing a logical endpoint or as consisting of homogenous subparts lacking such an endpoint. [This hypothesis remains neutral as to whether these representations are specific to language or may be part of a more general "core knowledge" system (37).] There would additionally exist nonlinguistic knowledge about how such representational structures should be mapped onto visual form. Thus, the process would resemble, for example, the process by which people intuitively map number sequences onto lines (38).

This view is supported by the fact that structural iconicity has been observed across a wide range of sign language phenomena including the representation of plurals by reduplication (39), of pronouns by using pointing signs toward structured areas of space (8, 9, 40, 41), of agreement markers (9), as well as of metaphors (42, 43), and thus may be a general property of signing systems. Moreover, the precise nature of the mapping biases that sign languages appear to use suggests an iconic and nonarbitrary mapping between telic structure and visual structure. The logically encoded endpoint of telic verbs maps neatly onto a visually salient endpoint in signing structure. The homogenous subparts of atelic verbs map onto repetitive movements, which themselves are homogenous repetitions. Thus, according to this view, the forms of sign languages have been influenced by these mapping biases due to a general pressure for sign languages to iconically represent as much information as possible. Nonsigners would share with signers the conceptual distinction between telic and atelic predicates as well as an intuition about how to iconically map this distinction onto visual form.

An alternative view is that the telic versus atelic distinction is a central feature of a universal grammar (44). According to this view, sign languages are special in making some of these elements perceptible by a universal or near universal phonology-to-semantics mapping (45). Future research will be crucial in deciding between these theoretical possibilities. A common aspect of the two views is that rather abstract notions such as event telicity enjoy a privileged status in our cognitive system, and these notions can have a powerful influence on the structure of language.

Methods and Additional Information

Experiment 1. Twenty-four participants from the United States completed a paid study online through Amazon's Mechanical Turk. Informed consent was obtained from all participants. All reported having no prior significant experience with sign language. All stimuli were created by a native Italian signer according to a prespecified list of verbs. In total there were 18 verbs (9 telic and 9 atelic), from three conceptual domains (physical, psychological, and social interaction). Those verbs were the following: atelic/physical, "run," "float," and "play"; atelic/psychological, "think," "ponder," and "imagine"; atelic/social interaction, "talk," "discuss," and "negotiate"; telic/physical, "enter," "die," and "leave"; telic/psychological, "decide," "confirm," and "forget"; and telic/social interaction, "marry," "sell," and "buy."

During the experiment, participants were instructed that they would be shown videos from a sign language and that their task would be to guess the meanings of the signs. Eighteen videos appeared in a randomized order with two answer choices on the screen (arranged horizontally), and participants were allowed to watch each video as many times as desired. One answer choice corresponded to the actual meaning of the sign (in English), whereas the other answer choice corresponded to a different, randomly selected verb from a different domain than the correct choice. This answer choice always had a different telicity than the actual meaning of the sign. The alternative choice was always the translation of another verb from the stimulus list, and the horizontal arrangement of the answer choices was randomly assigned. The pair of answer choices and horizontal arrangement assigned to each video was the same for each participant. After the experiment ended, participants were presented with a series of follow-up questions including what their native language was and whether they had encountered any problems viewing the videos.

Table 1. Results from experiments 7–10

Judgment type	Experiment 7 LIS, $n = 16$		Experiment 8 NGT, $n = 15$		Experiment 9 TİD, $n = 16$		Experiment 10 artificial, $n = 16$	
	Telic	Atelic	Telic	Atelic	Telic	Atelic	Telic	Atelic
Boundary	5.59	3.2	5.04	2.99	5.24	2.78	5.73	2.83
Repetition	1.6	5.17	1.81	6.17	1.9	5.9	1.28	6.27
P value	<0.01	<0.05	<0.01	<0.01	<0.05	<0.01	<0.01	<0.01

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For a demonstration of individual trials and a full list of experimental materials, please see *Supporting Information.*

Experiment 2. Experiment 2 was identical to experiment 1, except in the following ways: Twenty-five participants completed the study, but one participant was removed due to prior signing experience. One answer choice for the videos corresponded to the actual meaning of the sign, whereas the other answer choice corresponded to a different randomly selected verb from the same domain as the correct choice. Again this answer choice always had a different telicity than the actual meaning of the sign.

Experiment 3. Experiment 3 was identical to experiment 2, except in the following ways: Twenty-five participants completed the study, but three participants were removed due to prior signing experience. Neither answer choice corresponded to the actual meaning of the sign, and neither answer choice came from the same conceptual domain as the sign. One answer choice matched the sign's telicity, whereas the other answer choice did not match the sign's telicity. Both answer choices were randomly selected within these set criteria. Any individual answer choice appeared twice over the course of the experiment, once in the presence of an atelic video and once in the presence of a telic video. However, the randomization was performed twice in such a way that no pairing between individual answer choices occurred for both the telic and atelic categories. The randomly selected pairings between answer choices and videos were the same for all participants, and the same answer choice sets were used for experiments 3–6 (note that in experiment 11 we rule out the possibility that the pattern of responses observed here may have been due to anything peculiar about this particular meaning choice set).

Experiment 4. Experiment 4 was identical to experiment 3, except in the following ways: Twenty-four participants completed the study. Two were excluded due to prior signing experience, and two were excluded due to failing an attention/comprehension check.

All test stimuli were created by a native signer of NGT following an elicitation protocol in which she was instructed to create and videotape verbs in her native sign language that corresponded to our predefined list from experiment 1. In NGT, the distinction between "ponder" and "think" does not exist, thus the corresponding NGT sign (which is polysemous between both) was included twice in the experimental stimuli. After responding to the test stimuli, participants viewed an attention/comprehension check video.

Experiment 5. Experiment 5 was identical to experiment 4, except in the following ways: Twenty-five participants completed the study. One was excluded due to technical error, and two were excluded for failing the comprehension check. All stimuli were created by a TİD signer. In TİD, there is no sign for "float"; thus, we included the sign for "play" twice (given that play is the same telicity and from the same conceptual domain).

Experiment 6. Experiment 6 was identical to experiment 5, except in the following ways: Twenty-five participants completed the study. One participant was removed due to a technical error, and three were removed for failing the comprehension check. We used nonsigners, however, which meet all relevant criteria to be well-formed LIS signs. These can be considered as accidental gaps of the language, and it is possible that in some other sign languages they would correspond to a lexical sign. All stimuli were created by two native LIS signers. The signs differed in hand shape to add a sense of realism to the signs and task. Across telicity categories, we manipulated the presence of repetitive motion and gestural boundaries. For the nine atelic signs, each sign involved a motion that was repeated at least four times. Five videos included rapidly repeating trilled motions, and the other four included slow and discrete repetitions. In all cases, there was no clear gestural boundary at the end of the sign. For the nine telic signs, the sign involved motion but no repeated motion. There was a clear gestural boundary at the end of the sign, which in all cases was a rapid stop (and thus deceleration of motion).

Experiments 7–10. Sixteen participants completed the survey in experiment 7, with one removed for failing the comprehension check; 15 participants in experiment 8; 16 in experiment 9; and 16 in experiment 10, with one participant removed for failing the comprehension check. Participants in experiments 7–10 saw the same test stimuli as participants in experiments 3–6 (e.g., participants in experiment 7 saw the same test stimuli as those in experiment 3, participants in experiment 8 the same as those in experiment 4, and so forth). Instead of being asked to guess word meanings, they were asked to rate the extent to which they perceived a gestural boundary (1–7 scale) and the extent to which they perceived repetitive motion (1–7 scale). Experiments 7–10 were otherwise identical to experiments 3–6.

Experiment 11. In experiments 3–6, all participants saw the same answer choice sets for the telic and atelic videos, respectively. For example, the (atelic) signs meaning "to run" were paired with the answer choices of "to think" and "to decide." On the other hand, the (telic) signs meaning "to leave" were paired with "to confirm" and "to think." Although randomly selected within set criteria, the answer choice sets were fixed for all participants across all languages. This has the advantage of reducing variability in response patterns between participants by ensuring that every participant for every language saw exactly the same answer choice sets (thus making between-experiment comparisons more meaningful). However, our design also has the disadvantage that some random element unrelated to our main hypothesis could have driven the effects found here. For example, perhaps participants could have a tendency to choose "think" over "decide" because it is more frequent.

Thus, to rule out this possibility, in experiment 11 we replicated experiment 4, with the exception that we switched the answer choices for the atelic and telic categories. For example, previously the sign meaning "to run" was paired with the answer choices "to think" and "to decide," and the sign meaning "to leave" was paired with the answer choices "to confirm" and "to think." In the current experiment, these answer choices were assigned to signs from the opposite telic category than in experiment 4. So for example, "to think" and "to decide" were now the answer choices assigned to the sign meaning "to enter," which is telic. And "to confirm" and "to think" were now the answer choices assigned to the sign meaning "to play," which is atelic. All of the new pairings respected the same constraints as in experiment 4 so that the answer choices themselves were always from the same domain, while coming from a domain different from that of the actual meaning of the sign.

Experiment 11 was otherwise identical to experiment 4. Twenty-four participants completed the study. Two were excluded for failing the attention/comprehension check.

Our results almost perfectly replicated those found in experiment 4. Thus, when presented with NGT signs, nonsigning participants chose a meaning with matched telicity 73.23% of the time, which was significantly better than chance ($P < 0.01$). A second Wilcoxon Signed Rank Test revealed that participants also correctly provided more telic responses for telic verbs than for atelic verbs (73.74% vs. 27.27%, $P < 0.05$). These results confirm that our original randomly chosen answer choice sets did not bias the experimental results in favor of our original hypothesis.

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