Semantic P600—but not N400—effects index crosslinguistic variability in speakers’ expectancies for expression of motion

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ABSTRACT

The expression of motion shows strong crosslinguistic variability; however, less is known about speakers’ expectancies for lexicalizations of motion at the neural level. We examined event-related brain potentials (ERPs) in native English or Spanish speakers while they read grammatical sentences describing animations involving manner and path components of motion that did or did not violate language-specific patterns of expression. ERPs demonstrated different expectancies between speakers: Spanish speakers showed higher expectancies for motion verbs to encode path and English speakers showed higher expectancies for motion verbs to encode manner followed by a secondary path expression. Interestingly, grammatical but infrequent motion expressions (manner verbs in Spanish, path verbs and secondary manner expressions in English) elicited semantic P600 rather than the expected N400 effects—with or without post-N400 positivities—that are typically associated with semantic processing. Overall, our findings provide the first empirical evidence for the effect of crosslinguistic variation in processing motion event descriptions at the neural level.

1. Introduction

The world’s languages differ systematically in the way they express the manner and path components of a motion event (Talmy, 1985, 2000). However, less is known about the effect of differences in linguistic expression on speakers’ expectations for the lexicalization of motion information during online processing. The scarce literature that exists on expectancies for motion expression focuses exclusively on behavioral differences, leaving crosslinguistic variation in the neural processing of such events largely unexamined. As an attempt to fill this important knowledge gap, our goal is to examine the neurophysiological responses of adult native speakers of two structurally different languages (English, Spanish) to violations of language-specific expression of motion events in their native language, using event-related brain potentials (ERPs). Our study, with its neural approach, has the potential to expand our knowledge of the effect of language on motion event processing in several important ways. It examines the processing of real words (as opposed to pseudowords) in a sentential context and captures changes throughout the course of processing itself rather than measuring the end state of processing as is typical in behavioral studies; it also provides a more nuanced examination of processing than is observable with behavioral measures alone.

1.1. Crosslinguistic differences in motion expression

Languages differ in how they describe motion events, particularly with respect to two key motion components: manner (e.g., ‘run’, ‘roll’) and path (e.g., ‘ascend’, ‘exit’; Talmy, 1985, 2000). Speakers of one
group of languages, such as English, frequently express manner in the verb followed by a secondary path expression (i.e., manner-verb construction; e.g., ‘The dog runs into the house’). Speakers of another group of languages, such as Spanish, on the other hand, prefer to express manner in the verb, optionally followed by a secondary manner expression (i.e., path-verb construction; e.g., ‘El perro entra la casa’ (corriendo/rápidamente) = ‘The dog enters the house (running/quickly)’; Slobin, 2004; Talmy, 1985, 2000). Such differences remain robust across numerous languages of the world, drawing a binary distinction between two types of languages, with speakers of satellite-framed languages (S-languages; e.g., English, Polish, German, Dutch) using mostly manner-verb constructions and speakers of verb-framed languages (V-languages; e.g., Spanish, Turkish, Japanese, Korean) relying mostly on path-verb constructions in their descriptions of motion (e.g., Choi and Lantolf, 2008; Ibarretxe-Antuñano, 2004a, 2004b; Kita and Ozyurek, 2003; Lewandowska and Ożułaṣk, 2015; Naigles et al., 1998; Ożułaṣk, 2004, 2009, 2016; Ożułaṣk et al., 2016, 2018; Ożułaṣk and Slobin, 1999; Ożułaṣk and Slobin, 2003; Papafragou et al., 2002; Papafragou et al., 2006; Slobin, 1996, 2004). Moreover, S-language speakers’ preference for the manner-verb construction (i.e., manner in the verb, path in a secondary expression) allows them to express manner more frequently than speakers of V-languages, also resulting in a greater variety of manner verbs that capture a broader and more fine-grained set of distinctions (e.g., Hohenstein, 2013; Ożułaṣk, 2005; Slobin, 2004).

1.2. Expectancies for the lexicalization of motion expressions

Language-specific biases for the expression of motion events—particularly with regard to manner and path—are well established (Talmy, 2000; see Ożułaṣk and Emerson, 2016 for a review). However, less is known about the effect of motion patterns on speakers’ expectations about the lexicalization of motion information while perceiving language in real time. For example, the verb is habitually used to express manner information in S-languages and path information in V-languages (Slobin, 1996, 2004). Thus, if habitual patterns of expression affect speakers’ expectations for the type of motion information that verbs should express, S-language speakers should expect that a motion verb will express manner, and V-language speakers should expect that the verb will express path information. Similarly, S-language speakers routinely use constructions that tightly package a manner verb with a secondary path expression into the same clause while V-language speakers frequently express path of motion with a path verb with optional secondary expressions of manner (e.g., Choi and Lantolf, 2008; Ibarretxe-Antuñano, 2004a, 2004b; Kita and Ozyurek, 2003; Lewandowska and Ożułaṣk, 2019; Naigles et al., 1998; Ożułaṣk, 2004, 2009, 2016; Ożułaṣk et al., 2016, 2018; Ożułaṣk and Slobin, 1999, 2003; Papafragou et al., 2002, 2006; Slobin, 1996, 2004). Thus, given the relatively preferred status of secondary path expressions in manner-verb constructions, S-language speakers should have a stronger expectancy for the secondary expression of path than secondary expressions of manner. In contrast, the optional status of secondary manner expressions in path-verb constructions suggests that V-language speakers should either show a small preference for secondary expressions of manner over path or show no strong expectancies for one type of secondary motion expression over the other. Previous research on speakers’ expectancies for motion expression in different languages has focused exclusively on how speakers learn or interpret novel pseudowords that encode either manner or path of motion. Two such existing studies—one by Emerson et al. (2016) and the other by Kersten et al. (2010)—asked speakers to learn pseudowords that described variations in either path or manner of motion of an animated character. Surprisingly, the results showed that both English (S-language) and Spanish (V-language) speakers were better able to learn pseudowords referring to path than manner of motion. One potential explanation for the higher-than-predicted learning for path pseudowords in English is that the path information may be more salient than manner information, regardless of the native language of the speaker—given that path constitutes core aspect of a motion event (Talmy, 2000). Alternatively, English speakers—similar to V-language speakers—also express path frequently, albeit in secondary motion expressions instead of the verb (Lewandowski and Ożułaṣk, 2019; Naigles et al., 1998; Ożułaṣk, 2004, 2009, 2016; Ożułaṣk et al., 2016, 2018; Ożułaṣk and Slobin, 2003, 1999; Papafragou et al., 2006; Slobin, 1996, 2004). Thus, the relatively higher rates of learning for path information may relate to the frequency of expression regardless of the way in which that information is expressed. While direct comparisons between manner and path did not yield the predicted manner-biases in English, Kersten et al. (2010) nonetheless did find some evidence of an effect of habitual expression on expectations for motion type expression. When comparing English and Spanish speakers in their learning of pseudowords that encoded manner, English speakers showed better learning than Spanish speakers, but both groups of speakers showed equivalent performance when the pseudowords encoded path. The results thus suggest that the greater expression of manner in English might have influenced speakers’ expectations about the type of information conveyed by a word in a behavioral novel word-learning paradigm.

One potential limitation of these studies is that the words were taught in isolation without a sentential context. Learning novel words in isolation might not have provided a strong enough cue to evoke different expectations for the conflation of manner compared to path of motion. In fact, studies that examine the learning of novel motion words that are embedded in a sentence have shown notable language-specific biases. Such studies typically demonstrate an overall effect for S-language speakers (English) being more likely to interpret a pseudoword as expressing manner rather than path and the reverse pattern for V-language speakers (e.g., Greek, Spanish; Maguire et al., 2010; Naigles and Terrazas, 1998; Papafragou and Selimis, 2010; Shafto et al., 2014; Skordos and Papafragou, 2014; cf. Japanese in Maguire et al., 2010). The studies also showed an added effect of type of sentence construction in assigning meaning to pseudowords in the two groups of languages. When sentences had a prototypical path-verb construction (i.e., a verb without secondary motion), speakers of both language types were more likely to interpret an ambiguous verb (e.g., ‘She’s kradding the tree’) as referring to path information (Naigles and Terrazas, 1998; Shafto et al., 2014; Skordos and Papafragou, 2014). In contrast, when the sentences had a manner-verb construction, speakers of both S- and V-languages were more likely to interpret an ambiguous verb as manner (e.g., ‘She’s krading toward the tree’). Naigles and Terrazas, 1998; Shafto et al., 2014) and an ambiguous preposition as path (e.g., ‘She’s going krad the tree’; Skordos and Papafragou, 2014). The results of these studies thus suggest the importance of sentential context as an additional factor in speakers’ interpretation of novel words in a language-learning context.

While earlier paradigms provide valuable insight into the learning or interpretation of new words, they do not fully elucidate the online processing of familiar, as opposed to novel, speech. The existing work also typically requires the speaker to make a binary decision (e.g., manner vs. path) about the meaning of the pseudo-word at the end of each sentence. However, language processing continues to change throughout the course of hearing or reading a sentence. As such, assessing outcomes only at the end of a sentence falls short in examining language processing as it unfolds in real time—particularly given the prominent role sentence construction type has been shown to play on semantic processing in earlier behavioral studies (Naigles and Terrazas, 1998; Shafto et al., 2014; Skordos and Papafragou, 2014)—thus raising the need for online measures of the processing of motion event descriptions, such as event-related brain potentials (ERP).
1.3. Neural correlates of semantic processing

One way to examine the processing of language as it unfolds in real time is through the use of ERPs. ERPs yield both incremental (quantitative differences in amplitude) and qualitative (different components) information about linguistic processing and can, thus, provide a more nuanced measure of motion expectancy than prior behavioral work, which has focused primarily on binary choices between manner and path of motion. One way differences in semantic processing between types of words (e.g., manner vs. path words) can be assessed is by comparing the mean amplitude of the conditions during a time window of interest after the onset of the presentation of the word. Traditionally, processing differences in semantic expectancy for grammatical sentences has been examined with a component known as the N400.

The N400 is a negative component with a centro-parietal scalp distribution that peaks in amplitude approximately 400 ms after the onset of a semantically incongruent stimulus (e.g., ‘I take my coffee with milk and socks’; Kutas and Hillyard, 1980). As proposed by Kutas and Federmeier (2000, 2011), the N400 reflects the online integration of meaningful stimuli—both linguistic and nonlinguistic—as it becomes available. The component is likely to be comprised of a combination of signals with overlapping spatio-temporal properties reflecting multiple processes including prediction, integration, and plausibility (Fleur et al., 2020; Nieuwland et al., 2019). Rather than increasing in response to violations of a predicted word, the amplitude of the N400 is thought to decrease in response to words that have been pre-activated by a combination of linguistic and contextual factors (Brouwer et al., 2012; DeLong et al., 2014b; Kutas and Federmeier, 2000; Van Petten and Luka, 2012). The amplitude of the N400 is graded with words that are more expected producing smaller amplitudes (i.e., less negative) and words that are less expected producing greater amplitudes (i.e., more negative; Kutas et al., 1984). As such, the amplitude of the N400 is a good index of how pre-activated an encountered word is given the preceding context and the lexical patterns of a speakers’ language stored in long term memory.

N400 effects have been the most widely-studied measure of semantic processing. At the same time, semantically anomalous words have been shown to elicit two other types of late positive potentials known as post-N400 positivities (PNPs) and the semantic P600 effect. PNPs are positive components that sometimes occur after an N400 effect in response to a semantically unexpected word (i.e., later than approximately 500 ms post-stimulus; Van Petten and Luka, 2012). The scalp distribution tends to be more anterior in response to semantically unexpected words that are congruent with the sentential context (i.e., have low cloze probabilities) and more parietal in response to semantically unexpected words that are incongruent with the sentential context (DeLong et al., 2014a; Van Petten and Luka, 2012).

The P600 is another late positive component that typically occurs between 500 and 800 ms after stimulus onset and has a centro-parietal scalp distribution (Osterhout and Holcomb, 1992). While the P600 is traditionally associated with the processing of syntactic violations or greater syntactic complexity (Kaan et al., 2006; Molinaro et al., 2011; Osterhout et al., 1994), the semantic P600 is a positivity that does not follow an N400 effect—unlike the NPN—and is found in response to certain types of semantic anomalies, such as thematic role reversals that are grammatically correct and unambiguous (e.g., ‘For breakfast the eggs would only eat toast and jam’; for reviews see Bornkessel-Schlesewsky and Schlesewsky, 2008; Brouwer et al., 2012; DeLogu et al., 2019; Kuperberg, 2007). Unlike the conditions that elicit N400 effects with or without a PNP, a semantic P600 effect is more likely to occur when the anomalous word is semantically related to the rest of the sentence (Kim and Osterhout, 2005; van Herten et al., 2006) and embedded within a syntactic construction that provides strong cues to the meaning or roles of its arguments (e.g., word order cuing the thematic role of noun phrases; Bornkessel-Schlesewsky and Schlesewsky, 2019; Bornkessel-Schlesewsky et al., 2011; Schlesewsky and Bornkessel-Schlesewsky, 2009).

Similarities between the antecedent conditions, latencies, and topographies of the parietal PNP and the semantic P600 have led to the prediction that the two components reflect memory processes associated with the re-analysis or checking of the preceding context (DeLong et al., 2014a; Kolk et al., 2003; Kuperberg, 2007; van de Meerendonk et al., 2009; Van Petten and Luka, 2012; Vissers, Kolk, van de Meerendonk and Chwilla, 2008). The relatively less-studied frontal PNP is thought to reflect processing related to a lexical prediction that has been disconfirmed (DeLong et al., 2014a; Van Petten and Luka, 2012).

Earlier work, thus, suggests that both late positive ERP indices, along with the N400, might be highly relevant to the examination of online processing of expectancy for motion event descriptions. More specifically, if typological patterns of expression affect speakers’ expectations for motion lexicalization during online processing, such preferences should be evident in the ERPs following the onset of a word motion. In particular, greater negativities between 200 and 500 ms after the onset of a motion word might suggest that a word is less pre-activated than the baseline condition, indicative of an N400 effect. At the same time, greater positivities relative to a baseline condition 500 ms or later after the onset of a motion word—either in the presence or absence of a concurrent N400 effect—could suggest that the word is not anticipated and either triggered a re-analysis of the preceding information (i.e., parietal PNP or semantic P600 effect) or the word required additional resources to process it after a failed prediction (i.e., frontal PNP effect).

1.4. Current study

The current study focuses on the lexico-semantic expectancies for motion expression in native speakers of English (S-language) and Spanish (V-language) during the online processing of motion event descriptions, using ERPs. Our first question is whether habitual patterns of motion expression influence speakers’ expectancy for the type of motion information conveyed in the verb. If habitual patterns of expression do influence speakers’ expectations for motion lexicalization, English speakers (who habitually express manner in the verb) should show stronger expectancies for manner verbs than path verbs while Spanish speakers (who habitually express path in the verb) should show the reverse effect.

Our second question is whether type of sentence construction affects speakers’ expectancy for the inclusion of a non-redundant secondary motion expression (i.e., path prepositions and path adverbs in manner-verb constructions, e.g., ‘walk up the bridge’, or manner gerunds in path-verb constructions, e.g., ‘ascend the bridge running’). If habitual expression has an influence on speakers’ expectations, then English speakers (who typically use manner-verb constructions with a secondary expression of path) will have a higher expectancy for secondary path information to follow a manner verb than for secondary manner information to follow a path verb. In contrast, Spanish speakers (who typically use path-verb constructions, in which a secondary expression of manner is optional) should either have a slightly higher expectancy for secondary expressions of manner over path or show no expectancy for
one type of secondary motion expression over the other.\footnote{Predictions were based on previous behavioral research that showed that speakers’ expectations for the meaning of novel motion words were influenced by the type of sentence construction in which the word was embedded (path-verb vs. manner-verb construction; Naigles and Terrazas, 1998; Shafo et al., 2014; Skrodos and Papafragou, 2014) and the relative production of different construction types in each language. Manner-verb constructions (manner verb followed by secondary path expression) has been shown to be the most commonly used construction type for speakers of S- but not V-languages (Choi and Lantolf, 2008; Ibarretxe-Antuñano, 2004a, 2004b; Kita and Ozurek, 2003; Lewandowski and Özçalışkan, 2019; Naigles et al., 1998; Özçalışkan, 2004, 2009, 2016; Özçalışkan et al., 2016, 2018; Özçalışkan and Slobin, 2003, 1999; Papafragou et al., 2002, 2006; Slobin, 1996, 2004). Research on speakers’ use of path verb constructions (path verb followed by secondary manner expression) remains scarce; however, the few existing studies suggest that it occurs infrequently in both language types (Özçalışkan, 2003, 2004; Özçalışkan and Slobin, 2003).} We test both questions by examining ERP responses to real motion words embedded in grammatical sentences describing brief motion animations. We predict that, if speakers have language-specific expectations about the lexicalization of motion in an ongoing sentence based on habitual patterns of expression detectable at the electrophysiological level, the less preferred motion expression type (i.e., path verbs and secondary manner expression in English; manner verbs and secondary path expressions in Spanish) should elicit greater N400 effects with or without a PNP or greater semantic P600 effects than the preferred motion expression type.

2. Methods

2.1. Participants

Participants included 23 native English speakers (M = 26.04, SD = 10.87; 12 males; 22 right-handed, 1 ambidextrous) and 21 native Spanish speakers (M = 22.43, SD = 7.39; 4 males; 19 right-handed, 2 amibidextrous), all attending a university in urban Southeastern United States. Because data were collected in an English-speaking institute, all native Spanish speakers were proficient in English. Bilingualism was not an exclusion factor for the native English group either; however, none of the native English speakers reported being simultaneously English–Spanish bilinguals. Participants received either a small monetary award or course credit for their participation. None of participants had any known neurological or language disorders and all had normal or corrected to normal vision. Informed consent was obtained from all participants in their native language by a researcher who was a native speaker of the language.

2.2. Stimuli

2.2.1. Animation stimuli

Thirty-two, 3.5s-long animations were created consisting of a character (i.e., ‘Felix’/‘Felix’) moving in relation to a landmark (i.e., ‘bridge’; see Fig. 1A). Each animation contained one of eight manners and one of four paths. The eight manners included ‘walk’, ‘run’, ‘jump’, ‘fly’, ‘crawl’, ‘roll’, ‘march’, and ‘slide’. The four paths included ‘ascend’ (character moves from the base of the bridge to the apex), ‘descend’ (character moves from the apex of the bridge to the base), ‘approach’ (character moves from the right side of the screen towards the base of the bridge), and ‘cross’ (character moves right to left across the bridge).

2.2.2. Linguistic stimuli

The study consisted of 256 trials. In each trial, one of the 32 animations was followed by a sentence that varied in congruency (congruent, incongruent) and in sentence construction (path-verb construction, manner-verb construction). Congruent sentences (n = 128) accurately described both the path and manner of the preceding animation. Incongruent sentences were included to provide participants with a task to ensure that they were attending to the meaning of each sentence. Each incongruent sentence either accurately described the manner in the animation while describing a different path (path-incongruent; n = 64) or accurately described the path in the animation while describing a different manner (manner-incongruent; n = 64). Congruent and incongruent trials were divided evenly between manner-verb and path-verb constructions. Sentences with a manner-verb construction included a subject, manner verb, and a path preposition or adverb along with a landmark (e.g., ‘Felix walks up the bridge’/‘Felix camina puente arriba’ = Felix walks bridge up), while sentences with a path-verb construction included a subject, path verb, landmark, and a manner gerund (e.g., ‘Felix ascends the bridge walking’/‘Felix sube el puente caminando’ = Felix ascends the bridge walking). Each participant completed 256 trials divided into four equal blocks of 64 randomized trials.

Because translations between languages did not always yield the same number of words (e.g., ‘approaches’ in English vs. ‘llega a’ = approaches in Spanish), all sentences were divided into four parts that were presented on four separate screens: subject (i.e., ‘Felix’, ‘Felix’), main verb (e.g., manner: ‘walks’/‘camina’ = walks; path: ‘ascends’/’sube’ = ascends), secondary motion expression (e.g., manner: ‘walking’/’caminando’ = walking; path: ‘up’/’arriba’ = up), and landmark (e.g., ‘the bridge’/’el puente’ = the bridge). Dividing sentences into such units ensured that participants received comparable amounts of information between languages on each screen.

The verbal stimuli in the two languages were similar in their ordering of path-verb constructions, but differed in their ordering of manner-verb constructions due to language-specific constraints in the expression of such sentences in each language. The path-verb construction for both the English and Spanish sentences followed the order of subject, path verb, landmark, and a manner gerund (e.g., ‘Felix ascends the bridge walking’/‘Felix sube el puente caminando’ = Felix ascends the bridge walking). The manner-verb construction followed the order of subject, manner verb, path preposition, and landmark (e.g., ‘Felix walks up the bridge’) in English. In contrast, for Spanish, half of the manner-verb constructions followed the order of subject, main manner verb, path preposition, and landmark (e.g., ‘Felix camina hacia el puente’ = Felix walks toward the bridge) as in English while the other half followed the order of subject, main verb, landmark, and path adverb (e.g., ‘Felix camina puente arriba’ = Felix walks bridge up) due to the constraints in the lexicalization of motion in Spanish. Because words that occur later in a sentence often elicit smaller N400 effects than words that occur earlier

\footnote{5 In order to verify the subjective typicality of the sentence stimuli as a whole (i.e., motion verb in combination with secondary motion expression), all 44 participants were asked to rate how natural each sentence sounded prior to the ERP task. Sentences were arranged in a pseudo-random order, mirroring the experimental setup-in test trials, to ensure that the typicality judgment task did not provide a cue to the participants about the aims of the study any further than the test trials themselves. The participants rated all 128 sentences (without the accompanying animation) on a scale of 1 (‘a native speaker would never use that type of sentence’) to 5 (‘a native speaker would be very likely to use that sentence’). Due to an unexpected error, the responses of some of the participants were not accurately recorded, resulting in meaningful data from only a subset of the participants (Spanish: n = 14; English: n = 15). Nonetheless, survey data from the subset of the participants showed strong point-biserial correlations for both languages with English speakers giving higher ratings to manner-verb constructions (r = 0.843, p < .001) and Spanish speakers giving higher ratings to path-verb constructions (r = –0.668, p < .001). This provided further confirmation that, on the whole, the sentences with a manner-verb construction were more typical (and likely more expected) than sentences with a path-verb construction by English speakers—a pattern that was reversed for Spanish speakers (see Appendix A for further details on participants’ responses).}
in a sentence (e.g., Van Petten and Kutas, 1990), the location of the target word was included as a control factor (random intercepts by-item) in all analyses for the secondary motion expressions.

2.3. Procedure

Participants were first familiarized with the experimental stimuli. During familiarization of path, each of the four paths was presented as a static image of an arrow indicating a direction in relation to the landmark along with the path verb and secondary path expression listed on the screen (e.g., ‘ASCEND’ ‘UP’ + arrow stretching from the base of the bridge to the apex). During familiarization of manner, each of the eight manners was presented as a dynamic video of the figure performing the manner in a single location with the manner verb on the screen (e.g., ‘RUN’ + figure moving legs and arms as if running). Exposing participants to all the labels associated with each path and manner ensured that the participants were familiar with the correct verbal labels for stimuli in the study.

The familiarization trials were followed by test trials. For each test trial, the participant watched a short animation, read a sentence about the animation, and then pressed a button to indicate whether the sentence matched (i.e., congruent) or mismatched (i.e., incongruent) the animation (Fig. 1). Participants were told that sentences that matched the manner and path depicted in the animation should be considered a ‘match’ (i.e., congruent) while sentences that differed in either manner or path from the animation should be considered a ‘mismatch’ (i.e., incongruent). Participants were also warned that some sentences may sound strange to them and that, in such cases, they should ignore the sentence construction.

Each animation lasted 3500 ms, followed by a blank, black screen for a total of 500 ms. Next, a fixation cross (i.e., a ‘+’ symbol) appeared in the center of the screen for 1500 ms. Participants were instructed not to blink during presentation of the animation or sentence. The sentence for the animation was then provided in the following four screens. Each of the sentence screens was displayed for 500 ms followed by a blank screen for 200 ms before the onset of the next screen. At the completion of the entire sentence description for each motion animation, participants were presented with a screen that requested a forced-choice response on whether the sentence matched or mismatched the preceding animation. The placement of the words ‘match’ and ‘mismatch’ on either the left or right side of the screen and the corresponding button on a button box were counterbalanced between participants.

2.4. Electroencephalography recording & analysis

Electroencephalography (EEG) was recorded using Electrical Geodesics Inc. (EGI) Net Amp 400 amplifier and HydroCel Geodesic Sensor Nets with 256 silver/silver chloride electrodes arranged in the standard EGI 256-sensor geodesic configuration (see Fig. 2). Electrode impedances were kept below 50 kΩ, and data were digitized at 250 Hz. The vertex sensor served as the reference and an isolated common served as
EEG recordings were processed with Net Station 4.0. EEG was filtered with a 0.1–30 Hz bandpass filter offline and segmented into epochs ranging from 200 ms prior to the onset of the stimulus until 700 ms post-onset. Because each portion of the sentence was displayed for 500 ms and preceded and followed by a 200 ms screen, the 200 ms prior to the stimulus always corresponded to the presentation of a blank screen, and the 700 ms window corresponded to the presentation of stimulus itself as well as the following blank screen. As such, each epoch contained the presentation of only one word, and there was no overlap with the presentation of the next stimulus. ERPs were time-locked to the onset of each critical word in the trial (i.e., motion verb, secondary motion word), baseline-corrected to the 200 ms prior to stimulus onset, and average referenced after correcting for the polar average reference effect (Junghoefer et al., 1999). Any trial that contained ocular artifacts (i.e., blinks, eye movements, other movements) or an inaccurate response was excluded from analysis.

### 3. Analyses

We had two aims in our analysis of lexico-semantic expectancies: Our first aim was to examine whether speakers of English and Spanish had language-specific expectancies for motion events to be lexicalized with either a manner verb or a path verb. In line with typical patterns of expression, it was predicted that English speakers would demonstrate a higher expectancy for manner verbs than path verbs, and Spanish speakers would demonstrate a higher expectancy for path verbs than manner verbs in motion event descriptions. Our second aim was to determine whether construction type influenced expectancies for overall packaging of the motion information in a sentence by comparing the expectancies for secondary manner and path expressions. Given the more frequent use of secondary path expressions in manner-verb constructions by English speakers, it was predicted that English speakers should expect secondary path expressions in manner-verb sentences (e.g., ‘Felix walks up the bridge’) more than they should expect the optional secondary manner expressions in the path-verb sentences (e.g., ‘Felix ascends the bridge walking’). In contrast, Spanish speakers tend to use path-verb constructions in which secondary manner expression is optional. Thus, if expectancies for secondary motion expressions are determined by language-specific patterns of expressions, Spanish speakers should either show a weak expectancy for secondary manner over path expressions or show no strong expectancies for one type of secondary expression than the other.

To test our hypotheses, a total of four separate linear mixed model (LMM) analyses were conducted using the lmer() function from the lme4 library (Bates et al., 2015) in R (R Core Team, 2017). The dependent variable for each analysis was the mean amplitude for the ERP in either the 200–500 ms time window or the 500–700 ms time window post-stimulus onset. Centro-parietal negativities in the 200–500 ms window would be consistent with the N400 effect. If an N400 effect was present, additional frontal positivities in the 500–700 ms time window would be consistent with a frontal PNP effect, and posterior centro-posterior positivities in the 500–700 ms time window would be consistent with a posterior PNP. If, on the other hand, an N400 effect was not present, centro-posterior positivities in the 500–700 ms time window would be consistent with a semantic P600 effect.

For the verb analyses (aim 1), ERPs were time-locked to the onset of all congruent verbs, including all congruent trials and trials where the secondary motion expression was incongruent resulting in a maximum of 96 possible trials per motion type per participant. After the removal of trials with inaccurate responses or ocular or motor artifacts, there were a total of 1646 manner trials ($M = 71.57, SD = 21.17$) and 1621 path trials ($M = 70.48, SD = 20.20$) for English speakers and 1348 manner trials ($M = 64.19, SD = 18.93$) and 1483 path trials ($M = 70.62, SD = 17.08$) for Spanish speakers. The maximal LMM is detailed in Model 1.

\[
\text{Amplitude} \sim \text{MotionType} \times \text{Language} \times \text{Block} \times \text{AntPost} \times \text{Laterality} + (1 + \text{Block} | \text{Subject})
\]

The optimal model for each analysis was found by iteratively excluding factors from the maximal model and comparing the Akaike information criterion (AIC). Items that did not significantly improve model fit were excluded from the model (Baayen, Davidson and Bates, 2008). Once the optimal model was identified, only the highest order interaction that included unique factors with MotionType were probed using post hoc simple main effects analyses from the testInteractions() function of the phia library (De Rosario Martínez, 2015). All post hoc analyses were adjusted for multiple comparisons using the Holm-Bonferroni method (Holm, 1979). Results from the omnibus tests and all post hoc comparisons are provided in Appendix B.

The fixed factors included MotionType (manner, path), Language (English, Spanish), Block (1–4), and nine regions of interest (Rois) divided into two factors: AntPost (anterior, central, posterior) and Laterality (left, medial, right; see Fig. 2 for electrode clusters). Random factors included the random slopes for Block within Subjects.

For the analysis of secondary motion expressions (aim 2), ERPs were time-locked to the onset of congruent critical words in only the trials that were entirely congruent with the preceding animation to ensure that no effects from incongruent verbs would carry over into the critical time frame. There was a maximum of 64 trials per motion type per participant; and after the removal of trials with inaccurate responses or ocular or motor artifacts, there were a total of 662 trials for manner ($M = 28.78, SD = 16.66$) and 1074 trials for path ($M = 46.70, SD = 14.07$) in English and 633 trials for manner ($M = 30.14, SD = 18.30$), and 692 trials for path ($M = 32.95, SD = 13.44$) in Spanish. The maximal model was identical to that of Model 1 with the exception that Location was added as a by-item random intercept to account for the fact that the critical motion word could occur either in the third (i.e., all secondary path expressions in English and the Spanish path prepositions ‘a través del’ = across and ‘hacia’ = toward) or fourth (i.e., all secondary manner expressions and the Spanish secondary path adverbs ‘arriba’ = up and ‘abajo’ = down) screen. The full model is detailed in Model 2.

\[
\text{Amplitude} \sim \text{MotionType} \times \text{Language} \times \text{Block} \times \text{AntPost} \times \text{Laterality} + (1 + \text{Block} | \text{Subject}) + (1 | \text{Location})
\]
4. Results

4.1. Speakers’ expectancies for type of motion conveyed in the verb

We first examined the ERP responses to manner compared to path verbs. The fixed effect of Block was not found to significantly contribute to model fit in either time window and was subsequently removed from analyses. (See Fig. 3 for the grand averaged mean waveforms prior to corrections for random effects, i.e., random slopes for Block by-subject.)

First looking at mean amplitudes in the time window for the N400 (i.e., 200–500 ms), we found a significant interaction for Language × MotionType ($\chi^2(1) = 28.47, p < .001$). Simple main effects contrasts (Fig. 4A) revealed that the amplitudes for path verbs were more positive than manner for English ($\chi^2(1) = 23.92, p < .001$) and middle regions ($\chi^2(1) = 20.75, p < .001$). In contrast, for Spanish, manner verbs produced a greater positivity than path verbs ($\chi^2(1) = 12.37, p < .001$), particularly in the middle region ($\chi^2(1) = 6.76, p = .037$). The lack of an N400 effect along with the

![Fig. 3. Grand Average Waveforms for Verbs. Grand average waveforms for manner (blue) and path (red) verbs across the nine regions of interest for Spanish (upper) and English (lower) speakers. Waveforms are not adjusted for random effects. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)](image-url)
latency and the middle laterality for the effects in the later window were suggestive of a semantic P600 effect in both languages.

In summary, our results showed that English speakers had a greater expectancy for manner verbs than path verbs while Spanish speakers had a greater expectancy for path verbs than manner verbs—in line with our predictions and the habitual patterns of motion expression in the two languages. At the same time, different from our predictions, the results of the analyses of motion verbs in both time windows were consistent with a semantic P600 (but not a N400) effect, which also had an earlier onset latency in English speakers than in Spanish speakers.

4.2. Speakers’ expectancies for secondary motion expressions

Turning next to secondary motion expressions, we found that all factors contributed significantly to model fit in both time windows. (See Fig. 5 for the grand averaged mean waveforms prior to corrections for random effects, i.e., random slopes for Block by-subject and random intercepts for Location by-item.)

First looking at mean amplitudes in the time window for the N400 (i.e., 200–500 ms), we found a significant Block × Language × MotionType × Laterality interaction ($F(2, 27383.2) = 3.74, p = .024$). Simple main effects contrasts (Fig. 6A) revealed a greater positivity in the middle region for secondary manner expressions than path expressions for English speakers; and the effect was seen in all four blocks (block 1: $\chi^2(1) = 10.91, p = .006$; block 2: $\chi^2(1) = 22.91, p < .001$; block 3: $\chi^2(1) = 26.30, p < .001$; block 4: $\chi^2(1) = 16.18, p < .001$). Similar to verbs, the results on secondary motion expression in English did not reflect an N400 effect but could be indicative of an early onset for a semantic P600 effect. Different from English speakers, Spanish speakers showed a larger positivity in the right region for secondary path expressions than secondary manner expressions for the second ($\chi^2(1) = 9.75, p = .009$), third ($\chi^2(1) = 20.06, p < .001$), and fourth ($\chi^2(1) = 16.39, p < .001$) blocks but not the first block ($\chi^2(1) = 1.26, p = .787$). Results for Spanish speakers did not resemble the latency or distribution of any of the predicted ERP components.

Turning next to the time window associated with late positivities (i.e., 500–700 ms), we found a significant Block × Language × MotionType × Laterality interaction ($F(2, 27446.0) = 13.01, p = .049$). Simple main effects contrasts (Fig. 6B) for the interaction revealed that English speakers exhibited a greater positive amplitude for secondary manner
Fig. 5. Grand Averaged Waveforms for Secondary Motion Expressions. Grand average waveforms for manner (blue) and path (red) secondary motion expressions across the nine regions of interest for Spanish (upper) and English (lower) speakers. Waveforms are not adjusted for random effects. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)
Fig. 6. Adjusted mean amplitudes for (A) the Block × Language × MotionType × Laterality interaction in the 200–500 ms time window and (B) the Block × Language × MotionType × AntPost interaction in the 500–700 ms time window for secondary motion expressions.
than secondary path expressions across all four blocks. The effect was localized to posterior regions during the first block ($\chi^2(1) = 11.06, p = .005$), the central and posterior regions during the second (central: $\chi^2(1) = 16.66, p < .001$; posterior: $\chi^2(1) = 16.04, p < .001$) and third blocks (central: $\chi^2(1) = 53.00, p < .001$, posterior: $\chi^2(1) = 12.27, p = .002$), and to the central region during the final block ($\chi^2(1) = 29.55, p < .001$). Thus, the lack of an N400 effect along with the latency and centro-parietal topography of the effect are in line with a semantic P600 effect, suggesting that English speakers had a higher expectancy for secondary path expressions in Spanish during Block 2.

Through 4 (all manner expressions in English produced significantly greater positives in the four-way interactions including Block in each time window). While the three-way interaction in each time window was consistent with a semantic P600 effect rather than an N400 effect, the results of the post hoc analyses—in line with our observations—showed that both types of secondary motion expressions in Spanish elicited a positivity with a similar scalp distribution as the component elicited by secondary manner expressions in English. These results thus suggest that differences between secondary motion expressions in Spanish in the initial contrasts likely reflect shifts in the scalp distribution of the positivity over time (with secondary path expressions becoming more right-lateralized and anterior compared to manner expressions) rather than the activation of a different component.

In summary, our results showed that English speakers had a lower expectancy for secondary manner than path expressions, and Spanish speakers (based on exploratory analysis) had a low expectancy for both types of secondary motion expression—a pattern in line with the habitual expressions in each language and our predictions. Importantly, the results of the analyses of secondary motion expressions in both time windows were consistent with a semantic P600 (but not a N400) effect, mirroring the pattern observed in the processing of motion verbs.

### 5. Discussion

Our study examined the ERP correlates of motion expression in two typologically distinct languages: English (S-language), in which motion is typically encoded in a manner verb tightly coupled with a secondary path expression, and Spanish (V-language), in which motion is typically encoded in a path verb alone. We predicted that motion lexicalizations that were not consistent with typological patterns of motion expression would elicit N400 effects, possibly accompanied by PNPs. In line with our predictions, speakers did show greater expectancies for motion descriptions to be consistent with habitual patterns of expression. However, in contrast to our predictions, effects were indexed by the semantic P600 effect instead of the N400 effect.

#### 5.1. Speakers’ expectancies for the lexicalisation of motion in the verb and in secondary motion expressions

The analyses of lexical expectancies for motion verbs show a semantic P600 effect for path compared to manner verbs in English and for manner compared to path verbs in Spanish, as exhibited by mean amplitudes in the 500–700 ms time window. Despite eliciting a different component than predicted, the results support the hypothesized outcome: English speakers showed a greater expectancy for motion verbs to express manner rather than path while Spanish speakers showed a greater expectancy for motion verbs to convey path than manner—results that match the habitual patterns of expression for each language.

Similar to verbs, analyses of lexical expectancies for secondary motion expressions also revealed a semantic P600 effect rather than an N400 effect for English speakers with larger positivities elicited by secondary manner expressions than secondary path expressions. Again, the elicitation of a semantic P600 effect rather than an N400 effect was unexpected, but the direction of the effect matched the hypothesized outcomes. English speakers—in line with our predictions—had a higher expectancy for secondary path expressions to accompany manner verbs (e.g., ‘Felix walks up the bridge’) than for secondary manner expressions to accompany path verbs (e.g., ‘Felix ascends the bridge walking’). For Spanish speakers, exploratory analyses of secondary motion expressions revealed that both manner and path expressions elicited a centro-
parietal positive component. The component had a similar latency and scalp distribution as the semantic P600 component found for secondary manner expressions in English, suggesting that both types of expressions elicited a semantic P600 effect in Spanish—though future research with a highly expected baseline condition for Spanish speakers is necessary to further confirm this finding.

Overall, ERP patterns match the habitual patterns of expression in each language as shown in earlier speech production studies: English speakers express manner in the verb and path in a secondary linguistic element (i.e., particle, preposition) associated with the verb; Spanish speakers, on the other hand, typically express path in the verb, frequently without a secondary manner or path expression (e.g., ‘Félix sube el puente’ = Félix ascends the bridge; e.g., Kita and Ozyurek, 2003; Naigles et al., 1998; Ozçalıskan, 2004, 2009, 2016; Ozçalıskan et al., 2016, 2018; Papafragou et al., 2002, 2006; Slobin, 1996, 2004; Talmy, 1985, 2000). Altogether, findings for motion expressions lexicalized within the verb or in a secondary expression thus suggest that neural processing of motion event lexicalization is consistent with patterns of habitual expression for speakers of two typologically distinct languages.

Interestingly, processing for verbs did not change over the course of the four blocks during the experiment (i.e., no significant contribution of Block to model fit). This result is in contrast with previous behavioral studies on pseudoword-learning that showed a change in online comprehension in English speakers’ expectancies (i.e., choice among a manner and a path interpretation) based on the proportion of manner versus path pseudowords that they had been trained on earlier in the experiment (Shafto et al., 2014). If participants were to adjust their expectancies to match the even distribution of manner versus path words—similar to participants in Shafto and colleagues’ experiment—their expectancy for the preferred verb type (i.e., manner in English, path in Spanish) ought to have decreased with exposure across the blocks of the experiment resulting in smaller ERP effects. However, this was a pattern that was not evident in our study. One possible explanation for the discrepancy in findings between earlier behavioral work (Shafto et al., 2014) and our ERP study could be that speakers’ expectancies about motion information may be more susceptible to change in the learning of novel words compared to the processing of already familiar speech. Given the relatively well-established patterns of expression for manner and path words in one’s language by adulthood, the brief exposure to a dis-preferred motion verb type over the course of an experiment may not have been enough to unlearn the established patterns of expression. Our results thus highlight that type of speech (familiar vs. novel) might play an important role in processing linguistic stimuli that do or do not follow habitual patterns of expression in one’s language.

5.2. Functional significance of elicited ERP components

Our study, as the first of its kind, demonstrates that speakers show neural biases that are consistent with their native patterns of language expression. This, in turn, suggests that habitual expression in production of motion events affects expectancies in online comprehension of motion event descriptions. Importantly, these conclusions do not rely on the type of component (i.e., N400, PNP, or semantic P600) observed. However, the presence of certain components—and absence of others—may provide insight into the types of cognitive processes that are involved in lexical expectancies for motion expression. Of particular relevance are the questions of why N400 effects were not present, why semantic P600 effects were seen instead, and why the positive effects were seen in the earlier time window—each of which we expand upon below.

5.2.1. The absence of N400 effects

Traditionally, semantic expectancy of a word is measured with the N400 effect (Kutas and Federmeier, 2000, 2011), sometimes also followed by a post-N400 positivity (PNP; DeLong et al., 2014a; Van Petten and Luka, 2012). In our study, however, dis-preferred lexicalizations of motion (i.e., path verbs and secondary manner expressions in English; manner verbs and both secondary manner or path expressions in Spanish) elicited late positivities but without an N400 effect. Our results thus suggest that speakers’ expectations concerning the expression of manner compared to path of motion within or outside the verb are indexed by the semantic P600 effect.

One potential reason why the N400 was not elicited could be that the motion event descriptions were all congruent with the preceding animation and, as such, had relatively strong pre-activations. This contrasts with previous research on the N400 effect where an incongruent word is often not predictable based on the preceding context (e.g., ‘I take my coffee with milk and socks’; Kutas and Hillyard, 1980). The N400 effect has been theorized to reflect predictive processes in which the amplitude of the component is inversely related to the degree of expectancy for that word, namely that N400 will be reduced whenever a word is pre-activated by some preceding context (Brouwer et al., 2012; DeLong et al., 2014b; Kutas and Federmeier, 2000; Van Petten and Luka, 2012). Given that all motion descriptions were congruent with the preceding motion animation in the present study, viewing the motion event depicted in the animation may have equally pre-activated both preferred and dis-preferred lexicalizations of manner and path. This, in turn, may have reduced the amplitude of the N400 component for both motion types, resulting in no differences between the amplitudes and, consequently, no N400 effect. Analysis of incongruent compared to congruent trials in the same group of participants (Emerson et al., 2020) suggests, however, that this is unlikely the case. If the N400 reflects pre-activation of a word based on the preceding context, then motion words that mismatched the animation should have elicited N400 effects, regardless of how the motion information was lexicalized. Instead, however, incongruent motion information elicited N400 effects only when the information was expressed with certain types of linguistic elements (e.g., secondary manner expressions in both languages, secondary path expressions in Spanish) but not with others (e.g., verbs in both languages). Thus, results all together suggest that the N400 must be both sensitive to pre-activation (or predictive processes) and the particulars of the linguistic expression in which the information is packaged (Bornkessel-Schlesewsky and Schlesewsky, 2019).

5.2.2. The presence of semantic P600 effects

While dis-preferred lexicalizations did not elicit N400 effects, they did elicit a greater positivity than preferred lexicalizations. The effect had a centro-parietal topography for verbs in both languages and secondary manner expressions in English. Such scalp distributions are consistent with both the posterior PNP and the semantic P600. Because N400 effects were not elicited in the present study, the late positive component cannot accurately be described as a PNP, which, by definition, always follows an N400 effect. The posterior PNP and the semantic P600, however, have been theorized to be related to one another, with both reflecting the triggering of a re-analysis of the preceding context (DeLong et al., 2014a; Kokk et al., 2003; Kuperberg, 2007; van de Meerendonk et al., 2009; Van Petten and Luka, 2012; Vissers et al., 2008). It is interesting to note that, despite the centro-parietal distribution of the effects, the study design had more in common with the antecedent conditions for the frontal PNP than with the posterior PNP. More specifically, the posterior PNP is predicted to occur in response to words that are incongruent with a preceding context while the frontal
PNP is predicted to occur in response to words that are congruent but have a low probability of occurring. In our design, all motion words were congruent with the preceding animation but had a low probability of occurring due to lexical preferences and, thus, were more in line with the conditions known to elicit the frontal PNP. As such, the lack of the N400 effects, in concert with the centro-parietal distribution of the positivity, bolster our interpretation of a semantic P600 effect.

From a functional perspective, the presence of semantic P600 effects suggests that the dis-preferred lexicalizations might have triggered a re-analysis of the preceding context. In most P600 research, the context that is re-analyzed is typically thought to be the rest of the sentence preceding the critical word (DeLong et al., 2014a; Kolk et al., 2003; Kuperberg, 2007; Van Petten and Luka, 2012). This is unlikely to be the case for our study, especially for verbs, which were always preceded by only a single proper noun (i.e., ‘Felix’/’Félix’) across both conditions. A more likely explanation could be that the re-analysis served to verify whether or not the dis-preferred descriptor matched the participants’ memory of the preceding animation—a result that closely resembles that of Visser, Kolk, van de Meerdonk, and Chwilla (2008). In their study, Visser and colleagues asked speakers to view an image of two shapes that were arranged either vertically or horizontally. The image was then followed by a grammatical sentence that either provided a congruent or incongruent description of the orientation of the depicted shapes, with the incongruent descriptions eliciting P600 effects. The findings were then taken as evidence that the P600 reflects general re-analysis rather than specific processing of the structure of the sentence itself. Thus, the presence of a P600 effect in response to dis-preferred lexicalizations of motion expressions in our study might reflect a general re-analysis of what speakers have seen (animation) with what they have read (a lexically unexpected motion description)—akin to earlier work (Visser et al., 2008).

5.2.3. The early latency of positivities

One question our findings raise is the reason for the presence of positivities for dis-preferred verbs (in English) and secondary motion expressions as early as the 200–500 ms time window. Previous studies have shown that syntactic anomalies can elicit a P600-like effect that begins to diverge as early as 200 or 300 ms, particularly when the ambiguity is relatively easy to resolve (Friederici, Mecklinger, Spencer, Steinhauser and Donchin, 2001; Mecklinger et al., 1995; Qi et al., 2017). The early positivity also appears to have been stronger for individuals who were quicker to comprehend the sentences or to learn new syntactic structures (Mecklinger et al., 1995; Qi et al., 2017). Thus, earlier latencies of the P600 (and possibly the semantic P600) effect may reflect greater ease of processing, and consequently, shorter latencies. The early latency of the positivity, thus, may indicate that verifying the congruency of the lexically unexpected motion word with the preceding motion animation (i.e., the re-analysis) was relatively easy, particularly for secondary motion expressions in both languages and for verbs in English.

An alternative explanation, however, could be that the early and long-lasting positivities may reflect the summation of two distinct components rather than a single monolithic component; the later portion of the positivity may reflect a language-specific P600 effect while the earlier portion may reflect a component known as the P300 (Friederici et al., 2001). The P300 (also known as the P3b) is another positive component with a centro-parietal distribution that is domain-general, appearing in response to novel or rare stimuli in a sequence (Sutton, Brodie, Zilles, and John, 1977). The peak latency of the component is typically 300 ms after the onset of the critical stimulus; however, the latency of the effect has been shown to be delayed in response to more complex stimuli (Kutas, McCarthy and Donchin, 1977). In fact, similarities in topography and ancillary conditions have led to multiple theories that suggest that the traditional P600 and semantic P600 effects may be sub-types of the P300 effect or members of the same family of late positive components (Bornkessel-Schlesewsky et al., 2011; Bornkessel-Schlesewsky and Schlesewsky, 2019; Coulson, King and Kutas, 1998a, 1998b; Gunter, Stowe and Mulder, 1997; Leckey and Federmeier, 2020; Sassenhagen and Bornkessel-Schlesewsky, 2015; Sassenhagen, Schlesewsky and Bornkessel-Schlesewsky, 2014; van Herten, Kolk and Chwilla, 2005). Thus, rather than reflecting an earlier latency of the semantic P600 effect, the positivity in the earlier time window may instead reflect an additional P300 component.

The cognitive processes underlying the P300 are still unclear, but the component has been predicted to reflect categorization of a stimulus based on attention or working memory processes (Kok, 2001), processes involved in decision making (Kelly and O’Connell, 2015; Twomey et al., 2015), or processes involved in the neural inhibition of irrelevant information to facilitate the processing of a novel stimulus (Polich, 2007). Thus, the presence of a separable P300 component would suggest that speakers were engaging in additional processing prior to re-analysis of the stimuli. For example, categorization-based interpretations of the P300 (Kok, 2001) would suggest that participants were attempting to categorize the type of motion (i.e., manner or path) being expressed by the critical word. A decision-making interpretation of the P300 (Kelly & O’Connell, 2015; Twomey et al., 2015) could indicate that speakers were making binary decisions as to whether or not the sentence was well-formed based on habitual patterns of expression. And a neural-inhibition interpretation of the P300 (Polich, 2007) would suggest that dis-preferred lexicalizations required additional attention to appropriately determine whether they matched with the video, and consequently non-relevant activity was suppressed in order to allocate additional resources to the task for those stimuli.

At the same time, it remains unclear as to why the positivity does not appear in the earlier window for verbs in Spanish speakers. One possibility could be that it is related in part to Spanish speakers’ weaker bias to use path verbs over manner verbs compared to verb biases in English speakers (Slobin, 2004; Talmy, 1985, 2000). More specifically, English speakers have a strong tendency to express motion with a manner verb. While path verbs tend to be preferred by Spanish speakers, the use of manner verbs also occurs relatively frequently (e.g., Özçalışkan and Slobin, 1999). Thus, Spanish speakers show a greater degree of flexibility in their choice of lexicalizations than English speakers. The rigidity for the use of the manner-verb construction in English might have made deviations more immediately salient, resulting in either an earlier onset of the semantic P600 effect or an additional cognitive process associated with the P300 effect.

5.3. Limitations and venues for future work

One caveat of our study is that the native Spanish speakers were all Spanish–English bilinguals who were also fluent in English, raising the possibility of an effect of second language in the processing of first language. However, we took extensive steps to mitigate the use of English during the experiment, conducting procedures, including consent, in Spanish by native Spanish speakers. Our study also compared neural patterns in only two languages, namely Spanish and English, as representative of the broader S- versus V-language dichotomy. Even though English and Spanish provide good exemplars of the two language types, future studies that extend our paradigm to a greater variety of the world’s languages could provide further insight about the generalizability of the patterns that we have observed in our data.

In addition, in our study, we did not include filler trials, which might have resulted in habituation to both manner- and path-verb sentence constructions over the course of the trials. However, we added an additional control for potential habituation and learning effects by adding Block as a random by-subject slope to all analyses. In other words, we controlled for changes in mean amplitude across time (as measured in blocks) separately for each participant. As noted previously, after adding in this control, Block was not found to significantly contribute to the variance in mean amplitudes for motion verbs but did significantly contribute to the variance for secondary motion expressions. Our results, however, indicate that observed differences across time were limited to
changes in the scalp distributions. The inclusion of filler trials in future studies could further confirm lack of a change due to habituation.

Finally, language-specific constraints forced us to use two different parts of speech (i.e., prepositions, adverbs) to encode secondary path descriptions in Spanish. While subjective ratings suggest that Spanish speakers found path prepositions to be more typical than path adverbs (see Table 1 of Appendix A), the present study does not have adequate power to probe the differences between the two parts of speech ($n < 16$ per participant) to determine if the heterogeneity in secondary path typicality affected the ERPs. Furthermore, because both secondary manner and secondary path expressions are typically not included in Spanish motion descriptions, neither provides a strong baseline for ERP comparisons making it difficult to confirm the identity of the component elicited. As such, future work should further probe the effect of part of speech on expectancy for motion expression with a particular emphasis on secondary path expressions in Spanish.

### 5.4. Conclusion

Our study, as the first experiment to examine the effect of language type on the neural indices of habitual motion expression, revealed two important findings: First, neural processing of real motion expressions followed cross-linguistic differences in the expression of motion. Spanish ($V$-language) speakers had a high expectancy for motion verbs to encode path, and English speakers had a high expectancy for motion verbs to encode manner, tightly coupled with a secondary path expression—mirroring language-specific patterns observed in the production of motion events. Second, expectancy for manner compared to path information in motion expression was indexed by a semantic P600 but not the ERPs of the congruency of the word with the preceding animation rather than changes in the scalp distributions. The inclusion of filler trials in future studies could further confirm lack of a change due to habituation.

Our study, as the first experiment to examine the effect of language type on the neural indices of habitual motion expression, revealed two important findings: First, neural processing of real motion expressions followed cross-linguistic differences in the expression of motion. Spanish ($V$-language) speakers had a high expectancy for motion verbs to encode path, and English speakers had a high expectancy for motion verbs to encode manner, tightly coupled with a secondary path expression—mirroring language-specific patterns observed in the production of motion events. Second, expectancy for manner compared to path information in motion expression was indexed by a semantic P600 but not the traditionally predicted N400 effect with or without a PNP, suggesting that the lexically unexpected motion descriptions triggered a re-analysis of the congruency of the word with the preceding animation rather than showing differences in levels of pre-activation. Overall, our study—as the first study of its kind—provide support for attunement to language-specific patterns of motion expression at the neural level between two typologically distinct languages and provide additional insight into the functional nature of these language-specific expectations.

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### CRediT authorship contribution statement

**Samantha N. Emerson:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Visualization, Writing - original draft. **Christopher M. Conway:** Conceptualization, Methodology, Resources, Supervision, Writing - review & editing. **Seyda Özçalıskan:** Conceptualization, Methodology, Resources, Supervision, Writing - review & editing.

### Declaration of competing interest

The authors report no conflicts of interest.

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### Appendix A

#### Table 1

Mean (and standard deviation) of ratings for manner-verb constructions in Spanish.

|            | a través de | abajo | arriba | hacia | Grand Mean |
|------------|-------------|-------|--------|-------|------------|
| camina     | 4.43 (1.05) | 2.57 (1.64) | 2.57 (1.59) | 4.21 (1.21) | 3.45 (1.66) |
| corre      | 4.14 (1.30) | 2.64 (1.59) | 2.57 (1.55) | 3.93 (1.33) | 3.32 (1.63) |
| gatea      | 4.29 (1.10) | 2.29 (1.53) | 2.29 (1.53) | 4.07 (1.22) | 3.23 (1.67) |
| marcha     | 4.21 (1.08) | 2.07 (1.03) | 2.50 (1.50) | 4.00 (1.07) | 3.20 (1.52) |
| rueda      | 4.36 (1.04) | 2.50 (1.50) | 2.00 (1.41) | 3.07 (1.39) | 2.98 (1.62) |
| salta      | 4.43 (0.73) | 2.50 (1.45) | 2.43 (1.50) | 4.07 (1.28) | 3.36 (1.58) |
| se desliza | 3.79 (1.15) | 2.07 (1.39) | 1.86 (1.19) | 3.71 (1.28) | 2.86 (1.55) |
| vuelta     | 3.64 (1.49) | 2.21 (1.47) | 2.00 (1.25) | 3.57 (1.24) | 2.86 (1.58) |
| Grand Mean | 4.16 (1.17) | 2.36 (1.48) | 2.28 (1.48) | 3.83 (1.31) | 3.16 (1.60) |

$n = 14$; rows = manner verbs, columns = secondary path expressions

#### Table 2

Mean (and standard deviation) of ratings for path-verb constructions in Spanish.

|            | baja    | cruza    | se acerca | sube | Grand Mean |
|------------|---------|----------|-----------|------|------------|
| caminando  | 4.71 (0.45) | 4.64 (0.61) | 4.64 (0.61) | 4.21 (1.21) | 4.55 (0.81) |
| corriendo  | 4.43 (1.12) | 4.43 (0.52) | 4.79 (0.41) | 4.57 (0.49) | 4.55 (0.78) |
| deslizándose | 3.93 (1.33) | 4.21 (1.08) | 3.71 (1.39) | 3.36 (1.34) | 3.80 (1.34) |
| gateando   | 4.07 (1.22) | 4.36 (1.11) | 4.57 (0.62) | 4.64 (0.61) | 4.41 (0.97) |
| marchando  | 4.57 (0.62) | 4.21 (1.21) | 4.57 (0.62) | 4.29 (1.03) | 4.41 (0.93) |
| rodando    | 4.29 (1.03) | 4.64 (0.61) | 4.71 (0.59) | 4.14 (1.06) | 4.45 (0.89) |
| saltando   | 4.57 (0.82) | 4.43 (0.92) | 4.79 (0.41) | 4.36 (1.11) | 4.54 (0.85) |
| volando    | 4.21 (1.26) | 4.57 (0.82) | 4.21 (0.94) | 3.79 (1.32) | 4.20 (1.15) |
| Grand Mean | 4.35 (1.06) | 4.44 (0.93) | 4.50 (0.84) | 4.17 (1.14) | 4.36 (1.00) |

$n = 14$; rows = secondary manner expressions, columns = path verbs.
Table 3
Mean (and standard deviation) of ratings for manner-verb constructions in English.

|                   | across | down | toward | up    | Grand Mean |
|-------------------|--------|------|--------|-------|------------|
| crawls            | 3.94 (1.29) | 3.69 (1.62) | 3.88 (1.20) | 3.94 (1.12) | 3.86 (1.32) |
| flies             | 3.75 (1.48) | 3.38 (1.75) | 3.69 (1.49) | 3.06 (1.65) | 3.47 (1.63) |
| jumps             | 4.31 (0.79) | 4.06 (1.34) | 3.94 (1.24) | 3.75 (1.29) | 4.02 (1.18) |
| marches           | 4.06 (1.06) | 4.19 (1.11) | 4.19 (0.83) | 4.44 (0.81) | 4.22 (0.93) |
| rolls             | 3.69 (1.54) | 3.63 (1.45) | 3.75 (1.57) | 3.00 (1.46) | 3.52 (1.55) |
| runs              | 4.69 (0.70) | 4.75 (0.58) | 4.69 (0.60) | 4.69 (0.60) | 4.70 (0.43) |
| slides            | 3.25 (1.44) | 3.25 (1.57) | 3.69 (1.40) | 3.19 (1.33) | 3.34 (1.46) |
| walks             | 4.75 (0.58) | 4.75 (0.58) | 4.81 (0.54) | 4.50 (0.97) | 4.70 (0.54) |
| **Grand Mean**    | 4.05 (1.24) | 3.96 (1.42) | 4.08 (1.32) | 3.82 (1.36) | 3.98 (1.31) |

n = 15; rows = manner verbs, columns = secondary path expressions.

Table 4
Mean (and standard deviation) of ratings for path-verb constructions in English.

|                   | approaches | ascends | crosses | descends | Grand Mean |
|-------------------|------------|---------|---------|----------|------------|
| crawling          | 2.94 (1.29) | 2.25 (1.06) | 3.13 (1.26) | 2.44 (1.03) | 2.69 (1.18) |
| flying            | 2.38 (1.36) | 1.94 (1.12) | 2.44 (1.36) | 1.81 (1.05) | 2.14 (1.17) |
| jumping           | 2.44 (1.31) | 2.13 (1.20) | 2.81 (1.11) | 2.44 (1.03) | 2.45 (1.13) |
| marching          | 2.88 (1.26) | 2.44 (1.26) | 3.25 (1.24) | 2.88 (1.26) | 2.86 (1.26) |
| rolling           | 2.06 (1.39) | 2.00 (1.03) | 2.38 (1.41) | 2.19 (1.33) | 2.16 (1.22) |
| running           | 2.69 (1.30) | 2.56 (1.15) | 3.25 (0.93) | 2.19 (1.05) | 2.67 (1.14) |
| sliding           | 1.94 (1.12) | 2.00 (1.15) | 2.44 (1.36) | 2.00 (1.10) | 2.09 (1.10) |
| walking           | 3.06 (1.24) | 2.13 (1.02) | 3.13 (1.36) | 2.63 (1.15) | 2.73 (1.23) |
| **Grand Mean**    | 2.55 (1.30) | 2.18 (1.05) | 2.85 (1.29) | 2.32 (1.09) | 2.47 (1.21) |

n = 15; rows = secondary manner expressions, columns = path verbs.

Appendix B

Table 1
Summary of effects for the analysis of mean amplitudes in the 200–500 ms time window in response to motion verb expectancy.

| Factor                          | SumSq | MeanSq | NumDF | DenDF | F-Value | p     |
|---------------------------------|-------|--------|-------|-------|---------|-------|
| Language                        | 47    | 47.0   | 1     | 38    | 1.25    | .270  |
| MotionType                      | 357   | 357.5  | 1     | 54811 | 9.54    | .002 *** |
| Laterality                      | 1850  | 925.2  | 2     | 54755 | 24.68   | <.001 *** |
| AntPost                         | 34919 | 17459.6| 2     | 54755 | 465.75  | <.001 *** |
| **Language × MotionType**       | 648   | 647.7  | 1     | 54811 | 17.28   | <.001 *** |
| Language × Laterality           | 698   | 349.2  | 2     | 54755 | 9.32    | <.001 *** |
| MotionType × Laterality         | 34    | 17.2   | 2     | 54755 | 0.46    | .633  |
| Language × AntPost              | 6373  | 3186.4 | 2     | 54755 | 85.00   | <.001 *** |
| MotionType × AntPost            | 28    | 14.2   | 2     | 54755 | 0.38    | .685  |
| Laterality × AntPost            | 8261  | 2065.3 | 4     | 54755 | 55.09   | <.001 *** |
| Language × MotionType × Laterality | 98   | 48.8   | 2     | 54755 | 1.30    | .272  |
| Language × MotionType × AntPost | 58    | 28.8   | 2     | 54755 | 0.77    | .464  |
| Language × Laterality × AntPost | 757   | 189.4  | 4     | 54755 | 5.05    | <.001 *** |
| MotionType × Laterality × AntPost| 50   | 12.5   | 4     | 54755 | 0.33    | .856  |
| Language × MotionType × Laterality × AntPost | 19 | 4.7 | 4 | 54755 | 0.13 | .973 |

***p < .001, **p < .010, *p < .050, .p < .100; probed effects are in bold.
Table 2
Simple main effects analysis for the Language × MotionType interaction for motion verbs in the 200-500 ms time window.

| Language  | MannerM (SE) | PathM (SE) | Diff | DF | $\chi^2$ | p     |
|-----------|--------------|------------|------|----|---------|-------|
| English   | 1.56 (0.25)  | 1.94 (0.25) | −0.38 | 1  | 28.47   | <.001 *** |
| Spanish   | 1.38 (0.26)  | 1.32 (0.26) | 0.06  | 1  | 0.53    | .467   |

*** p < .001, ** p < .010, * p < .050, . p < .100; M: adjusted mean, SE: standard error of the link.

Table 3
Summary of effects for the analysis of mean amplitudes in the 500-700 ms time window in response to motion verb expectancy.

| Factor                          | SumSq | MeanSq | NumDF | DenDF | F-Value | p     |
|--------------------------------|-------|--------|-------|-------|---------|-------|
| Language                       | 16    | 15.7   | 1     | 38    | .30     | .590  |
| MotionType                     | 130   | 130.3  | 1     | 54808 | 2.45    | .117  |
| Laterality                     | 5779  | 2889.4 | 2     | 54755 | 54.36   | <.001 *** |
| AntPost                        | 52923 | 26461.7| 2     | 54755 | 497.85  | <.001 *** |
| Language × MotionType          | 2408  | 2408.1 | 1     | 54808 | 45.31   | <.001 *** |
| Language × MotionType × Laterality | 728  | 364.1  | 2     | 54755 | 6.85    | .001 ** |
| Language × MotionType × AntPost | 142  | 71.1   | 2     | 54755 | 1.34    | .263  |
| Language × AntPost             | 528   | 263.8  | 2     | 54755 | 4.96    | .007 ** |
| MotionType × Laterality        | 18    | 9.0    | 2     | 54755 | 0.17    | .844  |
| MotionType × AntPost           | 14057 | 3514.2 | 4     | 54755 | 66.12   | <.001 *** |
| Language × MotionType × Laterality | 311  | 155.6  | 2     | 54755 | 2.93    | .054  |
| Language × MotionType × AntPost | 145  | 72.6   | 2     | 54755 | 1.37    | .255  |
| Language × MotionType × AntPost | 160  | 39.9   | 4     | 54755 | 0.75    | .557  |
| Language × MotionType × AntPost | 71   | 17.7   | 4     | 54755 | 0.33    | .856  |
| Language × MotionType × AntPost | 59   | 14.8   | 4     | 54755 | 0.28    | .892  |

*** p < .001, ** p < .010, * p < .050, . p < .100; probed effects are in bold.

Table 4
Simple main effects analysis for the Language × MotionType × Laterality and Language × MotionType interactions for motion verbs in the 500-700 ms time window.

| Language × Laterality          | MannerM (SE) | PathM (SE) | Diff | DF | $\chi^2$ | p     |
|--------------------------------|--------------|------------|------|----|---------|-------|
| English Left                   | 1.52 (0.28)  | 2.04 (0.28) | −0.52 | 1  | 37.34   | <.001 *** |
| English Middle                 | 1.48 (0.29)  | 2.20 (0.29) | −0.72 | 1  | 23.92   | <.001 *** |
| English Right                  | 1.68 (0.29)  | 2.35 (0.29) | −0.67 | 1  | 20.75   | <.001 *** |
| Spanish Left                   | 2.15 (0.29)  | 1.83 (0.29) | 0.32  | 1  | 12.37   | <.001 *** |
| Spanish Middle                 | 2.07 (0.31)  | 1.76 (0.30) | 0.31  | 1  | 3.84    | .150  |
| Spanish Right                  | 2.77 (0.31)  | 2.35 (0.30) | 0.41  | 1  | 6.76    | .037  |

*** p < .001, ** p < .010, * p < .050, . p < .100; M: adjusted mean, SE: standard error of the link.

Table 5
Summary of effects for the analysis of mean amplitudes in the 200-500 ms time window in response to expectancy for secondary motion expressions.

| Factor                          | SumSq | MeanSq | NumDF | DenDF | F-Value | p     |
|--------------------------------|-------|--------|-------|-------|---------|-------|
| Block                          | 1414.19| 1414.19| 1     | 38.6  | 46.34   | <.001 *** |
| Language                       | 72.54 | 72.54  | 1     | 34.8  | 2.38    | .132  |
| MotionType                     | 12.91 | 12.91  | 1     | 7406.9| 0.42    | .515  |
| Laterality                     | 151.94| 75.97  | 2     | 27383.2| 2.49    | .083  |
| AntPost                        | 1623.55| 811.78 | 2     | 27383.2| 26.60   | <.001 *** |
| Block × Language               | 257.78| 257.78 | 1     | 38.6  | 8.45    | .006 ** |
| Block × MotionType             | 3.10  | 3.10   | 1     | 19004.4| 0.10    | .750  |

(continued on next page)
Table 5 (continued)

| Factor | SumSq | MeanSq | NumDF | DenDF | F-Value | p     |
|--------|--------|--------|-------|-------|---------|-------|
| Language × MotionType | 115.68 | 115.68 | 1     | 18606.9 | 3.79    | .052  |
| Block × Laterality | 473.06 | 236.53 | 2     | 27383.2 | 7.75    | <.001 *** |
| Language × Laterality | 33.92 | 16.96 | 2     | 27383.2 | 0.56    | .574  |
| MotionType × Laterality | 163.74 | 81.87 | 2     | 27383.2 | 2.68    | .068  |
| Block × AntPost | 256.21 | 128.10 | 2     | 27383.2 | 4.20    | .015 * |
| Language × AntPost | 59.87 | 29.93 | 2     | 27383.2 | 0.98    | .375  |
| MotionType × AntPost | 73.88 | 36.94 | 2     | 27383.2 | 2.68    | .068  |
| Block × Language × Laterality | 61.05 | 30.52 | 2     | 27383.2 | 1.00    | .368  |
| Block × MotionType × Laterality | 152.71 | 76.36 | 2     | 27383.2 | 1.00    | .368  |
| Language × MotionType × Laterality | 120.13 | 60.07 | 2     | 27383.2 | 4.20    | .015 * |
| Block × Language × AntPost | 315.53 | 157.77 | 2     | 27383.2 | 5.17    | .006 ** |
| Block × MotionType × AntPost | 27.63 | 13.81 | 2     | 27383.2 | 1.09    | .338  |
| Block × Laterality × AntPost | 66.30 | 33.15 | 2     | 27383.2 | 0.42    | .797  |
| Block × Language × Laterality × AntPost | 317.65 | 79.41 | 4     | 27383.2 | 2.60    | .034 * |
| Language × Laterality × AntPost | 50.88 | 12.72 | 4     | 27383.2 | 0.42    | .797  |
| MotionType × Laterality × AntPost | 46.92 | 11.73 | 4     | 27383.2 | 0.38    | .820  |
| Block × Language × MotionType × Laterality | 228.25 | 114.12 | 2 | 27383.2 | 2.74    | .024 * |
| Block × Language × MotionType × AntPost | 143.67 | 71.83 | 2 | 27383.2 | 2.35    | .095  |
| Block × Language × Laterality × AntPost | 156.99 | 39.25 | 4 | 27383.2 | 1.29    | .273  |
| Block × MotionType × Laterality × AntPost | 34.70 | 8.68 | 4 | 27383.2 | 0.28    | .888  |
| Language × MotionType × Laterality × AntPost | 36.75 | 9.19 | 4 | 27383.2 | 0.30    | .877  |
| Block × Language × MotionType × Laterality × AntPost | 6.83 | 1.71 | 4 | 27383.2 | 0.06    | .994  |

*** p < .001, ** p < .010, * p < .050, . p < .100; probed effects are in bold.

Table 6
Simple main effects analysis for the Block × Language × MotionType × Laterality interaction for secondary motion expressions in the 200–500 ms time window.

| Block × Language × MotionType × Laterality | Manner (SE) | PathM (SE) | Diff | DF | χ² | p       |
|-------------------------------------------|-------------|------------|------|----|----|---------|
| Block 1 | | | | | | |
| English | | | | | | |
| Left | 0.81 (0.53) | 0.24 (0.51) | 0.57 | 1 | 3.24 | .288 |
| Middle | 1.12 (0.53) | 0.08 (0.51) | 1.04 | 1 | 10.91 | .006 ** |
| Right | 0.83 (0.53) | 0.87 (0.51) | 0.04 | 1 | .02 | 1.000 |
| Spanish | | | | | | |
| Left | 0.09 (0.53) | 0.73 (0.51) | −0.64 | 1 | 4.19 | .204 |
| Middle | 1.06 (0.53) | 0.91 (0.51) | 0.14 | 1 | 0.21 | 1.000 |
| Right | 0.75 (0.53) | 1.10 (0.51) | −0.35 | 1 | 1.26 | .787 |

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Table 6 (continued)

| Block × Language × Laterality | MannerM (SE) | PathM (SE) | Diff | DF | χ² | p |
|------------------------------|--------------|------------|------|----|----|---|
| Block 2                      |              |            |      |    |    |   |
| English                      |              |            |      |    |    |   |
| Left                         | 1.32 (0.50)  | 0.76 (0.49) | 0.56 | 1  | 5.74 | .066 |
| Middle                       | 1.89 (0.50)  | 0.78 (0.49) | 1.11 | 1  | 22.91 | <.001 *** |
| Right                        | 1.41 (0.50)  | 1.41 (0.49) | 0.00 | 1  | 0.00 | 1.000 |
| Spanish                      |              |            |      |    |    |   |
| Left                         | 0.45 (0.50)  | 0.72 (0.49) | −0.27 | 1 | 1.58 | .628 |
| Middle                       | 1.39 (0.50)  | 1.52 (0.49) | −0.13 | 1 | 0.36 | 1.000 |
| Right                        | 0.67 (0.50)  | 1.34 (0.49) | −0.67 | 1 | 9.75 | .009 ** |
| Block 3                      |              |            |      |    |    |   |
| English                      |              |            |      |    |    |   |
| Left                         | 1.83 (0.51)  | 1.29 (0.50) | 0.54 | 1  | 5.60 | .072 |
| Middle                       | 2.65 (0.51)  | 1.47 (0.50) | 1.18 | 1  | 26.30 | <.001 *** |
| Right                        | 2.00 (0.51)  | 1.96 (0.50) | 0.05 | 1  | 0.04 | 1.000 |
| Spanish                      |              |            |      |    |    |   |
| Left                         | 0.81 (0.51)  | 0.71 (0.51) | 0.10 | 1  | 0.19 | 1.000 |
| Middle                       | 1.72 (0.51)  | 2.12 (0.51) | −0.40 | 1 | 3.27 | .212 |
| Right                        | 0.60 (0.51)  | 1.59 (0.51) | −1.00 | 1 | 20.06 | <.001 *** |
| Block 4                      |              |            |      |    |    |   |
| English                      |              |            |      |    |    |   |
| Left                         | 2.34 (0.56)  | 1.81 (0.54) | 0.53 | 1  | 2.95 | .258 |
| Middle                       | 3.42 (0.56)  | 2.17 (0.54) | 1.25 | 1  | 16.18 | <.001 *** |
| Right                        | 2.50 (0.56)  | 2.50 (0.54) | 0.09 | 1  | 0.09 | .770 |
| Spanish                      |              |            |      |    |    |   |
| Left                         | 1.17 (0.57)  | 0.70 (0.55) | 0.46 | 1  | 2.02 | .310 |
| Middle                       | 2.05 (0.57)  | 2.73 (0.55) | −0.68 | 1 | 4.29 | .153 |
| Right                        | 0.52 (0.57)  | 1.84 (0.55) | −1.32 | 1 | 16.39 | <.001 *** |

Table 7
Summary of effects for the analysis of mean amplitudes in the 500–700 ms time window in response to expectancy for secondary motion expressions.

| Factor                          | SumSq  | MeanSq  | NumDF | DenDF | F-Value | p  |
|---------------------------------|--------|---------|-------|-------|---------|----|
| Block                           | 1353.0 | 1352.99 | 1     | 37.4  | 28.29   | .001 *** |
| Language                        | 590.1  | 590.13  | 1     | 34.3  | 12.34   | .001 ** |
| MotionType                      | 18.7   | 18.67   | 1     | 2830.0| 0.39    | .532 |
| Laterality                      | 300.2  | 150.08  | 2     | 27446.0| 3.14    | .043 * |
| AntPost                         | 5336.6 | 2668.28 | 2     | 27446.0| 55.79   | <.001 *** |
| Block × Language                | 400.9  | 400.86  | 1     | 37.4  | 8.38    | .006 ** |
| Block × MotionType              | 36.3   | 36.34   | 1     | 23164.1| 0.76    | .838 |
| Language × MotionType           | 2.2    | 2.23    | 1     | 22652.6| 0.05    | .929 |
| Block × Laterality              | 984.7  | 492.35  | 2     | 27446.0| 10.29   | <.001 *** |
| Language × Laterality           | 271.4  | 135.70  | 2     | 27446.0| 2.84    | .059 |
| MotionType × Laterality         | 39.0   | 19.49   | 2     | 27446.0| 0.41    | .665 |
| Block × AntPost                 | 1973.8 | 986.88  | 2     | 27446.0| 20.63   | <.001 *** |
| Language × AntPost              | 52.4   | 26.20   | 2     | 27446.0| 0.55    | .578 |
| MotionType × AntPost            | 387.6  | 193.78  | 2     | 27446.0| 4.05    | .017 * |
| Block × Laterality × AntPost    | 140.3  | 35.06   | 4     | 27446.0| 0.73    | .569 |
| Block × Language × MotionType   | 276.5  | 276.55  | 1     | 23164.1| 5.78    | .016 * |
| Language × MotionType × Laterality| 67.9  | 33.95   | 2     | 27446.0| 0.71    | .492 |
| Block × Language × Laterality   | 84.6   | 42.30   | 2     | 27446.0| 0.88    | .413 |
| Language × MotionType × Laterality| 42.9  | 21.46   | 2     | 27446.0| 0.45    | .638 |
| Block × Language × AntPost      | 41.9   | 20.96   | 2     | 27446.0| 0.44    | .645 |
| Block × MotionType × AntPost    | 99.2   | 49.59   | 2     | 27446.0| 1.04    | .355 |
| Language × MotionType × AntPost | 309.4  | 154.69  | 2     | 27446.0| 3.23    | .039 * |

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Table 7 (continued)

| Factor | SumSq | MeanSq | NumDF | DenDF | F-Value | p     |
|--------|--------|---------|--------|--------|---------|-------|
| Block × Laterality × AntPost | 241.3  | 60.33   | 4      | 27446.0 | 1.26    | .283  |
| Language × Laterality × AntPost | 82.8   | 20.70   | 4      | 27446.0 | 0.43    | .785  |
| MotionType × Laterality × AntPost | 212.2  | 106.08  | 2      | 27446.0 | 2.22    | .109  |
| Block × Language × MotionType × Laterality | 288.1  | 144.07  | 2      | 27446.0 | 3.01    | .049  |
| Block × Language × MotionType × AntPost | 163.8  | 40.94   | 4      | 27446.0 | 0.86    | .490  |
| Block × Language × MotionType × AntPost | 67.6   | 16.90   | 4      | 27446.0 | 0.35    | .842  |
| Language × MotionType × Laterality × AntPost | 46.4   | 11.60   | 4      | 27446.0 | 0.24    | .914  |
| Language × MotionType × AntPost | 14.5   | 3.63    | 4      | 27446.0 | 0.08    | .990  |

*p < .001, **p < .010, *p < .050, .p < .100; probed effects are in bold.

Table 8
Simple main effects analysis for the Block × Language × MotionType × AntPost interaction for secondary motion expressions in the 500–700 ms time window.

| Block × Language × MotionType × AntPost | Manner M (SE) | PathM (SE) | Diff | DF | \( \chi^2 \) | p     |
|-----------------------------------------|---------------|------------|------|----|-------------|-------|
| Block 1                                 |               |            |      |    |             |       |
| English                                 |               |            |      |    |             |       |
| Anterior                                | −1.19 (0.51)  | −0.35 (0.47)| −0.85| 1  | 4.66        | .154  |
| Central                                 | 0.97 (0.51)   | 0.26 (0.47)| 0.71 | 1  | 3.27        | .282  |
| Posterior                               | 2.20 (0.51)   | 0.89 (0.47)| 1.31 | 1  | 11.06       | .005 **|
| Spanish                                 |               |            |      |    |             |       |
| Anterior                                | 0.26 (0.51)   | 0.48 (0.49)| −0.22| 1  | 0.32        | 1.000  |
| Central                                 | 2.18 (0.51)   | 1.86 (0.49)| 0.32 | 1  | 0.66        | 1.000  |
| Posterior                               | 2.55 (0.51)   | 2.37 (0.49)| 0.18 | 1  | 0.21        | 1.000  |
| Block 2                                 |               |            |      |    |             |       |
| English                                 |               |            |      |    |             |       |
| Anterior                                | −0.01 (0.45)  | 0.35 (0.43)| −0.35| 1  | 1.50        | .663  |
| Central                                 | 2.18 (0.45)   | 1.01 (0.43)| 1.18 | 1  | 16.66       | <.001 ***|
| Posterior                               | 2.57 (0.45)   | 1.42 (0.43)| 1.15 | 1  | 16.04       | <.001 ***|
| Spanish                                 |               |            |      |    |             |       |
| Anterior                                | 0.61 (0.45)   | 1.11 (0.44)| −0.50| 1  | 3.46        | .252  |
| Central                                 | 2.49 (0.45)   | 2.26 (0.44)| 0.23 | 1  | 0.72        | .791  |
| Posterior                               | 2.40 (0.45)   | 2.23 (0.44)| 0.17 | 1  | 0.38        | .791  |
| Block 3                                 |               |            |      |    |             |       |
| English                                 |               |            |      |    |             |       |
| Anterior                                | 1.18 (0.47)   | 1.04 (0.45)| 0.14 | 1  | 0.25        | 1.000  |
| Central                                 | 3.39 (0.47)   | 1.75 (0.45)| 1.64 | 1  | 33.00       | <.001 ***|
| Posterior                               | 2.94 (0.47)   | 1.94 (0.45)| 1.00 | 1  | 12.27       | .002 **|
| Spanish                                 |               |            |      |    |             |       |
| Anterior                                | 0.96 (0.48)   | 1.74 (0.46)| −0.78| 1  | 7.85        | .020 * |
| Central                                 | 2.80 (0.48)   | 2.66 (0.46)| 0.14 | 1  | 0.26        | 1.000  |
| Posterior                               | 2.25 (0.48)   | 2.09 (0.46)| 0.15 | 1  | 0.30        | 1.000  |
| Block 4                                 |               |            |      |    |             |       |
| English                                 |               |            |      |    |             |       |
| Anterior                                | 2.37 (0.56)   | 1.73 (0.53)| 0.64 | 1  | 2.71        | .299  |
| Central                                 | 4.60 (0.56)   | 2.49 (0.53)| 2.11 | 1  | 29.55       | <.001 ***|
| Posterior                               | 3.31 (0.56)   | 2.47 (0.53)| 0.85 | 1  | 4.79        | .115  |
| Spanish                                 |               |            |      |    |             |       |
| Anterior                                | 1.31 (0.58)   | 2.36 (0.55)| −1.06| 1  | 6.69        | .049 * |

(continued on next page)
Table 8 (continued)

| Block × Language × AntPost | MannerM (SE) | PathM (SE) | Diff | $\chi^2$ | p |
|----------------------------|-------------|-------------|------|-------|---|
| Central                    | 3.12 (0.58) | 3.06 (0.55) | 0.05 | 1     | 1 |
| Posterior                  | 2.09 (0.55) | 1.95 (0.55) | 0.14 | 1     | 1 |

$**p < .001$, $*p < .01$, $p < .050$, $p < .100$; M: adjusted mean, SE: standard error of the link.

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