The action dynamics of native and non-native speakers of English in processing active and passive sentences

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This study investigates processing of passive and active constructions between native speakers (NS) and non-native speakers (NNS) of English using traditional on-line mechanisms such as response time in conjunction with techniques that capitalize on the parallel activation of distributed mental representations during online syntactic processing. In the current study, hand motions captured by a mouse-tracking system were used to index listeners' cognitive processes while making commitments to different choice alternatives during the processing of English passive and active structures. During data collection, 57 NNS and 43 NS carried out an aural forced-choice picture identification task. Data analysis indicated differences and similarities between NS and NNS participants such that NS participants are faster at responding to passive and active stimuli, travel less distance, and make fewer directional changes when compared to NNS participants. However, all participants showed similar trends for passive processing, suggesting comparable difficulties in processing passive constructions.

Keywords: second language acquisition, syntactic processing, action dynamics, mouse tracking

1. Introduction

Previous research has shown that processing and producing passive linguistic constructions (e.g., "the ball was bounced by the boy") are more challenging than processing and producing active constructions (e.g., "the boy bounced the ball") (Bencini & Valian, 2008; Marchman, Bates, Burkardt, & Good, 1991; Messenger, Branigan, & McLean, 2012). Although both sentences intend to express the same

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meaning, passives involve a more complex constituent structure and require non-canonical mapping of thematic roles (Messenger et al., 2012). Because they are more challenging, the acquisition of passives emerges later in native speaker (NS) development (Diessel, 2004; Marchman et al., 1991) as well as non-native speaker (NNS) development (see Kim & McDonough, 2008 for a review). In addition, passives have been shown to be more difficult for NNS of English to learn and produce as compared to NS (Marinis, 2007).

Much of the research that has examined passive processing for NNS has tended to focus on a limited number of research paradigms, such as structural priming whereby speakers are exposed to either passive or active structures in discourse, and their ability to spontaneously reuse the heard structure is assessed (Bock, 1986). This research has demonstrated that when NNS have acquired the passive structure, reusing the passive structure after hearing or reading the similar construction is more likely to occur (Kim & McDonough, 2008; Marinis, 2007). Although this structural priming approach has provided several insights into the NNS' abilities for encoding and producing passive structures, it does not shed much light on the challenges in processing passive structures during the moments of comprehension. Thus, one understudied area is the degree by which the activation of a predominant active construction competes with the comprehension of a passive structure in real-time.

A better understanding of online processing dynamics would help characterize passive and active processing differences in both NS and NNS. Thus, the main goal of this paper is to compare passive processing differences between NS and NNS using traditional endpoint or overall response measures (i.e., response times) and techniques that capitalize on the parallel activation of distributed mental representations during online syntactic processing (i.e., an action dynamics approach). In an action dynamics approach, when hearing a sentence such as the passive: "the ball was bounced by the boy," both the active and passive interpretations for the initial noun (*the ball*) are automatically activated and compete for expression. Although this competition quickly resolves over time, typically with the correct, passive interpretation "winning out," the degree of initial and continued attraction of the competitor interpretation (i.e., the potential for an active construction interpretation), as well as the strength of activation from the target interpretation, provides insight into how well the correct interpretation has been encoded. Stronger encoding related to acquisition allows speakers to overcome the competitor activation in faster and more efficient ways.

To visualize and quantify these action dynamics, we turn to a method that captures participants' computer-mouse positions as they traverse a computer screen to click on response options (Dale & Duran, 2011; Duran, N. D., Dale, R., & McNamara, D. S. 2010). In a typical setup, participants click at the bottom of a screen to trigger a stimulus (e.g., a sentence) that requires a decision to be made between two response options (whether the sentence is passive or active) presented along the top of the screen in opposite corners. During selection, movement trajectories from the bottom to the top of the screen are recorded and analyzed for fine-grained "micro-behaviors," revealing details of decision processes. For example, moment-by-moment fluctuations, curvatures to alternative response options, longer times to initiate a movement, velocities of movement, and many other dynamical features can provide a more informative and cognitively rich picture of how decisions are enacted over time when compared to overall response measures.

We hypothesize that passives will not only take longer to process, but importantly, these differences will be exhibited in signatures of competition as expressed in hand/arm movements, such that during the initial processing of sentences, an active interpretation of the sentence will provide stronger attraction than a passive interpretation. Importantly, we expect that this effect will also be modulated by language experience, such that there will be less competition for NS than NNS. In what follows, we provide greater detail on the complexities of passive structure processing, as well as detail on research involving the action dynamics paradigm to investigate linguistic processing.

2. Syntactic processing of passive constructions

A primary goal of this study is to assess the cognitive processing of English passive and active structures (via continuous motor movements) by NS and NNS of English whose native language is Spanish. The form and meaning mapping in passive constructions is a complex phenomenon (Marinis, 2007). The reason passive structures are more challenging than active structures is that the two constructions involve different mappings of thematic roles to grammatical functions and different syntactic structures. In active constructions, the regular syntactic order of English is followed and thematic roles appear in predictable grammatical slots. For instance, in the sentence *The cat scratches the chair*, the subject appears in the initial noun phrase with a thematic mapping of agent. The subject (agent) is followed by the verb (*scratches*) and then an additional noun phrase (the object) with the thematic mapping of patient. In contrast, in the passive construction (*The chair was scratched by the cat*), the object (patient) serves as the grammatical subject (*the chair*), which is followed by an auxiliary *be*, a lexical verb in the past participle form, and an optional prepositional phrase containing the agent (subject) from the active sentence. Syntactically, English passive sentences contain an auxiliary verb and an optional preopositional phrase while, grammatically, the object and its accompanying thematic role fill the subject slot. The differing expectations found in passives cause challenges with their processing when compared to actives (Messenger et al., 2012) leading to the passive constructions being cognitively more challenging and emerging later in language acquisition when compared to actives (Diessel, 2004).

Theoretically, differences in processing passives and actives are often informed through Bates and MacWhinney's Competition Model (1989), which is based on the assumption that form and function in language cannot be separated and suggests that processing production is determined by relationships among elements in a sentence. During language processing, people depend on various cues available in a sentence including word order, thematic roles (agent and patients), grammatical arguments (subject and objects), and word meaning. According to MacWhinney and Bates (1989), cues are in competition and languages have different perferred cues. For instance, word order has greater influence on English speakers, whereas morphological information (e.g., agreement) is a more important cue in Italian.

In the Spanish passive constructions, the processing cues are similar to English in that passives contain the auxilary verb (*ser* or *estar*) and the past participle of the main verb as shown below (example taken from Benedet, Christiansen & Goodglass, 1996, p. 315):

> La cica fue encontrada por el perro
> The girl was found by the dog.

In general, passive constructions such as this are used when the semantic theme is topicalized (i.e., the object of the sentence is emphasized). However, unlike English, in Spanish, a frequent alternative to the passive construction above is active voice with an object-dislocation construction (i.e., OVS) as seen in the example below taken from Benedet et al. (1996, p. 316).

> A la chica la encontró el perro
> Do-animate the (fem.) girl she (DO clitic) find the dog

As a result, in Spanish, direct objects may be topicalized using object-verb-subject (OVS) word order with an active construction, instead of using passive construcction word order (Benedet et al., 1996). Thus, although Spanish and English passive constructions are similar to each other in terms of word order, Spanish speakers have two choices when constructing a passivized sentence, which may lead to different cues being in competition for Spanish speakers processing English passive in a second language.

Differences in the processing of passives and actives have been supported in research based on theoretical approaches inspired by the Competition Model. For example, Ferreira (2003) asked undergraduate native speakers of English to listen to active and passive constructions. The participants then named either the agent or the patient of each sentence (i.e., thematic role decision task), which is a common task used by proponents of the Competition Model. The findings showed that passive constructions were misinterpreted significantly more than active constructions, especially with implausible ideas, suggesting that passives are difficult to understand because thematic role assignment is challenging compared to actives. This is likely because English speakers rely on sentence word order as a primary cue to assign thematic roles to noun phrases.

Other approaches used to examine the acquisition of passives have depended on priming techniques. For instance, Bencini and Valian (2008) used a syntactic priming task to examine three-year-old children's comprehension of both structures. Although passive construction priming led to greater production of passives than exposure to active constructions, it did not facilitate greater comprehension of passive constructions. Using a similar method with six-year-old and nine-year-old children, Messenger, Branigan, and McLean (2012) found that both groups showed a strong tendency to reuse passive structures after priming. Their findings also indicated that passives were acquired by stages. By the age of six, children had mastered the passive structures, but had not mastered the non-canonical thematic role mapping found in passives (i.e., the subject slot is not occupied by the expected agent but rather by the patient usually found in the object slot). By nine, children had mastered both the syntactic and thematic dimensions of passives. Other research has reported that by nine years of age, children can produce and comprehend passives with almost 100% accuracy, whereas, at seven, they can only comprehend the meaning of passives with 80% accuracy and produce passives with 50–60% accuracy (Marchman et al., 1991).

Researchers have also examined differences in passive processing between NS and NNS. For instance, Marinis (2007) found that older English NNS children demonstrated on-line processing limitations compared to their NS counterparts. In this work, Marinis measured the on-line processing of passives by English NS and Turkish-English NNS children and found that NNS children showed overall longer reaction times and lower accuracy rates when compared to NS children. For NNS adults who vary across levels of language proficiency, there are also differences in the ability to process passive and active sentence structures. For example, Kim and McDonough (2008) show that NNS at beginning, intermediate, and advanced stages of proficiency are all able to produce passives in response to syntactic priming; however, the beginning and intermediate stage learners produced many fewer than the advanced learners.

3. Language processing and action dynamics: Methodological advantages

The methodological approach we take in this paper is to examine motor activity, i.e., action dynamics, as people respond to language stimuli. Motor activity is sensitive to continuous changes in perceptual and cognitive processing, and has been examined widely in various language domains (Abrams & Balota, 1991; Freeman & Ambady, 2010; Gold & Shadlen, 2001; Morett & MacWhinney, 2012; Song & Nakayama, 2006, 2008; Tipper, Howard, & Houghton, 1998). Unlike more traditional methods used in NNS research (where the focus tends to be on off-line or indirect observations) and even more recent methods that collect response times (RT), action dynamics can extend language insights by capturing continuous and real-time cognitive processing. For example, Spivey, Grosjean, and Knoblich (2005) used a mouse-tracking technique to assess phonological awareness, finding that spoken words activate multiple lexical terms while the phonetic representation of the word was concurrently continually updated. Other studies using mouse-tracking technology have examined syntactic processing (Farmer, Anderson, & Spivey, 2007; Dale & Duran, 2011). These studies support the notion that partially active syntactic constructions compete with each other over time, such that constructions are influenced by visual, contextual, and linguistic factors (Farmer et al., 2007), and that constructions can involve rapid shifts in comprehension (Dale & Duran, 2011).

Overall, an action dynamics approach provides insights into the ways in which language and motor processing are interconnected, and how such processing evolves over short time spans. Although traditional theories of cognition have viewed motor processing as the end-result of cognitive processing, recent research has demonstrated that the "dynamics of action do not simply reside in the aftermath of cognition," but "rather, they are part and parcel with cognition (Freeman, Dale, & Farmer, 2011, p. 1)." Given the promise of this approach in NS language processing, we seek to apply it to a domain of NNS syntactic processing research, particularly with consideration of differences between NS and NNS.

4. Current study

In the current study, we use RTs and hand motions captured by a mouse-tracking system to index listeners' cognitive processes while making commitments to different choice alternatives during the processing of English passive and active structures. Based on the studies reviewed above, the research hypotheses that guide the current study are:

1. We predict that passives will take longer to process than actives.
2. We predict that actives will exert greater competition on passives than passives on actives.
3. We predict that processing time competition will be modulated by language experience (NS versus NNS).

A better understanding of passive and active processing differences in both NS and NNS will allow for a greater understanding of how real-time (online) processing dynamics – such as competition from the predominant active structure – interact during language processing. Our hypothesis is that both response times and motor responses will demonstrate differences in the processing of active and passive constructions and that these differences will be greater for non-native speakers. Support for these hypotheses would have important implications for syntactic processing and second language acquisition.

5. Method

5.1 Participants

A total of 57 Spanish speaking non-native speakers (NNS) of English (24 females and 33 males) and 43 native speakers (NS) of English participated in the study. Of those NS participants that completed the post-experiment survey, 24 were female and 10 were male. All NS participants were students enrolled at a major southeastern university in the US. The participants received class credit in a freshman Psychology course for participating in the experiment or volunteered. All participants had normal or corrected to normal vision. NS participants ranged in age from 19 to 54 and had an average grade point average of 3.42 (for those that completed the post-experiment survey). All NNS participants were native speakers of Spanish and were enrolled at the Instituto Tecnológico y de Estudios Superiores de Monterrey (ITESM) campus in San Luis Potosi, Mexico, studying at either the high school or college level. All NNS participants had normal or corrected to normal vision. The NNS participants ranged in age from 15 to 24. All NNS participants had taken a paper-based institutional TOEFL one month before the data collection. The average paper-based TOEFL score for the participants was 519 (Min = 420, Max = 610). No scores indicated that any of the participants were bilingual or advanced speakers of English.

5.2 Materials and study design

For this experiment, we used a within subjects comparison design with an aural forced-choice picture identification task. The task contained 75 items which are adapted from Kim & McDonough (2016) in the form of complete sentences: 30 target items (15 passive constructions and 15 active constructions) and 45 distractors (15 relative clause constructions, 15 dative constructions, and 15 prepositional phrases of location constructions) (see Appendix A for the stimuli list). Because our main interest is comparing passive to active constructions, the relative, dative, and prepositional phrases were treated as filler constructions and were not analyzed in this study. While Spanish does have a passive structure that corresponds to English, passives are less common in Spanish than in English because Spanish has a range of structures available to occlude the agent (Blanco-Gomez, 2002). The verbs and nouns used in the passive and active items were checked for occurrence on the General Service List (http://www.newgeneralservicelist.org/) (West, 1953) to ensure that the learners would be familiar with their meaning and use. In order to ensure participants' familiarity with words, we gave vocabulary tests using the list of nouns and verbs in the language stimuli to ten English language learners who have similar background in terms of length of study and previous English education. Any words that were found unfamiliar were eliminated.

For each item, participants listened to a sentence (e.g., *The boy is pushed by his sister.*) and had to select the picture that corresponded to its correct meaning from two pictures. Participants could begin moving the mouse at the onset of the sentence reading. The passive and active targets involved pictures of reversible events. For example, the passive construction, *the boy is pushed by his sister* was paired with pictures of a girl pushing a boy and a boy pushing a girl. Similarly, the active construction, *the bus hits the motorcycle* was paired with pictures of a bus hitting a motorcycle and a motorcycle hitting a bus. We used animate nouns (i.e., human, human controlled, or animal) for agents and patients in each critical sentence to control for animacy following Kuperberg, Kreher, Sitnikova, Caplan, and Holcomb (2007). All pictures were hand drawn by a paid artist and were piloted with ten English language learners to assess whether the listening and picture materials were intelligible. Any stimuli which were judged to be unintelligible were modified and assessed a second time. After completing the experiment, participants were asked to complete a post-experiment survey that asked for basic demographic information (e.g., age, gender, first language).

5.3 Apparatus and procedure

We used MouseTracker software (Freeman & Ambady, 2010) to collect hand motion data. MouseTracker continuously catalogs participants' commitments to two choice alternatives during a behavioral response to language stimuli. The hand motion data provides real-time traces of the cognitive processes, including those involved in language processing (Coco & Duran, 2016; Freeman, Dale, & Farmer, 2011) and can reveal cognitive processing not readily accessible through traditional on-line measures (e.g., RTs), including how multiple sources of information are activated and compete at the scale of milliseconds (Song & Nakayama, 2009).

Participants were first given instructions on how to interact with the software and told they were free to use their dominant hand. However, data was not collected on which hand the participants used. They were then given eight practice trials to familiarize themselves with the task on a computer. Each trial contained a start button at the bottom center of the screen and a picture in the upper left and upper right of the screen. When the participants clicked the start button, a sentence that matched one of the pictures was presented aurally. Participants then moved

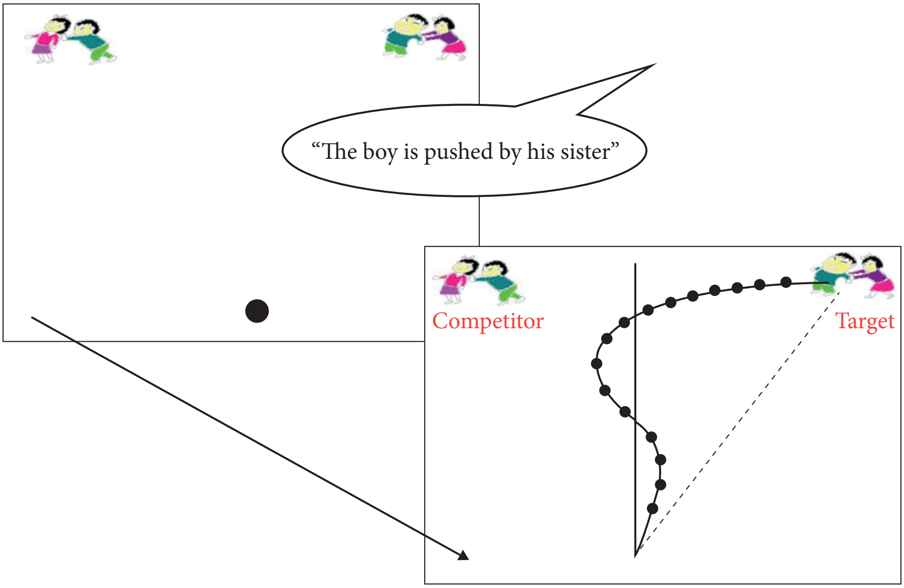

Figure 1. At the start of each trial, two response options (images) are presented at the top of the screen and participants click at the bottom of the screen to begin the audio of a sentence, either in passive or active voice, that corresponds to one of the two images. Participants must quickly move their mouse cursor to respond. An example movement is visualized here as a trajectory across xy points (small black circles) as a target is selected. From the xy trajectory, seven dependent variables were generated for analysis

the mouse to choose the picture that they thought best represented the sentence they heard (see Figure 1). Once the mouse reached the picture, the trial stopped. Participants were asked to begin mouse movements early and were warned if their mouse movements started 1000 ms after onset of the stimuli. If a response was not started within 2000 ms, the trial was discarded. Following training, the participants were tested on the 75 stimuli in the stimuli list (the 15 passive, active, relative clause, dative, and prepositional constructions). The presentation of the sentences, the presentation of the pictures, and the location of the pictures in either the left or right hand corner of the screen were randomized and counterbalanced across participants. Display resolution was set to 1280 x 800.

5.4 Mouse-trajectory properties

Using participants' raw x,y movement trajectories, we computed a number of dependent variables that have been widely used in two choice-categorization tasks (e.g., Dale, Kehoe, & Spivey, 2007; Duran, Dale, & McNamara, 2010; Duran & Dale, 2014; Freeman & Ambady, 2010). These variables capture various qualitative features of movement that are thought to provide a window into underlying processing dynamics (Freeman, Dale, & Farmer, 2011; Magnuson, 2005; Spivey & Dale, 2006). In what follows, we provide brief definitions of the seven variables computed for the current study. Each variable was analyzed via custom Matlab code inspired by the algorithms used in the R mousetrack package (version 1.0.0; Coco & Duran, 2015). The complete code, with extensive comments for interpretation, can be found on a public GitHub Repository that is licensed under the Creative Commons Attribution 4.0. It can be accessed at https://github.com/nick-duran/dynamical-NNS-passive.

Latency time
This variable captures the amount of time (in milliseconds) that it takes participants to move their mouse cursor 10 pixels in any direction at the onset of each trial. By setting a distance threshold, it helps ensure that the movement is directed rather than incidental. To generate this measure, we compute the Euclidean distance (measured in pixels) from the onset coordinate (0, 0) to the x,y coordinate at each time step. Because each time step represents an increase of approximately 16ms, the amount of time to reach a distance of 10 pixels is recorded. Latency time is typically thought of as measuring the time it takes participants to make an initial commitment to one of the response options. Greater time to do so has been associated with greater processing costs and initial uncertainty (Dale, Roche, Snyder, & McCall, 2008).

Motion time

This variable computes the amount of time (in milliseconds) that it takes participants to select a response option, minus latency time. Similar to traditional interpretations of overall response time, longer motion time is taken as a proxy of greater processing costs. However, because given latency time is not included in its computation, it targets middle and late phases of processing (Dale et al., 2008).

Velocity (max and max onset)

The maximum velocity ("Velocity (Max)") of movement is based on a velocity profile generated by computing velocity within a moving window of six time steps along the length of the trajectory. To do so, the Euclidean distance from time step to time step is recorded and summed, and this value is then divided by the amount of time that passed in the six time steps. The onset of maximum velocity ("Velocity (Onset)") captures the time taken for maximum velocity to occur.

For interpreting higher values in terms of cognitive processing, the research in this area is in its early stages. Based on the nascent work that has been done, higher values of maximum velocity have been taken to indicate greater certainty to a particular response option (Hehman & Freeman, 2015; McKinstry et al, 2008; Yu, Wang, Wang, & Bastin, 2012). However, complementary to this measure is when the maximum velocity occurs. If it occurs relatively late in the movement trajectory, this suggests that response commitment was delayed, which in turn points to increased cognitive processing demands (Duran et al., 2010; Wojnowicz, Ferguson, Dale, & Spivey, 2009).

Distance

This measure is the sum of Euclidean distances computed between every contiguous time step pair along the entire length of the trajectory. These values are reported as pixel distance within the normalized pixel space. Greater distance needed to reach the target again suggests increased processing demands (Tabatabaeian, Dale, & Duran, 2015).

Area under the curve (AUC)

AUC is the geometric distance between the x,y coordinates of the actual trajectory and the x,y coordinates of an idealized straight line from trial initiation point (at the 0, 0 coordinate) to the target response. In Figure 1, this area would correspond to the coordinate space between the trajectory and dashed line. It should be noted that if the trajectory moved to the right of the dashed line, the region of space between trajectory and dashed line that would have been formed was ignored. For this analysis, we were interested in deviation to the competitor relative to the most direct path to the target response. This measure captures the competition elicited by the activation of the distractor response. Higher AUC reflects greater competition as reflected in the spatial deviation of the trajectory toward the distractor (Barca & Pezzulo, 2012; Koop & Johnson, 2011; van der Wel, Sebanz, & Knoblich, 2014).

Directional change
This measure calculates the number of times that the trajectory changes direction along the x-axis. The x-axis has sometimes been referred to as the "axis of decision" because the two response options lie on the opposite sides of the x-axis (Tabatabaeian et al., 2015). Increased directional changes suggest increased vacillation between response options, and provides an index akin to "a change of mind" during processing (Dale & Duran, 2011).

6. Data analyses

Two primary exclusion criteria were employed to remove participants who did not pay adequate attention to the task. The first was to remove participants whose error rate across all trial types was greater than 30%. This rate was chosen to maximize the number of participants for inclusion while recognizing that some participants may have found the task particularly difficult. Overall, six NS speakers and nine NNS participants were excluded. For the next exclusion criteria, we plotted the trajectories and visually inspected for those that were consistently erratic (e.g., large swirls, pronounced and repeated movements back and forth across the screen) (see O'Hora, Dale, Piiroinen, & Connolly, 2013 for similar criteria). This evaluation removed an additional one NS and seven NNS participants. The final language groups sample sizes for NS were $n = 36$ and for NNS $n = 41$.

We first proceeded by computing Pearson correlations between the mouse-trajectory properties to examine how the properties might relate to each other and whether they were measuring similar or different cognitive processes. This analysis helped determine how the mouse-trajectory property outcomes should be interepreted. Then, for each of the trajectory variables, we used linear mixed effects modeling to evaluate the fixed effect factors for grammatical structure (Construction: Active; coded as 0.5 vs. Passive; coded as −0.5) and language experience (Proficiency: NS; coded as 0.5 vs. NNS; coded as −0.5).

In a separate set of analyses, we also examined how the mouse-trajectory measures might vary depending on NNS participants' TOEFL scores, and whether this relationship is further modulated by responding to active or passive sentences. Accordingly, this analysis involves NNS participants alone with grammatical structure (Construction: Active vs. Passive), TOEFL scores (mean-centered), and their interaction, entered as fixed factors in linear mixed effects models.

For both sets of models (e.g., NS and NNS speakers or NNS-speakers alone), subject and item were used as random effects that included random slopes for grammatical structure. All models were designed to examine main effects and their interaction. It should also be noted that given that the *directional change* dependent variable is a count variable, we used a generalized linear effects model with a Poisson distribution.

We report coefficients of the predictors based on significance at $p < .05$, their standard error, and derive p-values from the t-values for each of the factors in the model (standard procedure recommended by Mirman, 2014). All analyses were carried out in R version 3.1.3 using the lme4 package (version 1.1–7) (Bates, Maechler, Bolker, & Walker, 2014). Captured variance of overall models is reported as Conditional R^2 (R^2) – variance explained by fixed and random factors together – and computed using the MuMIn R statistical package (version 1.15.6) (Johnson, 2014).

7. Results

Beginning with the results from the correlation analysis, Table 1 shows the complete correlation matrix involving the seven trajectory properties, as well as overall response time. We focus here on the correlations greater than $r = 0.30$ (bolded in the table), which can be considered at or above moderate strength (Cohen, 1988). One of the most prominent relationships is that between overall response time and motion time. This extremely high correlation is not entirely surprising given both correspond to a similar and extended segment of the trajectory. Of interest is also the relationship between motion time and the other trajectory properties. It appears that as trajectories take longer to execute, the onset of maximum velocity is delayed, there is an increase in distance traveled, and there are a greater number of x-flips. Given increases in all these variables have been associated with increased processing costs, their relationship is consistent with previous research. Based on this rationale, it is also sensible to expect and find, as we do, moderate to strong correlations between distance traveled and x-flips, and between onset of maximum velocity and x-flips.

Another set of relevant associations is those involving AUC. In the current dataset, increases in AUC are most associated with increases in distance traveled and decreases in amount of time needed to initiate a response (latency time). The association between greater AUC and distance is fairly straightforward because the greater movement toward AUC necessarily entails longer distance paths. The relationship of AUC and latency time points to a unique aspect of the current task. Each trial was initiated with the stimuli being aurally presented and thus participants had an opportunity to make initial predictions towards one of the response options before disambiguating information was heard. The negative relationship between AUC and latency time would suggest that participants or a subset of participants routinely made incorrect early predictions (thus smaller latency times) toward a distractor that needed to be corrected (thus greater AUC).

Table 1. Pearson correlations between overall time and the seven trajectory property variables

Variable	Motion time	Velocity (max)	Velocity (onset)	Distance	AUC	X Flips
Latency Time	−0.26	0.25	0.16	−0.16	**−0.31**	−0.19
Motion Time		−0.19	**0.73**	**0.31**	0.13	**0.45**
Velocity (Max)			0.01	0.15	−0.04	−0.06
Velocity (Onset)				0.16	−0.04	**0.32**
Distance					**0.42**	**0.53**
AUC						0.20

The results of the mixed effects models involving both NS and NNS revealed a number of statistically significant main effects for language experience and grammatical structure. The means and standard errors for each of the trajectory-property variables are reported in Table 2, the results from the statistical models are presented in Table 3.

Starting with grammatical structure, active sentences, compared to passive sentences, showed no differences in movement initiation time or maximum peak velocities, but statistically significant differences were found for every other measure. The movement trajectories for active constructions took less time overall ($B = -322.923$, $p < .001$), less time while in motion ($B = -319.514$, $p < .001$), had earlier maximum velocity onsets ($B = -217.928$, $p < .001$), shorter distance lengths ($B = -57.135$, $p < .010$), exhibited less spatial competition toward the alternative response option ($B = -.020$, $p < .050$), and committed fewer x-flips ($B = -.134$, $p < .001$).

In consideration of language experience, NS, compared to NNS, took less time overall ($B = -518.048$, $p < .001$), initiated a movement toward a response option earlier ($B = -141.054$, $p < .001$), took less time while in motion ($B = -375.387$, $p < .050$), showed smaller maximum peak velocities, which also occurred much earlier in their movement trajectories (*velocity max:* $B = -843.725$, $p < .050$; *velocity onset:* $B = -443.413$, $p < .010$), traveled a shorter distance to get to the target response (albeit evidenced by a marginally statistical effect; $B = -81.453$, $p = .074$),

Table 2. Means and standard errors of overall response time and the trajectory property measures for native and non-native speakers of English across active and passive trial types. Mean differences between active and passives for each proficiency level are also provided, including the confidence interval (at 95% interval) on the difference between means.

	NS						NSS					
	Active		Passive				Active		Passive			
DV	*M*	*SE*	*M*	*SE*	*M-Diff*	*CI 95%*	*M*	*SE*	*M*	*SE*	*M-Diff*	*CI 95%*
Overall Time	2075.1	26.9	2498.8	42.0	−423.62	[−397.22, −450.03]	2684.4	82.6	2960.7	56.2	−276.29	[−335.63, −216.95]
Latency time	273.1	17.4	275.2	17.5	−2.06	[−3.18, −0.93]	413.1	21.0	429.9	25.2	−16.79	[−11.94, −21.65]
Motion time	1802.1	31.6	2223.6	45.4	−421.57	[−398.01, −445.13]	2271.3	83.0	2530.8	61.3	−259.50	[−310.1, −208.9]
Velocity (Max)	4298.6	84.0	4257.6	92.1	40.93	[49.93, 31.92]	5086.0	103.8	5173.1	112.4	−87.11	[−85.02, −89.2]
Velocity (Onset)	1594.2	34.6	1916.5	48.2	−322.29	[−299.38, −345.2]	2121.5	84.9	2314.1	65.9	−192.65	[−238.62, −146.67]
Distance	1086.7	13.0	1135.2	15.1	−48.51	[−45.6, −51.42]	1168.4	16.6	1223.8	18.7	−55.43	[−53.83, −57.04]
AUC	0.8	0.0	0.8	0.1	−0.24	[−0.25, −0.24]	2684.4	82.6	2960.7	56.2	−0.38	[−0.4, −0.35]
X Flips	2.1	0.1	2.4	0.1	−0.002	[−0.002, −0.002]	413.1	21.0	429.9	25.2	−0.03	[−0.03, −0.03]

Table 3. Coefficients of mixed effects linear models, reporting the B with associated standard error (SE), p-value, and the t-value from which it was derived. The overall captured variance for each model is also reported as Conditional R^2 (R^2). Each dependent measure is modeled as a function of the deviation coded predictors: Experience (NS = 0.5, NNS = −0.5), Voice (Active = 0.5, Passive = −0.5).

	NS v. NNS (Proficiency)					Active v. Passive (Construction)				Proficiency*Construction			
DV	R^2	*B*	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*	*B*	*SE*	*t*	*p*
Overall time	0.317	−518.048	159.118	3.256	**0.001**	−322.923	94.687	3.41	**< .001**	−160.147	100.567	1.592	0.111
Latency Time	0.263	−141.054	55.723	2.531	**0.011**	−1.147	18.030	0.064	0.949	−0.815	36.059	0.023	0.982
Motion Time	0.301	−375.387	167.786	2.237	**0.025**	−319.514	90.075	3.547	**< .001**	−163.282	104.495	1.563	0.118
Velocity (Max)	0.472	−843.725	349.102	2.417	**0.016**	−64.316	106.015	0.607	0.544	91.645	155.773	0.588	0.556
Velocity (Onset)	0.254	−443.413	162.617	2.727	**0.006**	−217.928	85.011	2.564	**0.010**	−158.794	112.384	1.413	0.158
Distance	0.298	−81.453	45.596	1.786	0.074	−57.135	20.148	2.836	**0.005**	8.644	27.602	0.313	0.754
AUC	0.271	0.003	0.027	0.103	0.918	−0.020	0.009	2.288	**0.022**	0.033	0.017	1.997	**0.045**
X Flips	0.208	−0.144	0.085	1.683	0.092	−0.134	0.034	3.968	**< .001**	0.031	0.060	0.521	0.603

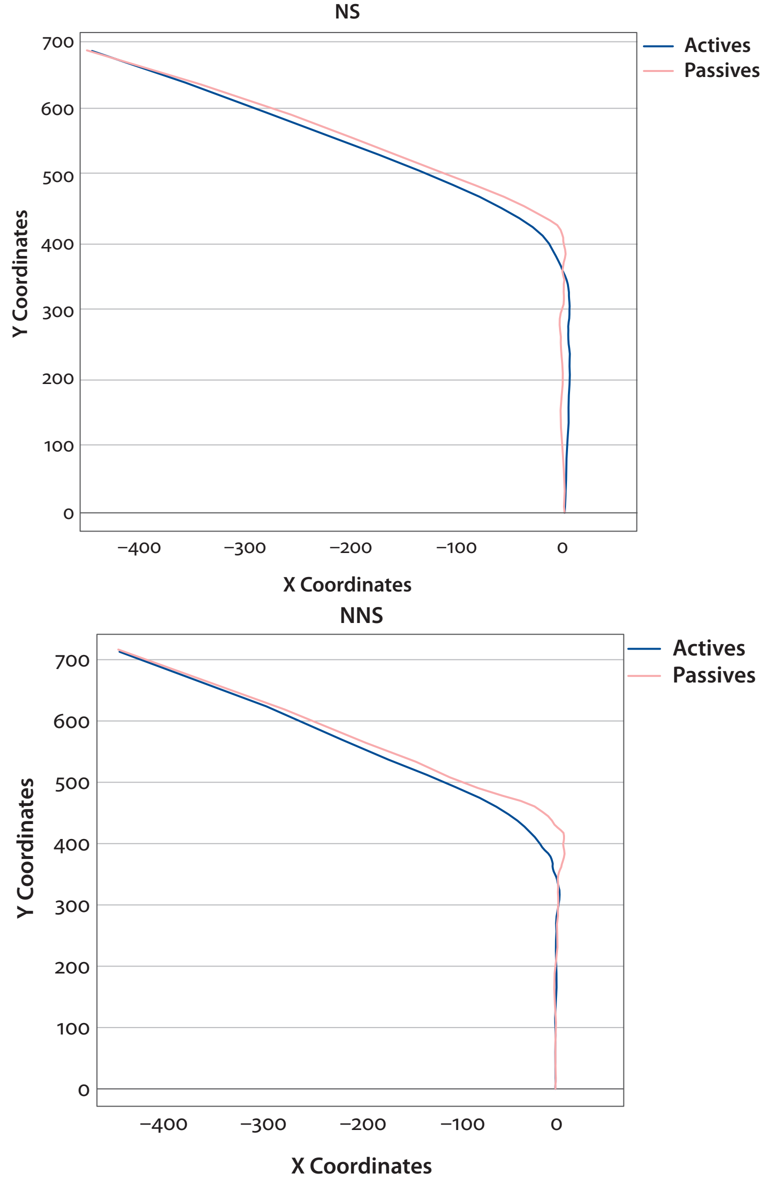

Figure 2. Composite trajectories for active and passive responses for NS and NSS participants. All trajectories were time-normalized to 50 time steps using interpolation (preserves shape of each trajectory). For visualization purposes, all trajectories terminate in the upper left corner, which corresponds to the correct grammatical interpretation. Curvature toward the right along the length of the composite trajectories corresponds to attraction to the opposing response. Note that this curvature is most extreme for NNS participants responding to passive grammatical sentences.

and committed fewer x-flips en route to the target response (also evidenced by a marginally statistically effect; $B = -.144$, $p = .092$). There were no differences in spatial competition toward the alternative response option as measured by the area under the curve.

There was also a single statistically significant interaction with AUC that further qualifies the main effect results. In follow-up post-hoc tests holding each level of language experience constant and comparing actives versus passives, there were no differences in AUC for native speakers ($B = -0.004$, $SE = 0.011$, $p = 0.756$), but for NNS, there was a decreased AUC with active constructions as compared to passive constructions ($B = -0.037$, $SE = 0.012$, $p = 0.002$). Figure 2 shows the composite trajectories for active and passive responses for NS and NNS separately, with differences in AUC visually depicted.

For the results of the mixed effects models involving just NNS, we focus on changes in trajectory-property values as a function of TOEFL scores and whether there is an interaction with grammatical structure. We found no statistically significant interactions, but we did find that as TOEFL scores increased, participants took less time (Response time: $B = -12.126$, $SE = 2.958$, $p < 0.001$; motion time: $B = -12.536$, $SE = 3.027$, $p < 0.001$) and had much earlier onsets of maximum velocity ($B = -10.878$, $SE = 3.134$, $p < 0.001$).

8. Summary

To better understand the action dynamics reported here, it is necessary to examine the mouse tracking variables as a constellation of measures that mutually inform each other, and thus together form a coherent picture of underlying cognitive processes. In this interpretation, it is important to consider task-specific constraints that are influencing the dynamical movement expressions. In our task, each trial begins with participants viewing two possible interpretations of a sentence. They are told that when the audio recording of the sentence begins playing – triggered by their clicking on a region at the bottom of their computer screens – they can start moving. However, at the initial moments of the sentence being played, the correct interpretation remains ambiguous at the noun phrase (e.g.,"The boy…"), and evidence for whether the sentence corresponds to an active or passive interpretation is not provided until the verb phrase is heard downstream ("…is pushed…").

Based on the pattern of results between NS and NNS, as well as what was learned from the correlation results, this anticipation between alternative response options and subsequent commitment appears to be expressed in unique ways (regardless of sentence structure). Specifically, NNS seem to experience greater cognitive processing demands as evidenced by longer response trajectories in terms of both time and distance, and by greater indecision as revealed in the greater number of x-flips. NNS were also less likely to wager an initial guess as to the outcome of the sentence based on the increased time they took to begin moving toward either response option (i.e., latency time). NNS participants also show a distinct velocity profile where their maximum velocities are much higher, but also occur later in responding. This signature suggests that the activation of the target and deactivation of the competitor happens more suddenly, akin to a sudden (but late) moment of realization. On the other hand, NS take less time overall, do so with less extreme maximum velocities, and when these maximum velocities do occur, it is much earlier in responding. This suggests an interplay of anticipation and activation that occurs at a more steady rate. With increases in proficiency, however, NNS particpants began to converge on NS performance by having faster response and motion times and by having earlier onsets of maximum velocity.

There are also unique action dynamics that appear to be elicited by whether the sentence is an active or passive (regardless of language experience). The first relevant, albeit null, finding is the lack of a statistically significant difference between actives and passives for movement initiation times. Because neither passive or actives can be disambiguated at the earliest moments of processing, it follows that participants would tend to wait an equivalent amount of time to begin making a committed response. However, passives, as compared to actives, ultimately appear to enact the greater cognitive processing costs as they took longer to process overall, for both time and distance, and were accompanied by greater x-flips, a measure of indecision. For the velocity measures, there were no differences of maximum velocity between passives and actives, which suggests that strength of commitment was similar. This finding is only part of the story as it is also important to consider when maximum velocity occurs. For passives, it occurs much later, which raises the possibility that maximal activation (as a type of response commitment) took longer to accrue.

For the AUC comparison between actives and passives, there was also greater displacement of movement toward the active response (as a distractor) when ultimately selecting the passive target. However, based on an interaction between language experience and syntactic construction, this only applies to the NNS participants. This is interesting given AUC provides the most direct evidence of response competition due to the distractor response. Whereas both NS and NNS participants may have shared greater processing challenges when encountering passives relative to actives (based on the main effects with the other variables), it was only in NNS where this translated into a pronounced deviation toward the alternative syntactic structure.

9. Discussion

In the current study, we demonstrated how English passive constructions are processed differently than active structures for both NS and Spanish speaking NNS using a number of variables calculated based on speakers' hand motions as captured by a mouse-tracking method. This method continuously indexed listeners' commitments to different choice alternatives during the processing of English passive and active structures in terms of overall time, latency time, motion time, velocity (max and onset), distance, area under the curve (AUC), and and x-flips. These are novel approaches that afford the collection of information unavailable through traditional behavioral measures such as RTs and accuracy on comprehension tests. These more traditional measures have been predominantly used in psycholinguistic oriented second language acquisition (SLA) research.

In total, the results suggest unique processing difficulties within and between language experience and syntactic structure such that Spanish speaking NNS seem to experience greater cognitive processing demands when compared to NS and that passives, as compared to actives, also increase processing demands. The findings indicate that NSs, for example, are able to accumulate evidence for the target response much earlier and at a steadier rate than NNSs across both active and passive sentences. This was evidenced in the earlier initiation and lower motion times, as well as in smaller maximum velocity and earlier onset values. But what does it mean to have a smaller maximum velocity and earlier onset while still reaching a target response faster? This processing signature is consistent with the possibility that the information supporting the target response accumulates, and is acted upon quickly, at a more steady and continuous rate for native speakers (also evidenced by the shorter distance traveled by their trajectories). In contrast, for non-native speakers, the findings suggest that there needs to be greater information accumulation before a response can be made with confidence. This greater accumulation, when realized and acted upon, would then result in a stronger response commitment, generating a greater maximum peak velocity in the movement trajectory (i.e., an "aha-moment" for the non-native speaker).

Despite the overall advantage of native speakers, they do not appear to possess strong advantages over non-native speakers when processing passive sentence structures as compared to active sentences except in the case of AUC. In general, the findings indicate that passive sentences are more challenging than active sentences across speaker type. This finding supports previous research that has demonstrated the challenges of mapping thematic roles in passive constructions (Ferreira, 2003; Messenger et al., 2012; Marinis, 2007). The challenge of processing passive sentences may be driven by a mechanism already discussed, where the supporting information for committing to a passive structure accumulates in such a way that it results in slower and longer movements that suddenly give way to moments of increased velocity (i.e., a sudden and pronounced commitment). The structure of the sentence is likely the cause of the processing difficulty in that the passive transformation places the expected object noun phrase (the patient) in the subject position. Participants likely initially process the patient as the expected agent and, upon processing the remaining sentence structure, realize that the sentence has been passivized. Once this realization occurs, there is an increased velocity toward the correct interpretation.

In addition to this underlying mechanism, there may be directional evidence that sheds further light on the challenges of passive sentence processing. Such evidence was captured by the increased *AUC* and *x-flip* values across speaker types. Both of these measures capture spatial changes in response trajectories driven by the co-activation of a distractor response whereby trajectories are drawn toward the distractor en route to a target response. In the current study, this would suggest that there is a bias to process sentences as active prior to hearing the passive structure. Thus, the mouse trajectories for passive constructions deviated toward the unselected alternative (i.e., the active structure) to a greater degree than the unselected alternative in active structures (i.e., the passive structure). Again, this finding likely indicates that participants initially processed the subject noun phrase in the passive construction as the agent. For instance, in the sentence, *the boy is pushed by his sister*, participants initially moved the mouse toward the incorrect picture that shows the boy pushing his sister and not the correct picture that shows the sister pushing the boy. Such motion indicates that the process of mapping forms to meanings in passive constructions is inherently more difficult when compared to active constructions. Once the participants realized that the sentence is not active and is instead passive, they deviated away from their initial interpretation toward the correct solution (hence the increase in x-flips during passive processing). In terms of x-flips, such bias is not limited to non-native speakers. However, in terms of AUC, we see differences in the processing of active passive structures by NS and NNS participants. While the AUC was greater for passives than actives across participants, no main effect was reported based on language experience. However, there was a significant interaction such that NNS participants showed a greater deviation toward the passive structure when compared to NS participants (see Figure 2). This indicates that NNS have greater competition from the default syntactic structure and this competition results in processing differences.

What do these results then say about the differences between NS and Spanish speaking NNS, at least in the particular sentence-processing contexts assessed here? The most likely interpretation is that NS are more adept than NNS at processing both passives and actives given their increased language experience, allowing earlier access to information supporting a particular interpretation, especially in terms of speed, distance traveled, and directionality. This is supported by the proficiency analysis, which showed that as NNS participants' TOEFL scores increased, they began to converge with NS participants in terms of response time, motion time, and maximum onset velocity. In terms of AUC differences, the findings may be the result of cue differences between Spanish and English. In English, subject-verb-object (SVO) word order is an important cue for mapping thematic roles. However, in Spanish, word order is more flexible, and, furthermore, there are two potential passivized constructions (a form in which the semantic theme is topicalized, much like English, and an active voice form with an object-dislocation construction). The competition between these two forms in the Spanish speaking NNS may account for the AUC differences reported for the NNS participants but not for the NS participants, whose language only affords one method for passivation.

Focusing on just Spanish speaking NNS does limit our interpretation of the findings, especially in light of overlap in the structural alignment of declaratives and passives between Spanish and English. Therefore, future research is warranted to investigate language processing with a larger sample of NNS learners from a variety of language backgrounds. Within our Spanish speaking population, a number of participants were excluded because either their error rate across trial types was too high or their mouse movements were too erratic ($n = 16$). A smaller number of NS participants were excluded as well ($n = 7$). This calls into question the generalizability of the findings and hints that some participants had a difficult time with the tasks found in the experiment. Future research using other endpoint or overall response processing methods should also be conducted to triangulate methods and provide concurrent validity for this study. Such studies could use event-related brain potential measures to provide extra information about real time processing of passive and active constructions or use eye-tracking data to investigate syntactic processing. Moreover, action dynamics studies in general could benefit from assessing baseline motor movements in participants to control for potential variance found in motor behavior (e.g., Incera & McLennan, 2016). In addition, future research using hand tracking methods to focus on a variety of other syntactic structures in various target languages that address learner variables such as language aptitude, language analytic skills, and working memory would help provide support for theories of syntactic processing and acquisition in NS and NNS populations. Another limitation is that the setences used in this study were not directly comparable because the sentences were presented as either passives or actives, but not both. Future studies should include each sentence as either a passive or an active so comparisons across sentences can be made. Lastly, while we controlled for proficiency level, we did not control for age, which could influence processing.[1] This should be a consideration in future studies.

10. Conclusion

The findings of the current study provide important methodological and theoretical implications for language processing and acquisition by examining the processing of English passives by NS and NNS of English. Although mouse-tracking methods have often been used in NS studies, it is still an under-explored approach in examining NNS language processing. By examining the "micro-behaviors" in speakers' response movements, the action dynamics discussed here reveal distinct processing difficulties that would not be captured by a simple response time measure. Thus, the current study provides insights into the processing of passive and active constructions and how hand motions can be used to index listeners' cognitive processes. Specifically, the findings demonstrate differences and similarities between NS and NNS participants such that NS participants are faster at responding to passive and active stimuli, travel less distance, and make fewer directional changes when compared to NNS participants. However, all participants showed similar trends for passive processing suggesting comparable difficulties in processing passive constructions as compared to active structures.

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[1] Age data beyond range was lost precluding the addition of age as a fixed factor in the analyses.

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Appendix A. List of sentence stimuli used in experiment

Datives	**Prepositions**	**Relative Clauses**	**Passives**	**Actives**
The actor brought pears to the actress.	The arrow is between the squares.	The athlete jumping rope is sweating.	The aunt is assisted by her niece.	The bird watches the alligator.
The boss left two keys for the janitor.	The ball is in front of the box.	The couple reading the map is lost.	The boxer is punched by the kangaroo.	The tiger lifts the bear.
The child delivered mail to the woman.	The basket is on the blanket.	The girl using a phone needs a cab.	The boy is pushed by his sister.	The cat attacks the fireman.
The clerk handed change to the shopper.	The bird is above the big tree.	The guy drinking coffee is reading books.	The chief was surprised by the mailman.	The fish eats the fisherman.
The coach threw the bottle to the boy.	The cabinet is near the chalkboard.	The guy fixing the fence is using tools.	The chicken was scared by the crow.	The baby touches the hamster.
The daughter made a sweater for her dad.	The café is at the corner.	The lady stirring juice feels thirsty.	The dog was bitten by the snake.	The zebra kicks the horse.
The driver explained the route to the girl.	The car is inside the garage.	The maid folding clothes is wearing bracelets.	The duck was led by the penguin.	The daughter kisses the king.

The farmer returned cups to his neighbor.	The chair is below the window.	The maid sweeping the floor has an apron.	The elephant was washed by the worker.	The kid tickles the mom.
The father lent money to his daughter.	The clock is by the entrance door.	The man cutting a board makes tables.	The hero is killed by the robber.	The bus hits the motorcycle.
The gentleman bought flowers for his love.	The desk is against the window.	The man eating snacks is watching TV.	The husband was fed by his wife.	The robber shoots the policeman.
The grandpa told stories to the boy.	The hamster is outside the cage.	The nurse drying her hair is singing.	The panda is colored by the monkey.	The princess slaps the prince.
The groom gave a gift to the bride.	The lamp is next to the dresser.	The student drawing maps has glasses.	The pig was followed by the hen.	The cloud hides the sun.
The nephew showed the website to his aunt.	The monkey is under the box.	The student watering flowers loves plants.	The puppy was licked by the kitten.	The nurse hugs the surgeon.
The niece sent a letter to her uncle.	The monster is behind the sofa.	The teacher writing words likes spelling.	The skier was crushed by the snowboard.	The seagull chases the tourist.
The woman poured juice for the guest.	The rabbit is in the red box.	The waiter carrying trays likes food.	The turtle was carried by the sheep.	The grandmother finds the grandson.

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