1. What research question is put forward in the paper?

The authors of the study were interested in investigating online syntactic processing, more particularly, whether processing occurs serially or whether there is parallel activation of multiple syntactic representations. They examined the dynamics of hand movements in a sentence comprehension scenario with the goal of determining whether computer mouse trajectories, which are continuous and non-ballistic in nature, can tease apart competing theoretical accounts, including two distinct parallel activation accounts. Their main research question was whether computer mouse trajectories provide evidence for graded competition between simultaneously active syntactic representations.

2. What [experimental] method is used by the researchers?

The researchers used a mouse-tracking paradigm where they recorded the mouse movements of participants who were viewing and interacting with visual displays presented on a computrer screen. Displays contained 4 objects, each located one one corner of the screen, and participants were tasked with moving target objects from one location to another, which was done by clicking and dragging the relevant pictures to their intended location. Instructions detailing which objects to move and where to move them where were provided verbally during the task via a playback recording.

The study had a 2x2 design where both the visual context and the verbal instructions were manipulated. The visual displays were constructed such that there were both one-referent contexts and two-referent contexts. One-referent visual contexts contained the target object, an incorrect destination, a correct destination, as well as a distractor. Two-referent visual contexts contained the same items except for the distractor which was replaced with a second possible referent. The placement instructions for the critical trials were could be either syntactically ambiguous or unambiguous.

Given the study design, the authors predicted that (1) the averaged trajectories in response to ambiguous sentences in the one-referent context would show more curvature toward the incorrect destination than the averaged trajectories elicited by unambiguous sentences, while (2) the curvature of averaged trajectories in the two-referent condition would not differ statistically between ambiguous and unambiguous sentences.

3. What is their primary measure? Are there any other measures in the study? If so, how do they relate to the main dependent variable?

The mouse movements produced by participants during the click-and-drag task were recorded. The authors were primarily interested in the x,y coordinates of the mouse trajectories. These trajectories were first normalized into 101 timesteps and then spatially aligned so that the first recorded point corresponded to the x,y coordinates (0, 0). In order to analyze the potential effects of the referential context on the processing of both ambiguous and unambiguous sentences, the authors plotted the averaged x,y coordinates, per condition, as elicited in each context. They also derived a second measure from the coordinates, namely the Euclidean distance at each timestep between the timesteps of the ambiguous and the unambiguous conditions, which allowed them to account for both the x and y coordinates in a single analysis.

In order to determine whether one or two syntactic representations were active during the processing of ambiguous sentences, the authors analyzed the response distribution in the ambiguous condition. They also computed a measure of curvature magnitude in order to more clearly tell whether the distribution was unimodal or bimodal, calculating the area between the observed trajectory and a straight line computed by time-normalizing the starting and ending coordinates of the observed trajectory.

4. What are the main descriptive results of the study?

In the one-referent condition, the authors found that the average ambiguous-sentence trajectory was more curved toward the incorrect destination than the average unambiguous-sentence trajectory, confirming their first prediction. Moreover, given the information from the normalized timesteps, they found that the average trajectory for the unambiguous sentences traveled more quickly to the correct destination than the average trajectory for the ambiguous sentences. There were no reliable differences between the trajectories in the two-referent condition, confirming their second prediction. The Euclidean distance between the ambiguous- and unambiguous trajectories was found to be similar at the beginning of the trial in both visual contexts, however, as the trial unfolds the distance becomes considerably larger in the one-referent condition. There were reliable differences in the measured Euclidean distance from timesetp 37 through timestep 73 (out of 101).

As for the distribution of trajectories in the ambiguous condition, the majority of the trajectories fell somewhere in between extreme garden-path trials and non-garden path trials, forming a single population of non-, somewhat-, and highly-curved responses. The shape oft the distribution of trajectory curvatures for the one-referent condition was found to be unimodal. The area-under-the-curve measure for the one-referent condition in both the ambiguous and unambiguous conditions showed similar distributional properties (i.e., similar standard deviations and similar interquartile ranges).

5. What are the overall findings reported by the authors?

When it comes to the results that in the one-referent condition the average ambiguous-sentence trajectory was more curved toward the incorrect destination compared to the average unambiguous-sentence trajectory, the authors interpreted thas as evidence that there was a garden-path effect associated with the condition. They took the absence of reliable differences in the two-referent condition as evidence that the visual context can prevent the syntactic garden path. Together, these results are taken as evidence that mouse movements can be used to investigate online syntactic processing, replicating previous results from visual world eye-tracking studies.

When it comes to the gradiency observed in the curvature of the trajectories in the ambiguous condition, the authors took the graded degree of spatial attraction to the incorrect destination as evidence for a view of gradual commitment to one syntactic interpretation, as opposed to a discrete selection of one with the immediate dismissal of the others.

6. In your opinion, did the researchers manage to answer their research question appropriately, regardless of any null results or issues related to the statistical modeling of the data? Do you think the study design was appropriate to the research question at hand? What changes would you make to the study?

The study provides converging evidence that syntactic processing can be investigated via the dynamics of hand movements. More concretely, the analyses employed provide evidence that the so-called garden path effect can be modulated by the visual context. They also provide evidence in favor of a specific parallel activation account of syntactic processing, namely the constraint-based approach. Overall, the authors were able to address both the more general question of the efficacy

of mouse-tracking as a methodology to study sentence processing in real time and the more specific research question of whether a serial or a parallel processing account is supported by online processing data. They employed a series of analyes, relying on different measures, and taking into account alternative lines of reasoning for each reported result. All in all, the design of the study as well as the analyses were very appropriate to the goals communicated at the outset of the article, as they allowed the researchers to infer, given a certain experimental manipulation, whether the measured mouse responses confirmed or disconfirmed different predictions obtained from competing theoretical accounts. The study would benefit from more clear visualizations.