The Noisy Channel Model and Sentence Processing in Individuals with Simulated Hearing Loss

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THE NOISY CHANNEL MODEL AND SENTENCE PROCESSING IN INDIVIDUALS WITH SIMUALTED HEARING LOSS

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Recent research (Gibson, Bergen, & Piantadosi, 2013; Levy, 2011; Levy, Bicknell, Slattery, & Rayner, 2009) provides empirical evidence that language users maintain uncertainty about perceived linguistic input and in order to increase the likelihood of a successful communicative exchange, where the meaning intended matches the meaning perceived, may interpret a perceived sentence in a way that is unfaithful to the literal syntax. Gibson, Sandberg, Fedorenko, Bergen, & Kiran (2015) and Warren, Dickey, & Liburd (2015) found that individuals with aphasia may be aware of the increased noise in their language processing mechanism, and as a result, rely more on semantic information as a means to increase the likelihood of a successful communicative exchange. The present study aims to further examine how properties of the comprehender, such as presence or absence of simulated hearing loss, may affect one's reliance on a perceived linguistic signal. 40 participants with a simulated high frequency hearing loss and 40 participants without a simulated hearing loss were administered the Gibson task, a forced choice picture task that asks participants to select which of two illustrations best represents a sentence they heard. One illustration represents the literal syntax while the other represents an alternate interpretation that may be obtained through edits or distortions of the literal syntax. The sentences presented vary in structure (double object, prepositional object, active, and passive) and plausibility (plausible, implausible, and impossible). Participants had their eyes-tracked while listening to sentences and making decisions. Both groups of participants partook in rational sentence inferencing. Participants in the simulated hearing loss exhibited lower accuracy scores and longer reaction times. Both groups of participants exhibited more competition in less reliable sentence conditions as evident through eye-tracking; however, participants with simulated hearing loss showed more competition between the target and competitor image than individuals with no hearing loss. Furthermore, participants with simulated hearing loss appeared the reach the ceiling in terms of available processing resources as evident through both reaction time and eye-tracking data.

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1.0 INTRODUCTION

Noise is ever-present in communication. This noise can manifest itself as errors in production (e.g., misspeaking) or perception (e.g., hearing loss, low signal to noise ratio). For example, a speaker may omit a word producing the sentence, “The mother mailed the letter the daughter” instead of “The mother mailed the letter *to* the daughter.” A successful communicative exchange can be thought of as an exchange in which the speaker’s intended meaning matches the listener’s perceived meaning. Given that noise is so prevalent in everyday communication, we need a well-adapted language processing mechanism that can recover intended meaning when given noisy input.

Rational models of sentence comprehension (Levy, 2011; Levy et al., 2009) posit that language users take advantage of all available information including perceptual, semantic, and syntactic cues to make predictions about what is likely to occur next in a sentence and to revise already parsed information. Such models assume that language users use available information to increase the probability of a successful communicative exchange and have the consequence that language users may end up with an interpretation of a sentence that is unfaithful to the perceived linguistic input.

A noisy channel model put forth by Gibson et al. (2013) aims to examine how a rational sentence comprehender may act in the face of noise and suggests language users use Bayesian reasoning when determining whether or not to remain faithful to the perceived linguistic signal.

Gibson et al. (2013) conducted experiments manipulating the types of sentences and amount of noise in a perceived linguistic signal. The task included alterations of various sentence structures: active/passive, subject-locative/object-locative, transitive/intransitive, double object/prepositional object, and double object/prepositional object benefactive. The sentences structures varied in the amounts and types of edits necessary to switch between alternations. Furthermore, sentences were presented in varying amounts of noise, one experimental condition had 50% of the filler items containing syntactic errors while another condition increased the amount of implausible filler material. Results showed that sentence comprehenders are influenced by the amount of errors and the amount of improbable sentences in a linguistic signal and that comprehenders rely less on the perceived linguistic signal when the amount of noise is increased. They also found individuals were more or less likely to remain faithful to a linguistic signal depending on the type and amount of errors necessary to switch from one alteration to another. Further research conducted by Gibson et al. (2015) and Warren et al. (2015) examining the noisy channel model in individuals with aphasia suggests that individuals with aphasia rely more heavily on semantic knowledge as a means to increase the likelihood of a successful communicative exchange. Gibson et al. (2015) and Warren et al. (2015) found that while persons with aphasia (PWA) rely more on semantic information, they also adapt their reliance based on sentence structure and plausibility conditions.

Given that individuals appear to be aware that input to their particular language processing mechanism may be considerably more "noisy," this raises the question as to what sorts of properties of the comprehender may influence reliance on semantic and syntactic information, and to what degree. The current study aims to further understand how properties of the comprehender, like presence or absence of a simulated hearing loss, influence one's reliance on semantic and syntactic information.

1.1 BACKGROUND

1.1.1 Rational Sentence Processing

Non-noisy channel accounts suggest that we are able to communicate despite the high incidence of noise by taking advantage of the redundancy in linguistic signals and the vast range of linguistic information available (i.e., perceptual and lexical cues) (Tanenhaus, Spivey-Knowlton, Eberhard, & Sedivy, 1995; Aylett & Turk, 2004). Such explanations suggest that once a word is parsed, the language user is faithful in interpreting the intended meaning based on the perceived input. Levy (2008) claims this does not account for times in which a language user may hear a grammatically sound sentence and be unfaithful to this utterance in their interpretation of the intended meaning. In these cases, syntactic and semantic priors may override fidelity to a linguistic signal. Syntactic priors relate to information about the frequency of a particular grammatical construction while semantic priors relate to the likelihood of a particular utterance or intended meaning being conveyed. Levy (2008) suggests a rational approach to sentence comprehension that works under the assumption that language users take advantage of all available information when parsing perceived sentences. This includes levels of expected uncertainty and may result in the literal form of an utterance and the perceived meaning not matching.

Recent research indicates that language users are influenced by uncertainty about the linguistic signal they previously perceived, suggesting that they sometimes assume that it may not be accurate (Levy et al., 2009; Levy, 2011). Levy et al. (2009) proposed that, comprehenders may be influenced by the probability of alternate interpretations involving orthographic near-neighbor substitutions or deletions. Levy et al. (2009) used sentences with the following structure in their study:

(1a) The coach smiled at the player tossed the frisbee.

(1b) The coach smiled at the player thrown the frisbee.

While the meaning of each sentence is equivalent, the (1a) alteration is much more difficult to parse than the (1b) alteration because, in (1a), the grammatical role of “tossed” is ambiguous and can be either a finite verb or a past participle. While the linguistic information prior to “tossed” may rule out any misinterpretations of (1a) the probability of a sentence that remains faithful to the previously parsed information is less likely than the probability of a sentence involving a near-neighbor substitution or deletion. For example, the orthographic neighbors of “at” (“as” and “and”), or a distortion involving the deletion of the word “who” following “player”, would indicate the word following “player”, “tossed”, is a finite verb—a more likely grammatical construction. Levy et al. (2009) believe that Bayesian reasoning upon reading “tossed” causes a probability shift away from the actual content and towards the alternate interpretations involving near neighbor substitutions. This shift does not occur in alteration (1b) because “thrown” cannot be a finite verb. Levy et al. (2009) predicted that language comprehenders can remain uncertain about the identity of a word they have already read and claimed that if a newly encountered word challenges a comprehender’s belief about the sentence, they may have behavioral responses such as longer fixation times or regressive eye-movements while reading.

In order to examine if comprehenders maintain uncertainty about previously read words, Levy et al. (2009) tested sentences (1a) and (1b) as well as sentences in which the word "at" was replaced with "toward," eliminating the possibility orthographic near-neighbor substitutions.

(2a) The coach smiled toward the player tossed the frisbee.

(2b) The coach smiled toward the player thrown the frisbee.

Levy et al. (2009) administered variations of these sentences to participants while they had their eyes tracked and found that comprehenders exhibited more regressive eye movements and longer fixation times when encountering sentence type (1a). These results suggest that readers maintain uncertainty about words they have previously read and that they consider alternatives of a previously read word.

Levy (2011) further explored rational sentence comprehension and the hypothesis that under certain circumstances, language comprehenders' interpretation of the sentence may be inconsistent with the linguistic input they received. Levy (2011) constructed sentences that may lead to a "hallucinated garden-path" in which a comma, which should in principle eliminate a garden path sentence, is ignored, creating a "hallucinated garden path." For example, take the garden path sentence "While Mary was mending the socks fell off her lap." Through the insertion of a comma after "mending" (i.e., "While Mary was mending**,** the socks fell off her lap") the ambiguity is eliminated and the sentence is no longer a garden path. The same should be true for the sentence below:

(3a) As the soldiers marched, towards the tank lurched an injured enemy combatant.

However, Levy (2011) suggests that because of the low frequency grammatical construction, language comprehenders will "hallucinate" a garden path. The structure leading to the hallucination is the locative inversion, in which the locative prepositional phrase ("towards the tank") is placed before the main verb ("lurched"). This is an extremely low frequency structure and as a result, sentence comprehenders may ignore the comma so that "toward the tank" would be a prepositional phrase of the subordinate clause "As the soldiers marched"—a more likely construction. Thus, by eliminating the comma, comprehenders "hallucinate" or create a garden path that should have been eliminated by the presence of the comma. This would support the notion that language users may maintain uncertainty about perceived linguistic input.

In order to examine this prediction, Levy (2011) administered a self-paced reading task to participants including a hallucinated garden path sentence (3a) as well as a version of (3a) in which a prepositional phrase is added, to eliminate the hallucinated garden path and to separate effects of the hallucinated garden path from effects of encountering the low frequency construction of a locative inversion.

> (3b) As the soldiers marched *into the bunker*, toward the tank lurched an injured enemy combatant.

Furthermore, to eliminate possible effects of sentence length, Levy (2011) used two more sentences containing locative un-inverted versions of (3a) and (3b). Levy (2011) predicted that if a comprehender is considering this alternate interpretation it should be evident in longer reading times for the main verb, "lurched" in sentence (3a). Levy (2011) administered the task to 40 monolingual English speakers and followed each sentence with a comprehension question such as "Did the tank lurch toward an injured enemy combatant?" Results found that reading times were, in fact, longest for the main verb in sentence construction (3a). This finding provides further support that language comprehenders entertain interpretations of sentences that are unfaithful to the linguistic input.

Levy et al. (2009) and Levy (2011) provide empirical evidence that language comprehenders are aware of possible alternatives to a perceived sentence and may seriously entertain these alternate grammatical constructions. Thus, language users are aware of the probability of an utterance or a particular grammatical construction and in cases where this probability is low, may assume that the linguistic input they received was incorrect and make edits to previously parsed input. Thus, language comprehension isn't only a forward process—language users also can go back and question the validity of their perceptual input. Furthermore, language users do not treat words as the most fundamental unit to language comprehension and may be unfaithful to a perceived word in their interpretations. This raises the question of what sources of uncertainty can push language comprehenders towards being unfaithful to linguistic input.

1.1.2 A Noisy Channel Model Approach

Gibson et al. (2013) sought to further understand how a rational sentence comprehender may act in the face of noise through the evaluation of four predications about a rational sentence comprehender. Gibson et al. (2013) put forth an equation intended to explain how comprehenders use Bayesian reasoning to recover intended meaning of a perceived sentence:

$$P(s_i|s_p) \propto \mathrm{P}(s_i)\, P(s_i \rightarrow s_p)$$

This model suggests that the probability of a language comprehender obtaining the sentence intended (s_i) from sentence the perceived (s_p) is proportional to the probability of s_i occurring, $P(s_i)$, times the probability that one could derive s_i from s_p, $P(s_i \rightarrow s_p)$. In other words, $P(s_i)$ is our semantic knowledge, which influences how likely a given sentence meaning or situation is. It also includes our knowledge of the kinds of sentences uttered and the likelihood of various grammatical constructions which, in turn, influence how likely a given sentence is. $P(s_i \rightarrow s_p)$ is our syntactic knowledge and represents the likelihood of s_i being corrupted or changed to s_p; this relates to how likely it is that someone uttered s_p but meant to utter s_i. Following this model, Gibson et al. (2013) predict how a comprehender would act under such conditions—the four predications are as follows:

(1) Comprehenders will be more faithful to the perceived sentence when more edits are necessary to switch to an alternate interpretation and vice-versa. For example, participants will be less likely to assume "The ball kicked the girl" was intended as "The ball *was* kicked *by* the girl." (2 edits) than to assume "The mother gave the candle the daughter" was intended as "The mother gave the candle *to* the daughter." (1 edit).

(2) Comprehenders will be more faithful to the literal interpretation when the distortion assumed is an insertion rather than a deletion and vice-versa. This is because it is more likely to imagine a speaker could omit a single word or a comprehender may not hear a reduced word like "to" than to imagine a language producer accidently inserted a particular word from their mental lexicon into a particular sentence position. For example, it is more likely the s_p "The mother gave the candle the daughter" was intended as "The mother gave the candle *to* the daughter" (1 deletion) than "The mother gave the daughter to the candle" was intended as "The mother gave the daughter the candle." (1 insertion).

(3) In the face of more noise, comprehenders will become less faithful to the literal interpretation relying more on their semantic knowledge. This is because in the face of more noise, the input becomes less reliable.

(4) In the face of more implausible sentences, comprehenders will be more likely to remain faithful to the literal interpretation relying less on their semantic knowledge. This is because the $P(s_i)$ being an improbable sentence increases.

Gibson et al. (2013) presented sentences with varying plausibility and structure to participants on the experimental platform, Amazon Mechanical Turk. Sentences were either plausible or implausible. Sentences were either active/passive, transitive/intransitive, double object/prepositional object. The different sentence structures varied in terms of the kinds and number of edits necessary to switch from an implausible to plausible version and vice-versa and allowed Gibson et al. (2013) to look at the interaction between edit distance and plausibility.

Structure	**Edit Distance**
Active/Passive	Two edits
Subject-locative/Object-locative	One edit
Transitive/Intransitive	One edit
Double Object/Prepositional Object	One edit
Double Object/Prepositional Object Benefactive	One edit

Table 1: Gibson et al. (2013) Sentence Types

Gibson et al. (2013) presented subjects with variations of these sentence types followed by a comprehension question where an answer of either “yes” or “no” revealed whether the participant was relying on the literal or non-literal syntax. The results supported all four predictions. This suggests language comprehenders are not only aware of the plausibility of an uttered sentence, but also use Bayesian reasoning when deciding whether or not to remain faithful to the literal interpretation of the syntax. This again supports the idea that language users maintain uncertainty about an incoming linguistic signal. Furthermore, this paper suggests that in addition to language users using semantic and syntactic priors (knowledge related to the types of sentences likely to be uttered and the base-rate frequencies of various grammatical constructions), properties of the linguistic signal (frequency of errors and frequency of improbable sentences) can also influence one's reliance on the literal syntax. Furthermore, language comprehenders are able to adapt to changes in the amount and type of noise in a linguistic signal and make changes to their reliance on said linguistic input relatively quickly.

1.1.3 Noisy Chanel Model and Aphasia

Gibson et al. (2015) further examined the noisy channel model in people with aphasia (PWA). Gibson et al. (2015) suggest the frequently noted trend that individuals with aphasia rely more on their semantic knowledge than controls may be explained by the noisy channel model. While heavier reliance on semantic information by PWA is often explained by impaired syntactic abilities causing PWA to rely more on their non-syntactic abilities, Gibson et al. (2015) believe that this explanation may be incomplete because it has been found that individuals with aphasia can judge grammaticality of a sentence. Gibson et al. (2015) propose that individuals with aphasia are instead aware there is a higher probability of the linguistic signal being corrupted by noise. This is comparable to the condition testing prediction 3 from Gibson et al. (2013), which found that in the face of more noise, individuals were less faithful to literal interpretations and more influenced by semantic information. Because PWA have more noise in their language processing mechanism, to increase the chances of recovering s_i from s_p they rely more on semantic information.

Gibson et al. (2015) used similar stimuli as the one used in Gibson et al. (2013). The task included active/passive and double object/prepositional object (DO/PO) sentences that were either plausible or implausible. Below are example sentences provided by Gibson et al. (2015).

Sentence Type	Plausible	Distortion	Implausible	Distortion
DO	The brother gave the sister the bike.	1 deletion	The brother gave the bike the sister.	1 deletion
PO	The brother gave the bike to the sister.	1 insertion	The brother gave the sister to the bike.	1 insertion
Active	The man drove the truck.	2 deletions	The ball kicked the nephew.	2 deletions
Passive	The cake was eaten by the son.	2 insertions	The daughter was folded by the blanket.	2 insertions

Table 2: Gibson et al. (2015) Sentence Stimuli

The task also included reversible active and passive sentences in which both alterations of the sentence were equally probable. The DO/PO and active/passive alternations differed in the types and amounts of edits necessary to switch between alternate interpretations. The "Distortion" column in the table above refers to the type of distortion produced by the speaker and how many edits must be made to the literal syntax to switch to the alternate interpretation. To test fidelity to the linguistic input, participants acted out their interpretation of a perceived sentence. Gibson et al. (2015) predicted individuals with aphasia would rely more on plausibility than controls. However, they also predicted that edit distance and sentence probability would affect both PWA and controls and that for both populations, they would be less faithful (1) to a sentence involving a deletion rather than an insertion and (2) to a sentence where more edits are necessary to switch from one interpretation to another.

Gibson et al. (2015) found that overall, compared to a group of younger and a group of older controls, PWA relied more on plausibility (semantic information). PWA relied on plausibility in both DO/PO and active/passive sentences. In terms of structure, persons with aphasia were more likely to remain faithful to the interpretation for implausible active and passive sentences (where the edit distance is larger) than for implausible DO and PO sentences. Furthermore, PO items (involving one insertion) were interpreted literally more than DO items (involving one deletion). This confirms that individuals with aphasia, while they do rely more on semantic information than controls, also partake in the same sorts of Bayesian reasoning as outlined in Gibson et al. (2013) suggesting that an individual with aphasia's reliance on semantic information may be attributed to a need to compensate for the excess noise present in their language processing mechanism.

In a comparable study, Warren et al. (2015) replicated similar results. Warren et al. (2015) also used DO/PO and active/passive sentence alterations. However, Warren et al. (2015) added additional plausibility conditions creating implausible/plausible active and passive sentences and adding more reversible items for which both the active and passive alteration were equally plausible. Below are example sentences provided by Warren et al. (2015).

Sentence Type	Plausible	Distortion	Implausible	Distortion
Active	The cat licked the girl.	2 deletions	The girl licked the cat.	2 deletions
Passive	The girl as licked by the cat.	2 insertions	The cat was licked by the girl.	2 insertions

Table 3: Warren et al. (2015) Active Passive, Implausible Stimuli

Sentence Type	Reversible
Active	The man held the woman.
Passive	The man was held by the woman.

Table 4: Warren et al. (2015) Active Passive, Reversible Stimuli

Rather than acting out the interpretation of the sentences, participants selected which of two illustrations (an illustration of the literal and an illustration of the non-literal syntax) best represented what was heard in the sentence.

People with aphasia were less faithful to the literal interpretation than age-matched controls. And the same main effects of structure and plausibility were present. These results confirmed that while PWA rely more heavily on their semantic knowledge perhaps as a means of increasing the probability of a successful communicative exchange. Warren et al. (2015) also compared individual's performance on a semantic knowledge battery consisting of Kissing and Dancing test (Bak & Hodges 2003), Pyramids and Palm Trees test (Howard & Patterson, 1992), and an event knowledge test. Interestingly, they did not find a correlation between syntactic or semantic impairment and semantic reliance. Perhaps, any increase in noise to an individual's language processing mechanism affects reliance on semantic information relatively equally.

1.1.4 Hearing Loss

Levy et al. (2009) and Levy (2011) provide empirical evidence that linguistic users maintain uncertainty while interpreting a linguistic signal. Gibson et al. (2013) present findings that support that language comprehenders take part in rational inferencing regarding a sentence's meaning, and that characteristics of a linguistic signal and environment may influence fidelity to a linguistic signal. Gibson et al. (2015) and Warren et al. (2015) then provided evidence that properties of a comprehender, like presence or absence of aphasia, influence fidelity to a linguistic signal. They suggested that PWA's reliance on semantic knowledge may be attributed to their higher uncertainty about the linguistic signal and an attempt to increase the likelihood of recovering s_p from $s_{i.}$ This raises two questions: what other properties of a comprehender influence fidelity to a linguistic signal, and furthermore, do different properties of the comprehender influence one's fidelity to a linguistic signal differently? Given that aphasia is a language disorder, the noise or uncertainty that people with aphasia experience lies in their processing the linguistic signal, and not noise in the linguistic signal itself. How would comprehenders with similarly consistent noise that manifests elsewhere in the system rely on semantic and syntactic information?

Take for example individuals with hearing loss. It is known that hearing loss affects speech comprehension (Desloge, et al., 2010; Duqesnoy, 1983; Gelfald, Ross, & Miller, 1987; Hornsby & Rickets, 2003). How would hearing loss affect fidelity to a linguistic signal? The sensory-processing impairments experienced by individuals with hearing loss can disrupt their ability to perceive different parts of the linguistic signal, including short and acoustically reduced function words like *to, was,* or *by*. Would this difficulty increase these individuals' uncertainty about the linguistic signal? It is these types of words that Levy et al. (2009) showed that language comprehenders were uncertain about in their study. These are also the words that distinguish the sentence structures that Gibson et al. (2015) and Warren et al. (2015) compared in their studies (active and passive, direct object and prepositional object). This is a question of interest as hearing loss is highly prevalent in the United States, with an estimated 30 million, or 12.7% of Americans having bi-lateral hearing loss (Lin, Niparko, & Ferrucci, 2011).

Recent research has found that individuals with hearing loss and without hearing loss have more difficulty understanding linguistically complex sentences in the face of noise. Carroll & Ruigendijk (2013), for example, presented sentences to 44 students with normal hearing in silence and in a signal to noise ratio (SNR) of -3dB, thus, the noise was 3dB louder than the speech signal. Carroll & Ruigendijk (2013) presented their participants with German canonical subject-verb-object (SVO) sentences and non-canonical object-verb-subject (OVS) sentences in their Experiment 1. Below are English translations of the sentences presented by Carroll & Ruigendijk (2013):

(4a) SVO: The little boy hugs the big Santa Claus.

(4b) OVS: It is the big Santa Claus that the little boy hugs.

(4c) OVS ambiguous: It is the big cook that the evil baker hugs.

In the ambiguous OVS sentence, the noun phrase is ambiguously case-marked and thus, comprehenders have difficulty assigning a syntactic role (i.e., subject or object) to the noun. These ambiguously case-marked sentences have been found to elicit similar effects as a garden path sentence (or the hallucinated garden paths in Levy (2011)) because listeners are unsure of whether or not the noun is a subject or an object. As a result, they may have to "reanalyze" their previous interpretation of the sentence to align with the recently parsed information (Carroll & Ruigendijk, 2013).

Carroll & Ruigendijk (2013) had participants complete a word-monitoring task, in which they pressed a button as soon as they heard a target word (the target word was specified before each sentence). The target word appeared in different positions in the sentences, and Carroll and

Ruigendijk predicted that participants would be slower to press the button if the target word was in a difficult sentence or was in a position where people were experiencing processing difficulty. Participants also answered sentence-final comprehension question about the sentences' meaning. For the SVO and OVS sentences, Carroll & Ruigendijk (2013) found an interaction between noise and sentence structure—participants had more difficulty processing the more complex, non-canonical OVS structures in the face of noise than the canonical SVO sentences, as evident in longer reaction times for the target words. Carroll & Ruigendijk (2013) posit that this may be because of an increase in the demands of working memory when processing non-canonical sentences.

Interestingly, Carroll & Ruigendijk (2013) also noted that their participants performed differently on the three structures they tested. This suggests that, although the signal was difficult to hear in the low SNR condition, the structures (including case-markings) were still recognizable. However, it appears as if this information was more difficult to perceive and parse in noise than in the silent conditions. Thus, the difficulty in comprehending complex structures is compounded by the difficulty perceiving the linguistic signal.

Furthermore, Carroll & Ruigendijk (2013) also observed what they refer to as a "reanalysis effect" for the ambiguous OVS subject. Specifically, after hearing the disambiguating part of the sentence (the case-marked adjective before the Subject noun), participants exhibited longer reaction times for the Subject noun. This affect was exacerbated in the noise condition. This finding is consistent with the findings by Levy et al. (2009) and Levy (2011) suggesting that participants may remain uncertain about previously parsed information and, as Carroll & Ruigendijk (2013) put it, face processing costs when they must "reanalyze" their previous interpretation. That is, they must go back and revise their initial understanding of some of the words they had previously heard, that they maintained uncertainty about. However, this study also finds this reanalysis effect is exacerbated in the face of noise. This may be because the increase in processing demands in the low SNR and the demands non-canonical structures have on working memory jointly take a toll on processing resources, resulting in a more exaggerated reanalysis effect. Another possibility is that the signal is so difficult to perceive that listeners are unable to identify the relevant words they must revise. Either way, when individuals without hearing loss hear a sentence in noise, it takes longer to revise previously parsed information. It would be interesting to understand at what point perceiving the signal becomes so taxing (or that the signal is so degraded) that participants are unable to "reanalyze" previously parsed information accurately.

Wingfield et al. (2006) found that individuals with hearing loss are also less accurate in their interpretations of syntactically complex sentences. Wingfield et al. (2006) presented participants with and without hearing loss with subject-relative and more complex object-relative sentences. All participants had lower accuracy scores for the object-relative clauses. For both subject- and object-relative clauses, individuals with hearing loss had lower accuracy scores. Furthermore, there were interactions between hearing acuity and speech rate in the more complex, object-relative sentences—participants with hearing loss' ability to interpret these more complex sentence accurately was more negatively influenced by increasing the speech rate of the linguistic signal. Perhaps, this is because of an increase on processing demands during the processing of more complex sentences. The increased processing demands for complex sentences may be especially hard for individuals with hearing loss, who may find listening to and comprehending sentences more effortful and demanding than people without hearing loss.

Larsby et al. (2005) and McCoy et al. (2005) showed that this is true for individuals with hearing loss. These studies found that individuals with hearing loss exert more effort when processing sentences than typical hearing controls. Larsby et al. (2005) administered speech-understanding tasks to individuals with and without hearing loss in the presence and absence of noise. They found that in the face of noise, participants in both groups showed lower accuracy and higher reaction times in tasks measuring semantic and lexical decision making. There was an interaction effect between group and noise condition—participants *without* hearing loss had longer reaction time increases than individuals with hearing loss when presented stimuli in the face of noise. This is an interesting finding because it suggests that individuals with hearing loss were closer to ceiling in terms of available processing resources, and as a result, were less able to increase their reaction times while individuals without hearing loss were able to adapt to the increase in uncertainty in the linguistic signal. Furthermore, Larsby et al. (2005) also measured the perceived effort necessary to complete the task—effort was measured by having participants self-report how much effort was necessary to complete the current task. They found that individuals with hearing loss reported more effort needed to complete the tasks than individuals without hearing loss, and all participants reported more effort necessary to complete the task in the face of noise. This study indicates that not only does hearing loss decrease accuracy and increase processing time, but also, individuals are aware of the increased effort necessary to process speech.

McCoy et al. (2005) also note the increased effort necessary for individuals with hearing loss to process a given sentence. McCoy et al. (2005) suggest an “effortful hypothesis,” which claims that because individuals with hearing loss must exert additional effort in order to perceive a linguistic signal, they have less available resources for processing the sentence. McCoy et al.

(2005) had participants with and without hearing loss listen to word lists and recall the last three words presented at randomly selected times. When word lists had lower levels of contextual constraint (meaning the words were less related to other words in the list), individuals with mild-to-moderate hearing loss had significantly lower levels of performance than individuals without hearing loss. Low levels of contextual constraint may cause lower levels of performance in individuals with hearing loss because of additional constraints on working memory—participants must exert more effort to remember unrelated words in a list than to remember related words. McCoy et al. (2005) suggest this decrease in performance is a result of a lack of available resources—because participants must exert additional effort to perceive the sentence, there are less processing resources available for processes like working memory. These resources are especially important for processing and understanding long or complex sentences.

Both McCoy et al. (2005) and Larsby et al. (2005) suggest that hearing loss results in expenditure of processing resources. This may be one of the reasons individuals with hearing loss perform poorly on sentence understanding tasks involving complex sentences—they lack the processing resources necessary to parse the linguistically complex sentence. However, another possible explanation could be akin to why PWA may rely more on their semantic knowledge—as a means to increase the likelihood of a successful communicative exchange. Perhaps longer processing times are an inevitable effect of optimization of communicative exchanges because one must more seriously consider alternate interpretations under higher levels of uncertainty. Individuals with hearing loss have higher levels of uncertainty because the linguistic signal that they perceived is constantly degraded, in particular, frequency information and phonetic information is lost and thus, there is a higher probability that what was perceived was actually intended as something else. Because the input is less reliable and language users want to optimize the probability of s_i matching s_p, individuals with hearing loss must more seriously consider competition between a perceived sentence and its possible alternatives.

An eye-tracking study conducted by Wendt, Kollmeir, & Brand (2015) found that individuals with hearing loss and individuals without hearing loss in the face of noise have longer processing times, in particular for complex non-canonical sentences. Wendt, Kollmeier, & Brand (2015) used a similar design to the ones used by Gibson et al. (2013), Gibson et al. (2015), and Warren et al. (2015) to examine how individuals with and without hearing loss comprehended sentences of varying syntactic complexity in the face of noise. Participants were presented with German canonical SVO and non-canonical OVS sentences, as well as non-canonical ambiguous sentences. These sentences, similar to the ambiguous OVS in the Carroll & Ruigendijk (2013), had ambiguously case-marked noun phrases making assigning the role of object or subject to the noun more difficult. Below are English translations of sentences used by Wendt et al. (2015):

(5a): SVO: The little boy greets the nice father.

(5b): OVS: It is the nice father that the little boy is greeting.

(5c): OVS ambiguous: It is the nice queen that the little boy is greeting.

Because the case-marked noun-phrases may contain phonological near-neighbors (for example, the article “the” is “der” (nominative), “den” (accusative), “die” (ambiguous)) the ambiguous sentence may result in more difficulty for individuals with hearing loss to understand, as slight phonetic differences result in meaning differences. Similar to the orthographic near-neighbors in the Levy et al.’s (2009) stimuli, these sorts of near-neighbor alternatives may increase uncertainty about a perceived linguistic signal.

Wendt et al. (2015) used the visual world paradigm, tracking participants' eyes while they listened to sentence stimuli and looked at images on a screen. Participants were presented with two images, one faithful to the literal syntax and one, unfaithful. The two images differed in that the roles of the agent and the theme were reversed, for example, for sentence (5a), the target image would show a boy greeting a father while the competitor image would show a father greeting a boy. Additionally, sentences were either presented in quiet or in noise. Across all auditory conditions, stimuli were presented at a speech recognition threshold (SRT) of 80, meaning that the sound level of stimuli presentation was adjusted so that each participant was able to understand 80% of the stimulus. This means that differences in groups may be attributed to characteristics of the group and not their ability to hear the sentence.

Results showed that participants were more accurate at interpreting the sentences in quiet as opposed to noisy conditions for SVO, OVS, and OVS ambiguous structures. Furthermore, there was an interaction effect between hearing status and structure—participants without hearing loss were more accurate in interpreting sentences than participants with hearing loss for the SVO structure in silence and noise, and for the ambiguous OVS structure in silence and noise. Sentence structure and noise condition did not significantly affect reaction time. There was, however, a main effect of group on reaction time—participants in the hearing loss group showed longer reaction times than the normal hearing group for the OVS structure in noise and the ambiguous OVS structure in quiet. The lower accuracy scores and higher reaction times for ambiguous structures may reflect uncertainty in the hearing loss group. Because participants with hearing loss are more uncertain about the case-markings of determiners in these sentences as a result of degraded input, they take more time processing these sentences and are less accurate in their final interpretations.

In order to analyze eye-tracking results, Wendt et al. (2015) looked at participant decision moment (DM), the amount of time before the participants were said to have decided on which image was correct. Decision moment was determined by using the single target detection amplitude (sTDA) which measured how often the participant gazed at the target image—a positive sTDA meant the participant gazed more at the target image, while a negative sTDA meant the participant gazed more at the competitor image**.** Decision moments were said to occur when the sTDA exceeded a value of 15 for 200 ms or longer. Wendt et al. (2015) also used disambiguation to decision delay (DDD), the amount of time it took for the participant to reach the decision moment after hearing the disambiguating part of the sentence. The disambiguating part of the sentence was the word in the sentence that, after hearing it, participants would be able to determine the subject and object of the sentence and select the correct image. For example, in sentence (5b), the OVS, “It is the nice father that the little boy is greeting.” the disambiguating part of the sentence is “father” while in sentence (5c), the OVS ambiguous, “It is the nice queen that the little boy is greeting.” it is not until the participant hears the case marked “the/der (nominative)” of the second article that participants can determine the subject and object of the sentence. Because there is case-marking in (5b) participants are able to recognize the target image sooner.

The results showed that a majority of participants took longer to process more complex and ambiguous structures, as evident through later DMs. The longest DDDs, however, were observed for the unambiguous OVS structure. Wendt et al. (2015) suggest that DDDs were longer for the unambiguous as opposed to ambiguous OVS structure because of the way in which the participants chose the target image. For the ambiguous OVS sentences, participants likely gazed first at the competitor image illustrating the more common canonical SVO structure, because this grammatical construction is more likely. This preference can be compared to Levy (2011), where participants were most likely to interpret a sentence as having a more probable structure. Recall that when participants heard: “As the soldiers marched, toward the tank lurched an injured enemy combatant.” they assumed “toward the tank” was a prepositional phrase describing where the soldiers were marching, a more likely construction than a locative inversion (“toward the tank lurched an injured enemy combatant”). As a result, upon hearing the disambiguating part of the sentence (in this case, “lurched”) participants had to reanalyze the sentence. This reanalysis was evident in longer reading times for “lurched.” Similarly, in Wendt et al. (2015) it is likely participants initially interpreted the ambiguous sentences as canonical SVO sentences, but upon hearing the disambiguating part of the sentence, they modified their interpretation. Because this change only required gazing at the other picture in this forced-choice task, the DDD was relatively short for ambiguous OVS sentences.

Furthermore, participants also showed longer processing times in all conditions in noise, as evident through longer DDDs. Individuals with hearing impairment showed longer processing times in the ambiguous OVS in quiet and noise, and for the SVO in quiet. This finding is of particular interest because during the experiment, stimuli were presented to all participants at an equal SRT. The fact that the hearing loss group had longer processing times indicates a property of this group (i.e., hearing loss) resulted in longer processing times despite stimuli being presented at equal levels. That is, hearing loss created longer processing time even when the linguistic signal was boosted to a higher speech-recognition threshold, to ensure that individuals with hearing loss could perceive the signal. This may indicate that they have greater uncertainty about the linguistic signal. This suggests that uncertainty is not only influenced by literal degradation of a signal but also by our expectations about the quality of a signal (which may be lower for people with hearing loss).

When analyzing their results, Wendt et al. (2015) noticed that some participants with hearing loss performed better than other individuals. To further understand this, Wendt et al. (2015) split the hearing loss group into those with hearing aids and those without and compared their performance. They found that participants without hearing aids had longer DDDs for the SVO and OVS structure in noise and silence. Again, because all stimuli were presented at an equal SRT across participants, this raises the question: what differences between hearing aid users and non-hearing aid users may affect processing times despite equal SRTs? Perhaps the groups differ in the way they adapt to uncertainty or the level of expected uncertainty. Alternatively, it may be related to the quality of their syntactic representations. Perhaps individuals with hearing aids have higher quality syntactic representations of various sentence structures because the long-term input to their language processing mechanism is of higher quality. As a result, they have stronger and more intact representations that they can use to assist in recovering meaning from a degraded complex linguistic signal. Individuals without hearing aids on the other hand receive more degraded input over time, and as a result, they may have lower quality syntactic representations. Because of this, it may be more difficult for them to recover intended meanings as evident through longer DDDs.

The current study aims to further our understanding of how different properties of the comprehender may affect reliance on semantic and syntactic information, by presenting the Gibson task to individuals with and without simulated high-frequency hearing loss. Simulated hearing loss has been shown to be effective in replicating the difficulty in understanding speech that is experienced by individuals with hearing loss (Desloge et al., 2010). Testing people with simulated hearing loss will help explain the differences between hearing aid users and non-hearing aid users that Wendt et al. (2015) reported. Normal-hearing listeners with simulated hearing loss have not received degraded input to their language-processing system over time, so their syntactic representations should not be lower quality than normal-hearing individuals without simulated hearing loss. Furthermore, participants will have their eyes tracked while listening to sentences and making decisions regarding those sentences' meaning. This will enable us to further understand how they are making their decisions, and what is influencing an interpretation that is or is not faithful to the literal syntax.

2.0 CURRENT STUDY: GOALS AND QUESTIONS

The current study aims to further explore the noisy channel model in individuals with simulated hearing loss. In order to understand how participants are deciding between interpretations that are or are not faithful to the literal syntax, participants will have their eyes tracked while listening to stimuli and making decisions. The specific research questions are as follows:

1. How does the absence or presence of simulated hearing loss affect one's fidelity to a perceived linguistic signal?
2. How will sentence structure and plausibility influence reliance on linguistic input?
3. How does absence or presence of simulated hearing loss affect one's consideration of target and non-target interpretations of the sentence, as measured through eye-tracking and reaction time data?
4. How does individuals with simulated hearing loss' performance on the Gibson task compare to individuals with aphasia's performance?

In order to answer these questions, participants will complete a modified version of the Gibson task used by Warren et al. (2015). This version of the task contains the same linguistic stimuli: double object/prepositional object and active/passive sentence alterations, varying in plausibility. Half of the participants will be given a task that simulates a high frequency hearing loss through the use of a low pass filter that will attenuate sounds in the stimuli above 2000 Hz, while the other half will be given an unmodified version of these stimuli. This method to simulate high frequency hearing loss was used as outlined by Will Strayer in Using Praat for Linguistic Research (2016).

If individuals with simulated hearing loss rely less on the literal syntax, this will complement Gibson et al. (2015) and Warren et al.'s (2015) findings that PWA are more likely to be uncertain about (or assume noise in) the linguistic signal. This will be evident as lower accuracy in the Gibson task, or fewer responses that are faithful to the linguistic signal. If individuals with simulated hearing loss also rely more on semantic information in the Gibson task, that will complement Gibson et al. (2015) and Warren et al.'s (2015) findings that PWA rely on semantic information as an attempt to increase the likelihood of a successful communicative exchange because more noise is present in their language processing mechanism.. It will also suggest that individuals with hearing loss may partake in the same sort of process to increase the likelihood of a successful communicative exchange. This will be evident as lower accuracy (fewer responses that are faithful to the linguistic signal) for implausible sentences than plausible sentences, and this difference should be greater for individuals with simulated hearing loss. This would also support models of rational sentence comprehension positing that individuals may maintain uncertainty about linguistic signals and support interpretations of sentences that are unfaithful to the literal syntax.

Participants with simulated hearing loss may also consider alternate interpretations of the syntax more seriously than individuals without simulated hearing loss, as evident in reaction time and eye-tracking data. Reaction time may reveal how much effort participants are exerting when choosing between the alternate interpretations of the sentence as well as how much processing resources are available to the participants. If participants with simulated hearing loss have longer reaction times than participants without simulated hearing loss, this would support Larsby et al. (2005) and McCoy et al.'s (2005) claims that hearing loss takes a toll on processing resources. Eye tracking data may show how much competition participants have between competitor images following hearing the disambiguating part of the sentence. Eye-tracking data may also reveal how long it takes participants to decide which image is correct. Eye-tracking data that reveals more competition between target and non-target interpretations may indicate that participants are more uncertain about what they are hearing and, thus, are having more difficulty determining which interpretation is faithful to the literal syntax. Longer latency to fixate on the target image may indicate participants are having more difficulty identifying the target image because they are more uncertain about the linguistic input. This may provide further support of rational models of sentence comprehension showing individuals maintain uncertainty about linguistic input and it may provide support as to how different types of noise influence uncertainty. Eye-tracking data may reveal the following:

1. When a sentence has a larger edit distance or is more probable, individuals are less likely to consider the non-faithful interpretation.
2. After hearing the disambiguating part of the sentence, individuals still show competition between the target and competitor image.
3. Participants with hearing loss take longer to fixate on the target image.
4. Individuals with simulated hearing loss, to increase successful communicative exchange where s_i matches s_p, consider each interpretation more than individuals with no hearing loss, as evident through more competition between the images.

2.1 HYPOTHESES

Given that when there is more noise in a linguistic signal individuals rely less on literal syntax (Gibson et al., 2013) and that individuals with aphasia rely less on literal syntax than age matched controls (Gibson et al., 2015; Warren et al., 2015), it is predicted that individuals with simulated hearing loss will also rely less on the literal syntax than individuals without simulated hearing loss. This will be evident in lower overall accuracy scores for individuals with simulated hearing loss. However, like typical language users and people with aphasia, individuals with simulated hearing loss and individuals without simulated hearing loss will be more likely to remain faithful to the literal syntax when (1) there are more edits necessary to go from one alteration to the other and (2) a distortion involves an insertion rather than a deletion. This will be evident in overall lower accuracy for DO and PO sentences as compared to actives and passives, as only 1 edit is necessary to switch between DO and PO alternations as compared to 2 edits for active and passive alternations. This will also be evident in lower accuracy scores in DO as compared to PO sentences as distortions in DO sentences involve deletions rather than insertions. However, it is not predicted that actives, although involving distortions containing deletions, will have lower accuracy scores than passives, but rather, that passives will have lower accuracy scores than actives. Gibson et al. (2013), Gibson et al. (2015), and Warren et al. (2015) found that participants, both with and without language impairments, are less faithful to passives as compared to actives. Gibson et al. (2015) posit this may be because passive sentences have longer dependencies and lower structural frequency contributing to passives' complexity and increasing the frequency of errors. Warren et al. (2015) suggest that the low frequency and high structural complexity of the passive structure may result in "lower-quality representations" in the PWA's memory and suggest language users may be less faithful to the literal syntax of a structure with a low-quality representation. Both of these speculations suggest that the noisy channel model may need to be adapted to better capture how PWA and non-impaired individuals interpret passive structures. This is because the noisy channel model suggests that participants should be more faithful to a sentence where a distortion involves an insertion rather than a deletion (i.e., more faithful to passives than actives) (Gibson et al., 2013). However, Gibson et al. (2013), Gibson et al. (2015), and Warren et al. (2015) found that participants are more faithful to actives than passive although the active structure involves deletions while the passive involves insertions. As a result, it appears as if the prediction that participants are more faithful to distortions involving insertions than deletions does not hold true for all sentence structures. This study's predictions are consistent with the above findings that participants will be less accurate for passives than actives. Finally, individuals, both with and without simulated hearing loss, will be less faithful to the literal syntax for improbable as compared to more probable sentences as evident in lower accuracy scores for implausible and impossible sentence alterations.

It is also predicted that participants with simulated hearing loss will have behavioral measures indicating that they are having more difficulty parsing the intended meaning of the sentence. This will be apparent in slower reaction times in the simulated hearing loss group than the no hearing loss group. Participants with both simulated and no simulated hearing loss will have reaction times that mirror the predicted accuracy scores, in other words, a low accuracy score should be associated with a longer reaction time. Thus, it is predicted there will be longer reaction times for DO and PO as compared to active and passive sentences as well as longer reaction times for DO as compared to PO sentences. However, again, consistent with findings by Gibson et al. (2013), Gibson et al. (2015) and Warren et al. (2015) that passives are less accurately interpreted than actives, there should be longer reaction times for passives as compared to actives. Finally, it is predicted there will be longer reaction times for improbable as compared to probable sentences.

Furthermore, participants with simulated hearing loss may take longer to fixate on the target image and show more gazes to the competitor image. This could be indicative that participants with simulated hearing loss are having to consider both alterations more carefully than individuals without simulated hearing loss even when there is a larger edit distance or the alternate interpretation involves an insertion. Also, individuals with simulated hearing loss, even after hearing the disambiguating part of the sentence, will consider the alternate interpretation more than individuals without simulated hearing loss—this is because there is more competition between the alternations.

Finally, it is predicted that individuals with simulated hearing loss would be more likely to remain faithful to the literal syntax than PWA. This is because the noise in the simulated hearing loss condition is more superficial than the noise in the language processing mechanism of an individual with aphasia (Gibson, et al., 2015)—simulated hearing loss results in a more peripheral disturbance than noise resulting from language difficulties in aphasia. For example, when a person with simulated hearing loss encounters noise (e.g., a degraded speech signal) they can still use other information available and, through top-down processing, recover the meaning of the sentence. This is because while the periphery is damaged, the more central representations (i.e., sentence structures and semantic knowledge) are still intact and thus, individuals with simulated hearing loss should still be able to use their intact representations and knowledge to recover meaning. However, individuals with aphasia may have more noisy central representations. This would reduce their ability to use these central representations in a top-down way to determine the intended meaning and likely structure of a sentence. If the representations of various grammatical constructions are low quality (like passives), it will be difficult to recover the intended meaning of a sentence. If on the other hand individuals with simulated hearing loss perform similarly to how the PWA from Gibson et al. (2015) and Warren et al. (2015) did, then it may suggest that individuals with aphasia do not have noisy central representations that would make them less able to recover from noise.

3.0 METHOD

3.1 PARTICIPANTS

Participants were divided into two experimental groups—40 individuals with normal hearing who were given a version of the Gibson task simulating a high frequency hearing loss, and 40 individuals with normal hearing given an unmodified Gibson task. It was decided that 40 participants in each experimental group would be ideal based on a previous study conducted by Carminati, van Gompel, Scheepers, & Arai (2008) that found significant results using a similar study design and using a similar-sized group of young adult participants. Participants in both groups were required to be between the ages of 18-70 and native English speakers. Furthermore, participants were required to have normal or corrected to normal vision and no history of speech, language, cognitive, or hearing disorders.

3.1.1 Recruitment

Participants in both experimental groups were recruited through the University of Pittsburgh Introduction to Psychology Participant Pool. Students enrolled in PSY 0010, Introduction to Psychology, are required to participate in 4 hours of research, and enrolled in the current study to obtain 1 hour of research participation credit. A brief description of the study and eligibility was available on the SONA website; students could then enroll for a scheduled time slot to participate. Interested volunteers who heard about the study and requested to participate were also scheduled a time slot. In total, 91 participants underwent screening procedures and 80 successfully completed the screening and experimental tasks.

3.1.2 Demographics

The mean age of the participants in the no hearing loss group was 19.7 years and ranged from 18 to 21 years. The mean age of participants in the simulated hearing loss group was 19.3 years and ranged from 18 to 24 years. All participants were University of Pittsburgh students.

3.2 MATERIALS

3.2.1 Screening Tests

As a part of the screening procedure, all participants completed a pencil and paper based questionnaire on demographic and medical history. All participants enrolled in the study reported they were Native English speakers with no history of speech, language, cognitive or hearing disorders. Participants also underwent a pure-tone bilateral hearing screening at 40dB using and audiometer and over the ear headphones. Participants also completed the Mini-Mental Status Exam (MMSE), a measurement of cognitive impairment, and scored a 28 or above (Folstein et al., 1975). Participants also completed Ravens Coloured Progressive Matrices (RCPM), a measure of non-verbal reasoning, and scored a 30 or above (Raven, 1965). Results for MMSE and RCPM were recorded on paper and pencil response sheets.

3.2.2 Experimental Tasks

Participants completed the following experimental tasks: Acuity and Mouse task and the Gibson task.

3.2.2.1 Acuity and Mouse

In order to ensure participants were comfortable using a computer, participants completed the “Acuity and Mouse Task”. The Acuity and Mouse task consists of four trials during which participants heard a word and are were instructed to choose which image presented on the screen best represented what they hear. If participants incorrectly selected an image, they were corrected and instructed on how to prevent a similar error in future trials.

3.2.2.2 Gibson task

The items from the Gibson task had previously been used in Warren et al. (2015) and Gibson et al. (2013). Items 1 a-d and 2 a-d were originally included in Gibson et al. (2013) study while items 3 a-d and 4 a-b were added to the task by Warren et al. (2015). Four lists were created using a Latin Square Design. Each list contained 86 trials: 20 DO/PO Implausible/Plausible sentences, 20 Active/Passive Impossible/Possible sentences, 20 Active/Passive Implausible/Plausible sentences, 10 Active/Passive Reversible sentences, and 16 filler sentences. Thus, participants were exposed to 5 trials with each sentence construction (i.e., 5 DO plausible trials, 5 DO implausible trials, 5 active possible trials, etc.) For the purpose of this study, only the DO/PO and Active/Passive Impossible/Possible sentences were analyzed and will be described below.

This first set of items crossed double object and prepositional object (DO/PO) syntactic alterations with plausible and implausible semantic coherence. The structures vary in the type of edits needed to get from one construction to the other. To get from a DO to a PO sentence, one must assume the speaker deleted the word “to.” In order to get from a PO to a DO, one must assume the speaker accidently inserted the word “to”. As consistent with the model presented by Gibson et al. (2013), comprehenders are more likely to be faithful to the syntax when the error involves an insertion rather than a deletion.

Item	**Structure**	**Probability**	**Sentence**	**Error if Distortion**
1a	DO	Plausible	The sister mailed the niece the letter.	None
1b	DO	Implausible	The sister mailed the letter the niece.	(1) Deletion of “to”
1c	PO	Plausible	The sister mailed the letter to the niece.	None
1d	PO	Implausible	The sister mailed the niece to the letter.	(1) Insertion of “to”

Table 5: Double Object Prepositional Object Sentences

The second set of 20 items crossed active and passive syntactic alterations with possible and impossible semantic coherence. The structures vary in the types of edits needed to get from one construction to the other. To get from an active to a passive sentence, one must assume the speaker deleted the words “was” and “by”. In order to get from a passive to an active, one must assume the speaker accidently inserted the words “was” and “by”.

Item	Structure	Probability	Sentence	Error if Distortion
2a	Active	Possible	The mother set the table.	None
2b	Active	Impossible	The table set the mother.	(2) Deletion of “was” & “by”
2c	Passive	Impossible	The mother was set by the table.	None
2d	Passive	Possible	The table was set by the mother.	(2) Insertion of “was” & “by”

Table 6: Active Passive, Impossible Sentences

The active/passive alterations differ from the DO/PO alteration in that DO/PO alterations are one edit away from an alternate interpretation while active/passive alterations are two edits away from an alternate interpretation. Recall that Gibson et al. (2013) found that language comprehenders are more likely to remain faithful to the literal syntax of a sentence when more edits are needed to go from one alteration to another.

The Gibson task used was a modified version of the task used by Warren et al. (2015). The task is a forced choice-task in which participants must select which of two images best illustrates what they heard in the sentence. One illustration represents the literal syntax while the other represents an alternate interpretation that may be obtained through edits or distortions of the literal syntax. Images were selected by pressing a key on a standard keyboard corresponding to the image. Accuracy and reaction time data were collected based on these measures. Below is an example of what participants may see upon hearing the sentence: “The janitor lent the teacher the mop.” The same images would be used for an alternate version of this sentence, “The janitor lent the teacher to the mop.” Left and right image placement was randomized during the creation of the task and fixed for each trial. The picture corresponding to the literal syntax was placed on the left and right side of the screen an equal number of times.

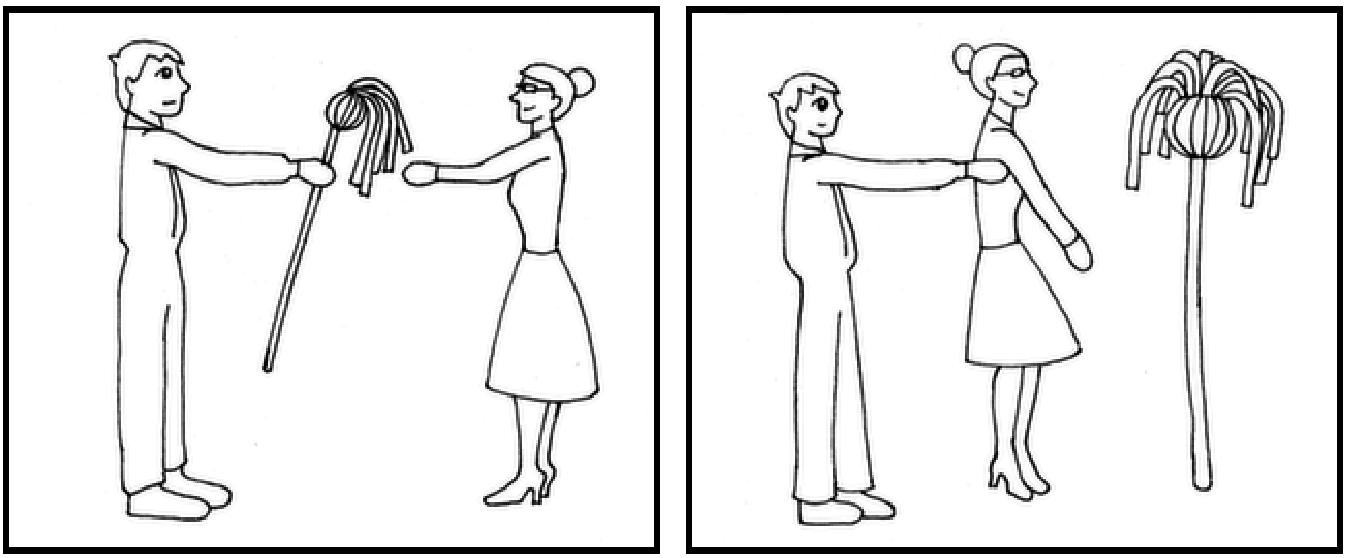

Figure 1: Gibson Task Illustration

The task used in Warren et al. (2015) was modified and rebuilt in Experiment Builder to allow eye-tracking. While listening to the sentence and making their choice, participants' eye-gaze was tracked using an Eyelink 1000 Tower Mount. Eye-tracking data was collected on: (1) the mean latency to fixate on the target image after the point of disambiguation (POD) and the sentence-offset; (2) the mean number of fixations on the target image after the POD and the sentence-offset; (3) the proportion of gazes at the target image after the POD and the sentence offset; and (4) the proportion of first fixations that were at the target image following disambiguation. Measurements were obtained from the POD or sentence-offset until participants responded. As a result, for the active and DO sentences, the POD and the sentence offset were the same measurement as the POD for actives and DOs was the sentence offset. Both proportion of gazes at the target and overall number of gazes were used to measure competition between the two images. This is important because the proportion of gazes at the target may present a misleading picture of how much competition a participant is experiencing. For example, one participant might look at the target image two times and the competitor image two times, which would result in 50% of gazes at the target image. Another participant might look at the target image 10 times and the competitor image 10 times, also resulting in a score of 50%. However, the second participant would seem to be exhibiting more competition between the target and competitor image.

The point of disambiguation (POD) was defined as the word in the sentence that after hearing participants would be able to determine which image was faithful to the literal syntax. This is similar to the disambiguating word in the Wendt et al. (2015) study that was used to determine their DDD measure. The POD differed for the different sentence constructions and is illustrated in the table below. The red asterisk marks the POD.

Items	Structure/Plausibility	Structure	Example	POD
1a & 1b	DO/Plaus-Implaus	NP V NP NP *	The sister mailed the niece the letter *.	Sentence offset
1c & 1d	PO/Plaus-Implaus	NP V NP *to* * NP	The sister mailed the niece to * the letter.	“to” offset
2a & 2b	Active/Poss-Imposs	NP V NP *	The mother set the table *.	Sentence offset
2c & 2d	Passive/Poss-Imposs	NP *was* V *by* * NP	The mother was set by * the table.	“by” offset

Table 7: Points of Disambiguation

Two versions of the task were created in Experiment Builder. The unmodified version used the original sound files from Warren et al. (2015). The simulated hearing loss version modified the original sound files to simulate high frequency hearing loss. Files were put through a low pass filter in Praat, a speech analysis software suite (Boersma & Weenink, 2016). The low pass filter attenuated frequencies of the signal higher than the determined cutoff frequency of

2000 Hz. As a result, speech sounds above 2000 Hz, like /s/, /h/, and /ð/, become difficult to hear (Olsen, Hawkins, & Van Tasell, 1987). Below is a spectrogram of a sentence before and after being put through the low pass filter. The before file is the file used in the unmodified version of the task. Sounds above 2000 Hz (the red line) in the simulated hearing loss file have decreased in amplitude (and thus, greyscale).

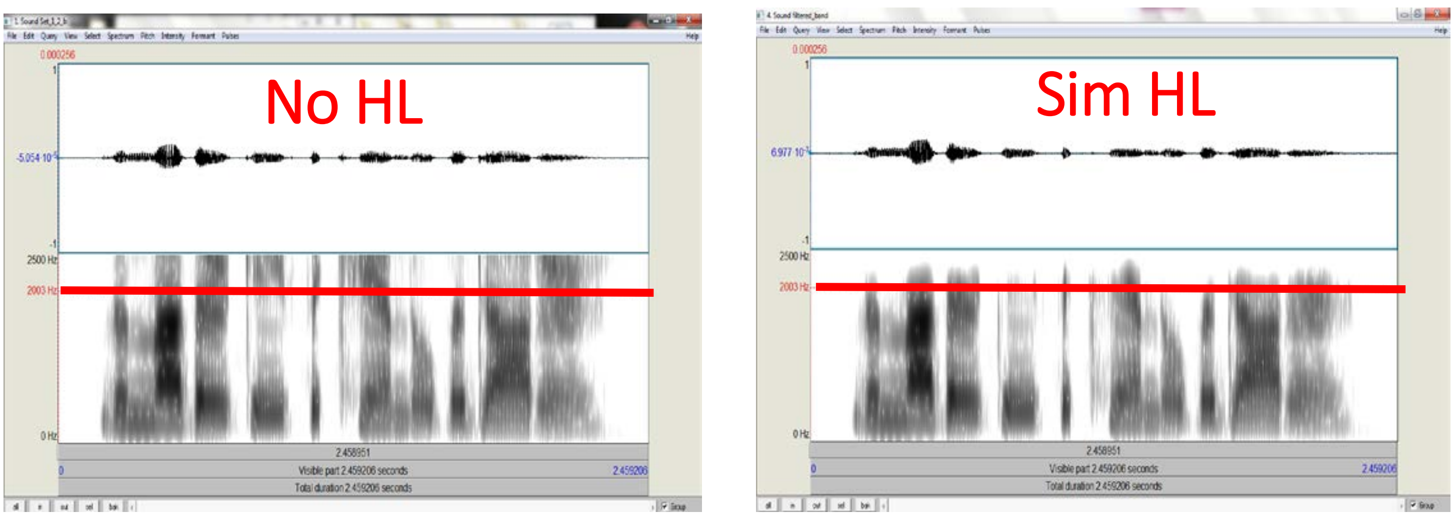

Figure 2: Simulated Hearing Loss Spectrogram

3.3 PROCEDURE

3.3.1 Screening

Upon arrival, participants underwent consent procedures and signed a consent form approved by the University of Pittsburgh Institutional Review Board. Participants then filled out two paper and pencil based questionnaires regarding their demographic history (i.e., date of birth, native language, handedness, etc.) and medical history (i.e., history of vision deficit, speech or language disorders, etc.). Participants also had a pure tone hearing screening of frequencies 500, 1000, 2000, and 4000 Hz at 40dB. Lastly, participants completed the Mini-Mental Status Exam (Folstein et al., 1975) and Raven's Coloured Progressive Matrices (Raven, 1965).

3.3.2 Experimental Task

Following the screening procedures, qualified participants began the experimental task. Participants first completed a short Acuity and Mouse task. Following the Acuity and Mouse task, participants began the Gibson task. Stimuli were presented through desktop speakers on either side of the computer monitor. Stimuli were presented at 60dB SPL (conversational loudness level). Participants were instructed to sit in a comfortable position and adjust the chair so they could place their head comfortably into the Tower Mount of the eye-tracker. The experimenter then read the experimental instructions and asked if the participant had any questions. Next, the participant was instructed to look straight ahead while the experimenter calibrated the equipment to their pupil size and corneal reflection. Then participants were directed to look directly at dots in different locations on the screen to map their eye-gaze in relation to the screen. These points were then validated using the guideline that the average error was no more than .5 degrees and the maximum error was no more than 1 degree. The participant was then told the experiment would start. At the end of the task, participants were debriefed and then awarded credit for their participation if applicable.

4.0 RESULTS

4.1 ANALYSIS AND DESIGN

The present study used a cross-sectional design. Two groups of participants, 40 individuals given a simulated hearing loss and 40 individuals with no simulated hearing loss, were administered the Gibson task. Participants in each group were presented with DO/PO plausible/implausible, and active/passive possible/impossible alterations of sentences. Four lists were created using a Latin Square design so that each participant was exposed to only one alteration of each item and that each list contained an equal number of each condition. Thus, within-subject independent variables included sentence structure and plausibility.

The following dependent variables were collected during the task: accuracy, reaction time, mean latency to fixate on the target image after the POD and the sentence-offset, the mean number of fixations on the target image after the POD and the sentence-offset, the proportion of gazes at the target image after the POD and the sentence offset, and the proportion of first fixations following disambiguation that were on the target image. Analysis of Variance was conducted in SPSS on the data. The within-subject independent variables were structure and plausibility and the between subject variable was group. In addition, in order to compare performance on DO/PO and active/passive structures, a one-way ANOVA was conducted on structure for accuracy and reaction time data.

4.2 ACCURACY

4.2.1 Double Object/Prepositional Object & Plausible/Implausible

There was a main effect of group: participants in the simulated hearing loss group (SimHL) (mean: .63) were less accurate than participants in the no hearing loss group (NoHL) (mean: .89, F=186.5, p<.001). There was also a main effect of structure. Participants in both groups were less accurate for the DO construction (mean: .66) than the PO construction (mean: .86, F=106.9 p<.001). There was also a main effect of plausibility. Participants were less accurate for implausible (mean: .60) than plausible items (mean: .92, F=352.4, p<.001). There was also an interaction between plausibility and group (F=147.7, p<.001). Participants in the SimHL group were influenced more by plausibility than participants in the NoHL group. Furthermore, there was an interaction between structure and plausibility (F=30.8, p<.001). Participants were more influenced by plausibility for double object than prepositional object sentences.

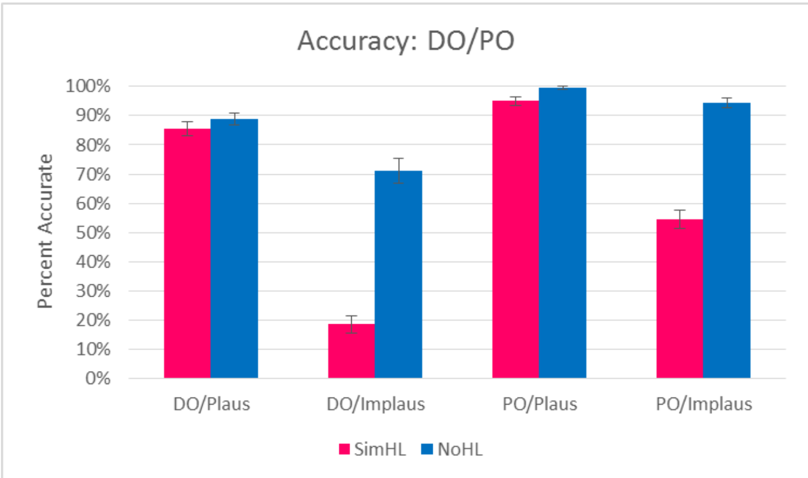

Figure 3: Accuracy: DO/PO

There was nearly an interaction between structure, plausibility, and group (F=3.6, p=.062). Participants in the SimHL group were more influenced by plausibility on double object sentences than the NoHL group.

4.2.2 Active/Passive & Possible/Impossible

There was a main effect of group: participants in the SimHL group (mean: .93) were less accurate than participants in the NoHL group (mean: .99, F=17.6, p<.001). There was also a main effect of structure: participants in both groups were less accurate for the passive construction (mean: .95) than the active construction (mean: .97, F=4.4, p>.05). While participants were less accurate for impossible sentences (.95) than possible (.97) the effects of plausibility were not significant (p=.067). There were no significant interaction effects.

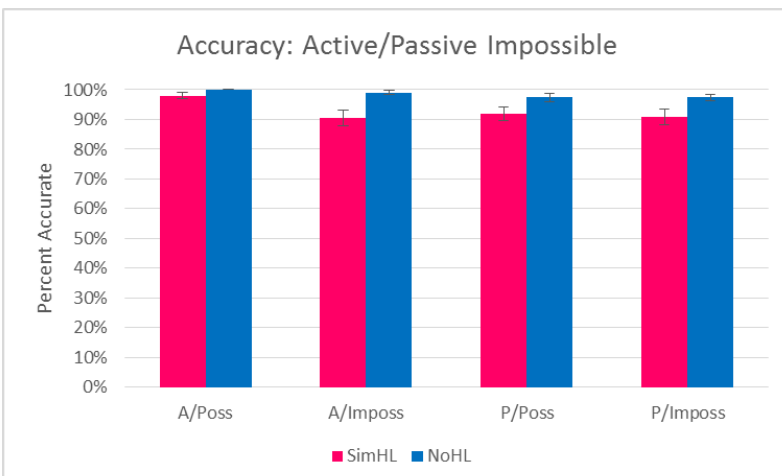

Figure 4: Accuracy: Active/Passive Impossible

Looking at performance on the DO/PO vs. the active/passive alterations, participants were more faithful to the active/passive conditions (mean: .96) compared to the DO/PO (mean: .76, F=47.4, p<.001). There was also an interaction effect between group and structure (F=36.2, p<.001). The difference in performance on DO/PO and active/passive structures was larger for the simulated hearing loss group.

4.3 REACTION TIME

4.3.1 Double Object/Prepositional Object & Plausible/Implausible

There was a main effect of group: participants in the SimHL group had longer reaction times (mean: 1472 ms) than the NoHL group (mean: 1027 ms, F=18.3, p<.001). There was also a main effect of structure. Participants in both groups were slower for the DO construction (mean: 1357 ms) than the PO construction (mean: 1142 ms, F=28.9, p<.001). There was also a main effect of plausibility. Participants took longer to respond to the implausible (mean: 1333 ms) than plausible items (mean: 1166 ms, F=9.6, p<.003). Furthermore, there was an interaction between structure and group (F=15.0, p<.001). Participants in the SimHL group were more influenced by structure than participants in the NoHL group. There was also an interaction effect

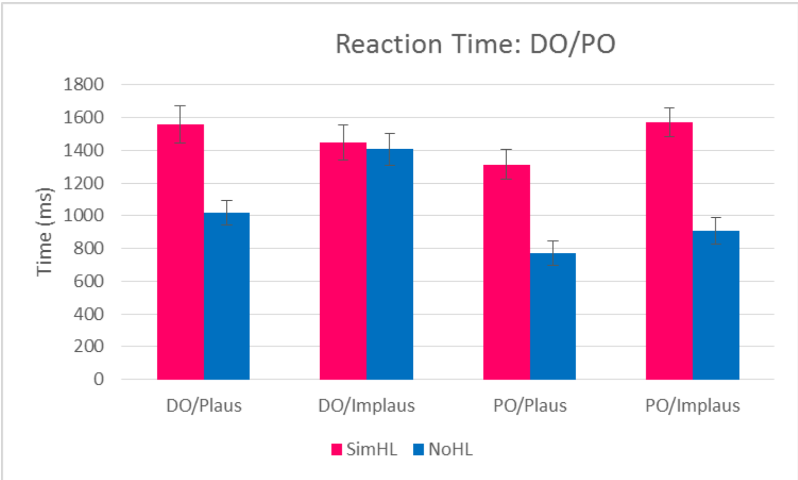

Figure 5: Reaction Time: DO/PO

between structure, plausibility, and group (F=14.9, p<.001). Participants in the simulated hearing loss group were *less* influenced by plausibility for different sentence constructions than participants in the NoHL group. This is the opposite of the pattern in the accuracy data.

4.3.2 Active/Passive & Possible/Impossible

There was a main effect of group: participants in the SimHL group had longer reaction times (mean: 1240 ms) than the NoHL group (mean: 790 ms, F=30.3, p<.001). There was also a main effect of structure; there were faster reaction times for actives (mean: 968 ms) than passive sentences (1062 ms, F=5.3, p<.05). There was also a main effect of plausibility; participants had faster reaction times for the possible (mean: 931 ms) than for the impossible sentences (mean: 1098 ms, F=12.5, p<.001).

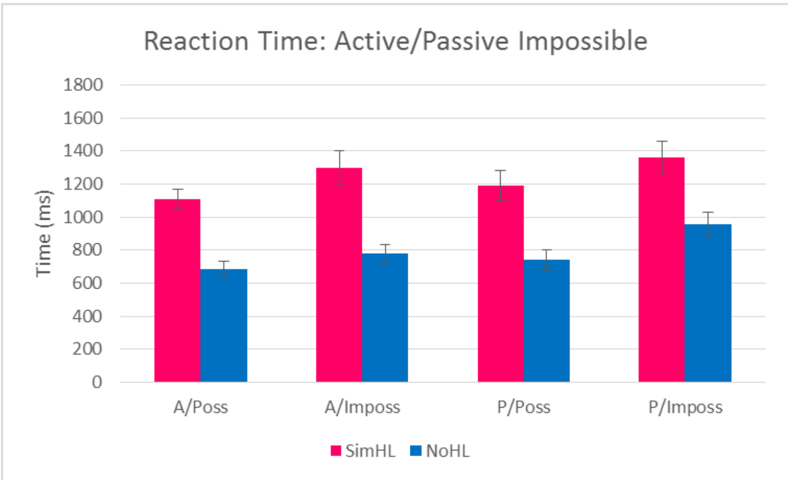

Figure 6: Reaction Time: Active/Passive Impossible

Overall, participants had longer reaction times for the DO/PO construction (mean: 1230 ms) than the active/passive sentence construction (mean: 1015 ms, F=47.4, p<.001).

4.4 EYE-TRACKING

The following measures were collected on eye-tracking: mean latency to fixate on the target image after the POD and the sentence-offset, the mean number of fixations on the target image after the POD and the sentence-offset, the proportion of gazes at the target image after the POD and the sentence offset, and the proportion of *first* fixations at the target image following disambiguation. Table 8 shows a summary of the eye-tracking measurement data and the main effects.

4.4.1 Latency to Fixate on Target Image

The mean latency of first target fixation represents how long it took for participants to gaze at the target image after a particular part of the sentence (the POD or sentence-offset). This was a measure of how quickly after participants were able to identify the sentence's literal syntax that they could identify the target image. The lower the latency, the easier it was for participants to identify the target image. It was predicted that latency would be higher in conditions where there was more competition between the syntax and semantics (i.e., DO-impossible) or if the group had a higher degree of uncertainty (i.e., SimHL). This measure was only collected on trials where participants' response was correct (faithful to the literal syntax).

	DO/PO			Active/Passive		
Measure	Effect	Mean	Significance	Effect	Mean	Significance
Latency - disamb (ms)	NoHL	1293	p<.010	NoHL	1076.699	p<.001
	SimHL	1546		SimHL	1377.299	
	DO	1149	p<.001	Active	843.0651	p<.001
	PO	1690		Passive	1610.933	
	Plaus	1390	ns	Poss	1191.396	p<.030
	Implaus	1450		Imposs	1262.602	
Latency - sent-off (ms)	NoHL	918	p<.001	NoHL	723.9713	p<.001
	SimHL	1179		SimHL	1022.038	
	DO	1149	p<.001	Active	843.0651	ns
	PO	947		Passive	902.9439	
	Plaus	1006	ns	Poss	809.5291	p<.001
	Implaus	1091		Imposs	936.4799	
Mean # Fix - disamb	NoHL	6.5	p<.020	NoHL	5.3875	p<.003
	SimHL	7.4		SimHL	6.3275	
	DO	6.2	p<.001	Active	4.7275	p<.001
	PO	7.7		Passive	6.9875	
	Plaus	6.8	p<.040	Poss	5.57	p<.002
	Implaus	7.1		Imposs	6.145	
Mean # Fix - sent-off	NoHL	5.2	p<.003	NoHL	4.28625	p<.001
	SimHL	6.4		SimHL	5.40875	
	DO	6.2	p<.001	Active	4.7625	ns
	PO	5.4		Passive	4.9325	
	Plaus	5.6	p<.030	Poss	4.485	p<.001
	Implaus	6.0		Imposs	5.21	
Proportion Fix - disamb	NoHL	0.64	p<.001	NoHL	0.674731	p<.001
	SimHL	0.55		SimHL	0.628074	
	DO	0.55	p<.001	Active	0.677272	p<.001
	PO	0.63		Passive	0.625534	
	Plaus	0.62	p<.001	Poss	0.596564	p<.001
	Implaus	0.57		Imposs	0.706241	
Proportion Fix - sent-off	NoHL	0.67	p<.001	NoHL	0.717832	p<.001
	SimHL	0.56		SimHL	0.649934	
	DO	0.55	p<.001	Active	0.677272	ns
	PO	0.68		Passive	0.690494	
	Plaus	0.64	p<.001	Poss	0.640015	p<.001
	Implaus	0.59		Imposs	0.727751	
Proportion First Fix -disamb	NoHL	0.47	ns	NoHL	0.559695	ns
	Simhl	0.50		SimHL	0.554702	
	DO	0.44	p<.030	Active	0.631503	p<.001
	PO	0.53		Passive	0.482894	
	Plaus	0.51	p<.020	Poss	0.46756	p<.001
	Implaus	0.46		Imposs	0.646838	

Table 8: Eye-tracking Measurements

4.4.1.1 Latency to Fixate on Target Image after the POD

For the DO/PO condition, there was a main effect of group: participants in the SimHL group took longer to fixate on the target image after the POD (mean: 1546 ms) than the NoHL group (mean: 1293 ms, F=9.9, p<.005). There was also a main effect of structure. Participants were overall slower for the PO (mean: 1690 ms) than for the DO structure (mean: 1150 ms, F=130.9, p<.001). There was also an almost-significant interaction of structure and plausibility (F=3.8, p=.056). Participants were more influenced by plausibility in the DO compared to the PO condition.

For the active/passive condition, there was also a main effect of group. Participants in the SimHL group took longer to fixate on the target image (mean: 1377 ms) than the NoHL group (mean: 1077 ms, F=30.8, p<.001). There was also a main effect of structure: participants took longer to fixate on the target image for the passive (mean: 1611 ms) than the active structure (mean: 843 ms, F=522.8, p<.001). There was also a main effect of plausibility. Participants took longer to fixate on the target image for impossible (mean: 1263 ms) than for possible sentences (mean: 1191 ms, F=5.4, p<.03).

4.4.1.2 Latency to Fixate on Target Image after the Sentence-offset

For the DO/PO condition, there was a main effect of group. Participants in the SimHL group took longer to fixate on the target image (mean: 1179 ms) than the NoHL group (918 ms, F=10.4, p<.001). There was also a main effect of structure. Participants took longer to fixate on the target image for the DO (mean: 1149 ms) than the PO structure (947 ms, F=19.0, p<.001).

For the active/passive condition, there was also a main effect of group. Participants in the SimHL group took longer to fixate on the target image (mean: 1022 ms) than the NoHL group (724 ms, F=30.4, p<.001). There was also a main effect of plausibility. Participants took longer to fixate on the target image for the impossible (mean: 937 ms) than the possible sentences (mean: 810 ms, F=16.6, p<.001). Finally, there was an interaction effect between structure and plausibility (F=5.4, p<.023). Participants' latency to fixate on the target image was more influenced by structure in impossible than possible conditions.

4.4.2 Mean Number of Fixations

The mean number of fixations represents the number of fixations on both the target and competitor image following a particular part of the sentence (the POD or sentence-offset) until the participant's response. This was a measure of how much competition there was between the faithful and unfaithful interpretations of the sentence. More fixations means there was more competition between the literal and non-literal interpretations. It was predicted that the number of fixations would be greater in conditions where there is more competition between the syntax and semantics (i.e., DO-impossible) and in the group with higher uncertainty about the perceived linguistic signal (i.e., SimHL).

4.4.2.1 Mean Number of Fixations after the POD

For the DO/PO condition, there was a main effect of group. Participants in the SimHL group had more fixations (mean: 7.4) than the NoHL group (mean: 6.5, F=6.5, p<.002). There was also a main effect of structure: participants had more fixations for the PO (mean: 7.7) than the DO structure (mean: 6.1, F=79.0, p<.001). This is the opposite of what was expected, since the DO structure should have greater uncertainty than the PO structure. There was also a main effect of plausibility: participants had more fixations for implausible (mean: 7.2) than for plausible sentences (mean: 6.8, F=4.8, p<.040). There was a three-way interaction between group, structure, and plausibility (F=10.5, p<.003). Participants in the simulated hearing loss group were more influenced by structure for different sentence constructions but not plausibility than participants in the NoHL group. That is, the SimHL group showed larger differences in the number of fixations between the different structure than the NoHL group did (mean difference between DO and PO, SimHL: -1.86, NoHL: -1.26).

For the active/passive condition, there was a main effect of group. Participants in the SimHL group (mean: 6.3) had more fixations than the NoHL group (mean: 5.4, F=10.5, p<.003). There was also a main effect of structure, participants had more fixations for the passive (mean: 7.0) than the active structure (mean: 4.7, F=256.1, p<.001). There was also a main effect of plausibility: participants had more fixations for impossible (mean: 6.1) than for possible sentences (mean: 5.6, F=12.8, p<.002).

4.4.2.2 Mean Number of Fixations after the Sentence-offset

For the DO/PO condition, there was a main effect of group. Participants in the SimHL group had more fixations (mean: 6.4) than NoHL group (mean: 5.2, F=10.17, p<.003). There was also a main effect of structure: participants had more fixations for the DO (mean: 6.2) than the PO structure (mean: 5.4, F=28.6, p<.001). There was also a main effect of plausibility: participants had more fixations for implausible (mean: 6.0) than for plausible sentences (mean: 5.6, F=14.3, p<.030). There was also an interaction between structure and group (F=13.4, p<.001). The NoHL group's number of fixations was more influenced by the different sentence structures than the SimHL group (mean difference between DO and PO, SimHL: 0.27, NoHL: 1.45). Finally there was a three-way interaction between group, structure, and plausibility (F=10.3, p<.003). Participants in the NoHL group were more influenced by structure and plausibility than the SimHL group (mean difference between implausible and plausible, SimHL: 0.22, NoHL: .62).

For the active/passive condition, there was a main effect of group. Participants in the SimHL group (mean: 5.4) had more fixations than the NoHL group (mean: 4.3, $F=14.8$, $p<.001$). There was also a main effect of plausibility: participants had more fixations for impossible (mean: 5.2) than for possible sentences (mean: 4.5, $F=20.5$, $p<.001$).

4.4.3 Proportion of Gazes

The proportion of gazes represents the proportion of gazes at the target image following a particular part of the sentence (the POD or sentence-offset) until the participant's response. This was a measure of how much competition there was between the faithful and unfaithful interpretations of the sentence. A lower proportion means more competition from the competitor image. It was predicted that the proportion of gazes towards the target image would be lower in conditions where there is more competition between the syntax and semantics (i.e., DO-impossible) or in the group with higher uncertainty about the perceived linguistic signal (i.e., SimHL).

The measure of proportion of gazes is distinct from the mean number of fixations towards the target image in that participants may show equal proportions of gazes while having a different mean number of gazes. For example, participants may gaze at the target image 2 times and the competitor image 2 times resulting in a proportion of .5 of the gazes towards the target image. They may also gaze at the target image 10 times and the competitor image 10 times. This too would result in a proportion of .5 of the gazes towards the target image; however, the second situation exemplifies more competition between the target and competitor image even though both proportions are equal. Therefore, these proportion of gazes analyses complement the number-of-gaze analyses above.

4.4.3.1 Proportion of Gazes after the POD

For the DO/PO condition, there was a main effect of group. Participants in the SimHL group had a lower proportion of gazes towards the target image (mean: .55) than the NoHL group (mean: .64, $F=64.6$ $p<.001$). There was also a main effect of structure: participants had a lower proportion of gazes towards the target image for the DO (mean: .55) than for the PO structure (mean: .63, $F=35.7$, $p<.001$). There was also a main effect of plausibility: participants had a lower proportion of gazes towards the target image for the implausible (mean: .57) than for the plausible sentences (mean: .62, $F=18.9$, $p<.001$). There was also an interaction effect between group and plausibility ($F=6.9$, $p<.020$). The SimHL group was more influenced by plausibility than the NoHL group. Finally, there was an interaction effect between structure and plausibility ($F=5.3$, $p<.030$). Plausibility influenced the number of fixations more in the DO than the PO structure.

For the active/passive condition, there was a main effect of group: participants in the SimHL group showed a lower proportion of gazes towards the target image (mean: .63) than the NoHL group (mean: .67, $F=13.2$, $p<.001$). There was also a main effect of structure: participants showed a lower proportion of gazes towards the target image for the passive (mean: .63) than the active (mean: .68, $F=27.0$, $p<.001$). Finally, there was a main effect of plausibility: participants had a lower proportion of gazes towards the target image for the possible (mean: .60) as compared to the impossible (mean: .71, $F=101.4$, $p<.001$).

4.4.3.2 Proportion of Gazes after the Sentence-offset

For the DO/PO condition, there was a main effect of group. Participants in the SimHL group had a lower proportion of gazes towards the target image (mean: .56) than the NoHL group (mean: .67, F=67.9 p<.001). There was also a main effect of structure: participants had a lower proportion of gazes towards the target image DO (mean: .55) than for PO structure (mean: .68, F=78.7, p<.001). There was also a main effect of plausibility, participants had a lower proportion of gazes towards the target image for the implausible (mean: .59) than for the plausible sentences (mean: .64, F=13.7, p<.001). There was also an interaction effect between group and plausibility (F=13.8, p<.001). Participants in the simulated hearing loss group were more influenced by plausibility information than participants in the NoHL group. Finally, there was an interaction effect between structure and plausibility (F=4.9, p<.030). Proportion of gazes to the target image were more influenced by plausibility in the DO compared to the PO structures.

For the active/passive condition, there was a main effect of group: participants in the SimHL group showed a lower proportion of gazes towards the target image (mean: .65) than the NoHL group (mean: .72, F=19.5, p<.001). There was also a main effect of plausibility: participants showed a lower proportion of gazes towards the target image for the possible (mean: .64) than the impossible (mean: .73, F=48.5, p<.001). This pattern is the opposite of the pattern seen for most other analyses of eye-tracking data.

4.4.4 Proportion of First Target Fixations after POD

This measurement represents the proportion of first fixations following the POD that were on the target. This is a measure of how likely it is that the first picture gazed at following the POD is the target image. A lower number means there was more competition between the faithful and non-faithful interpretation of the syntax. It was expected that the proportion would be lower where there was more competition between the syntax and semantics of the sentence (i.e., DO-Imposs) and for the group with more uncertainty (i.e., SimHL).

For the DO/PO condition, there was no main effect of group ($p>.1$). There was, however, a main effect of structure. Participants showed a lower proportion of first fixations on the target image for the DO (mean: .44) as compared to the PO structure (mean: .53, $F=9.8$, $p<.002$). There was also a main effect of plausibility: participants had a lower proportion of first fixations on the target image for the implausible (mean: .46) than the plausible sentences (mean: .51, $F=5.3$, $p<.03$). There was also an interaction between group and structure ($F=5.9$, $p<.018$): the NoHL group was more influenced by structure than the SimHL group. There was nearly an interaction between structure and plausibility ($F=3.9$, $p=.051$). Participants were more influence by plausibility in the DO as compared to the PO condition.

For the active/passive condition there was also no main effect of group ($p>.8$). There was, however, a main effect of structure. Participants showed a lower proportion of first fixations on the target image for the passive (mean: .48) as compared to the active structure (mean: .63 $F=33.4$, $p<.001$). There was also a main effect of plausibility: participants had a lower proportion of first fixations on the target image for the possible (mean: .47) than the impossible sentences (mean: .65, $F=45.5$, $p<.001$). This is again unexpected, and in the opposite direction from other effects of plausibility in the eye-tracking data.

5.0 DISCUSSION

This study aimed to answer the following four questions:

1. How will sentence structure and plausibility influence fidelity to a perceived sentence?
2. How does the absence or presence of simulated hearing loss affect one's fidelity to a perceived sentence?
3. How does absence or presence of simulated hearing loss affect one's consideration of target and non-target interpretations of a sentence as measured through eye-tracking and reaction time data?
4. How does individuals with simulated hearing loss' performance on the Gibson task compare to individuals with aphasia's performance?

The discussion will explore how the results answer these questions and possible explanations.

5.1 SENTENCE STRUCTURE & PLAUSIBILITY

The results were consistent with the predictions set forth by Gibson et al. (2013) that participants are (1) more faithful to a linguistic signal when more edits are needed to switch between interpretations and (2) more faithful to a linguistic signal when a distortion involves an insertion rather than a deletion. Consistent with prediction (2), participants were more faithful to PO sentences than DO. This is because to switch from a PO to a DO, participants must assume the speaker accidently inserted the word “to” while to switch from a DO to a PO, participants must assume the speaker accidently omitted the word “to.” Furthermore, participants were overall more accurate for the active and passive constructions than for the DO and PO constructions. This is consistent with prediction (1), because actives and passives require two edits to switch between alterations while DOs and POs involve one edit. Thus, individuals with and without stimulated hearing loss also partake in rational sentence processing.

Participants were also less accurate for the passive compared to the active sentences. This was consistent with findings by Gibson et al. (2013), Gibson et al. (2015), and Warren et al. (2015) who found participants are less likely to be faithful to a passive as opposed to an active. These findings contradict the noisy channel model presented by Gibson et al. (2013) that suggests that participants will be less faithful to the literal syntax when distortions involve deletions (i.e., actives) rather than insertions (i.e., passives). Warren at al. (2015) suggest the combination of low structural frequency and high complexity results in PWA having “lower quality representations” of passive sentences as compared to active sentences. This low quality representation makes the passive structure “unreliable” and results in fewer faithful interpretations of passive sentences. However, while this explanation may be applicable to individuals with aphasia and individuals with long-term hearing loss, it cannot explain why individuals with simulated hearing loss may act in this way. This is because the two experimental groups–SimHL and NoHL–did not have any history of hearing loss or communication disorders and thus, their linguistic representations should be intact. There are, however, two other possible explanations for why individuals with simulated hearing loss may be less faithful to passives than actives than individuals with no hearing loss.

(1) Passive sentences have less reliable structure than active sentences. This is because passive sentences contain more small and easily reduced function words (i.e., “was” and “by”) that are easy to miss in a given linguistic signal. These function words, although small, are important cues for the direction and meaning of the sentence. Thus, because passives have more easily reduced words and because individuals in the SimHL group had degraded linguistic input, the passive structure has increased “uncertainty” and as a result, is relied on less.

(2) Individuals with simulated hearing loss are already expending a majority of their processing resources to simply perceive the sentence. As a result, there are fewer resources available to parse more linguistically complex structures like passives. Thus, individuals with simulated hearing loss are more likely to “fall back” on their semantic knowledge because they have expended all of their processing resources simply perceiving the sentence.

When deciding which of these two possible explanations best fit the results at hand it is important to consider performance on sentence constructions other than passive and actives as this may provide supporting evidence for one explanation over the other. If, for example, explanation (1) is true, and individuals with simulated hearing loss rely less on passive structures because the high number of easily reducible words reduces the reliability of the structure and increases uncertainty, then similar results should be evident in the PO sentences that contain the word “to.” This is because individuals with simulated hearing loss should equally as likely to fail to hear the acoustically-reduced function word “to” as they would be to miss “was” or “by”. However, this is not the case, and in fact, individuals with simulated hearing loss are much more likely to remain faithful to PO sentences containing “to” than DO sentences.

Because individuals with stimulated hearing loss remain more faithful to POs that contain the function word “to” it seems more probable that passive constructions result in fewer faithful interpretations because individuals with simulated hearing loss are expending a majority of their processing resources on perceiving the signal. This hypothesis is consistent with studies finding that individuals with simulated hearing loss not only report more effort necessary to process a given sentence, but also, that individuals with hearing loss take longer to parse a given sentence, particularly if that sentence is more complex or lower in frequency (Carroll & Ruigendijk, 2013; Larsby et al., 2005; McCoy et al., 2005; and Wendt, Kollmeir, & Brand, 2015). It is also consistent with the results of the present study that indicates the SimHL group reached ceiling in terms of expenditure of processing resources. The SimHL group shows consistent high reaction times across conditions regardless of a particular structure’s accuracy score. This is particularly evident in the DO/PO alteration, where individuals with simulated hearing loss have robust differences in accuracy between DO possible (mean: .86) and DO impossible constructions (mean: .19) but have disproportionately similar reaction times (mean: 1556 ms, 1447 ms respectively). The structure-by-plausibility-by-group interaction in the reaction time data for the DO/PO condition further supports this. The pattern shows that it is the NoHL group that drives the structure by group interaction, not the SimHL group. This is because the NoHL has available processing resources to adjust their effort on a more complex sentence condition (i.e., DO impossible vs. DO possible) while the SimHL group has reached ceiling and shows relatively consistent RTs across conditions. Thus, the data are more consistent with explanation (2): individuals with SimHL are less faithful to passives as compared to actives because of a lack of available processing resources.

In terms of plausibility, results for the DO/PO and active/passive conditions were consistent with the prediction: participants were less accurate for the less plausible constructions. For the DO/PO structure, participants in the SimHL group were more influenced by plausibility than the NoHL group. This aligns with the notion that individuals with simulated hearing loss, as a result of being less certain about perceived input, are more likely to fall back on semantic knowledge. Similar to how PWA rely more on semantic knowledge (Gibson et al., 2013; Warren et al., 2015), individuals with high amounts of uncertainty may be more likely to rely on semantic knowledge as a means to increase the likelihood of a successful communicative exchange. This effect of relying on semantics is exacerbated in the structures both participants have lower accuracy scores for (i.e., DO and improbable). Reaction time data showed main effects of plausibility in both DO/PO and active/passive conditions. Participants had longer reaction times in the less probable constructions. This suggests that when syntax does not align with semantic knowledge, participants have increased uncertainty and thus, spend more time considering the alternate interpretation.

5.2 HEARING CONDITION

Results showed that the presence of simulated hearing loss significantly affected an individual's fidelity to a linguistic signal. Individuals with simulated hearing loss were less faithful to the literal syntax than individuals without simulated hearing loss in all conditions. This finding complements Gibson et al.'s (2013) prediction and findings that when there is more noise in a linguistic signal (for example, when there are many grammatical errors in a set of sentences), individuals are less faithful to the literal syntax and more likely to choose a more probable meaning. This also complements the findings by Gibson et al. (2015) and Warren et al. (2015) that individuals with aphasia are less faithful to literal input. Thus, this set of findings supports the idea that individuals are aware that there may be more noise in their language processing mechanism and can adapt their reliance on the linguistic signal in a relatively short period of time. The Gibson task took approximately 15 minutes to complete. Thus, participants were, in a matter of minutes, able to change their reliance on their language processing mechanism. Thinking about this through the lens of the rational approach to language processing, this implies individuals may rapidly adjust their uncertainty about the linguistic signal. Levy (2011) and Levy (2009) suggest that language users use *all* available information available to make predictions about information that is likely to occur next, and to revise information they have already parsed in a given sentence. The fact that participants adapted to the temporarily increased noise feeding into their language processing mechanism suggests that individuals are also able to use information about the quality of input to their language processing ability when parsing a sentence. In the case of individuals with stimulated hearing loss, participants adapted to a level of increased uncertainty resulting in less fidelity to the linguistic signal.

While individuals in Levy (2011) and Levy (2009) were able to adapt to the instantaneous increases in uncertainty in a particular grammatical construction (i.e., locative inversions or near neighbor substitutions), individuals with simulated hearing loss make somewhat longer-lasting adaptations to their uncertainty for the duration of the Gibson task. It would be particularly interesting to examine how individuals with simulated hearing loss would perform on a similar task with unmodified sentence stimuli immediately following the simulated hearing loss—would the increase in uncertainty be maintained or would it be eliminated as soon as the quality of the signal was restored? How easily is it to switch between levels of low and high uncertainty, especially when uncertainty is maintained for a relatively long period of time? While Levy (2008), Levy (2009), Gibson et al. (2013), Gibson et al. (2015), Warren et al. (2015) and the present study show that participants are relatively apt at adjusting uncertainty levels between individual sentence stimuli, in the face of relatively consistent noise, how easy is it to revert back to low levels of uncertainty? This would be particularly interesting to examine in the context of individuals with hearing loss—would unaided individuals reduce uncertainty immediately upon being fitted for hearing aids? Wendt et al. (2015) found that individuals with hearing loss who did not use hearing aids had longer processing times as evident through eye-tracking for sentences than individuals who did use hearing aids, even though both groups had similar hearing thresholds and were presented sentence stimuli at the same speech recognition threshold (SRT). Thus, perhaps, participants who did not use hearing aids were not used to the higher SRT and maintained a high level of uncertainty during the task. On the other hand, this may relate to Warren at al.'s (2015) discussion of the low quality representations of certain sentence structures that individuals with aphasia (and possibly individuals with long-term hearing loss) may have. Perhaps individuals who did not typically use hearing aids had lower quality representations of sentences that affected processing time regardless of the quality of the input. These representations of grammatical constructions may be more difficult to adjust than levels of uncertainty.

5.3 EYE-TRACKING MEASURES

In all eye-tracking measures, except for proportion of first target fixations after POD, there was a main effect of group, with participants in the simulated hearing loss group: (1) exhibiting more competition between the target and competitor image (as evident through measures of mean number and proportion of fixations); and (2) exhibiting more difficulty identifying the image faithful to the literal syntax (as evident through mean latency measures). This confirms the predictions that participants with simulated hearing loss have higher competition between the competitor images and by extension, the two possible interpretations of the sentence. This is likely because individuals with simulated hearing loss have higher levels of uncertainty about the perceived linguistic signal. Because the auditory input they receive is degraded, they must more seriously consider alternate interpretations of a sentence than their NoHL counterparts. The greater consideration of the competitor image (as well as the longer latency to gaze at the target image, even for trials where they choose it as the correct interpretation) also suggests that overall, individuals with simulated hearing loss are expending more processing resources deciding which image is faithful to the literal syntax. This is another way in which the simulated hearing loss group expends more processing resources leaving less resources available to comprehend more complex sentences.

Effects of structure and plausibility were also evident in the eye-tracking data. For the most part, these measures indicated that individuals had more competition between images or difficulty identifying the target image in structure and plausibility conditions where accuracy scores were lower (i.e., DO, passive, implausible, impossible). This makes sense because lower accuracy scores indicate that participants failed to correctly identify the target image. The fact that participants showed this both in proportion measures and mean number of fixation numbers indicates that when participants selected inaccurate interpretations, it was not a simple process in which they gazed only at the inaccurate interpretation. Rather, participants were jumping back and forth between images (evident through higher mean number of fixation numbers). Thus, lower accuracy scores don't only mean that participants selected the image that was unfaithful to the literal syntax but also that they had more competition when deciding between these images.

Thus, it seems that rational sentence processing is not an effortless task. While syntactic and semantic priors can point us in the direction of the more probable sentence, when deciding between two possible interpretations of sentence, individuals must expend processing resources when deciding between the two. Maybe this is another reason why individuals with simulated and real hearing loss have difficulty understanding more complex sentences. In addition to having to exert more processing resources to perceive a given sentence, individuals with simulated or real hearing loss are jumping back and forth between possible alternatives to a sentence, thus they must (1) exert effort to constantly reanalyze the sentence, or revisit an interpretation they are uncertain of, and (2) inhibit the alternative interpretation.

An unexpected result in the eye-tracking data was in the mean number of fixations after the POD—there was a main effect of structure, in which participants had more fixations for PO than DO structures. This is opposite of the accuracy data, which showed lower accuracy scores for the PO as opposed the DO structures. This is surprising because as prediction (2) of Gibson et al. (2013) claims, individuals should be more faithful to the literal syntax (and thus, should show less competition) when an edit involves an insertion rather than a deletion. Because this effect is only evident after the POD, in this case the offset of "to," this effect may be a result of the reduction of the word "to." In the simulated hearing loss files in particular, it is likely that the word "to" (because it is easily reduced and contains high frequency information) was very

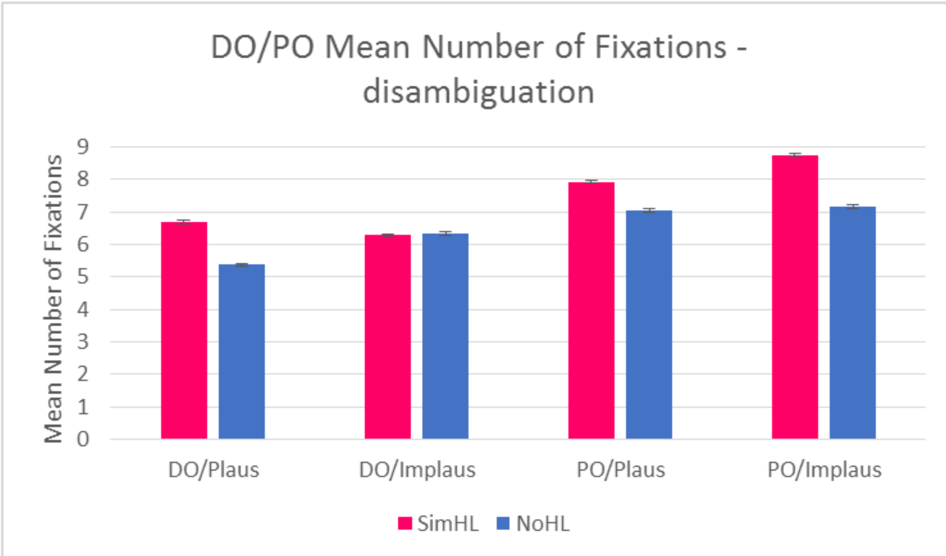

Figure 7: Mean Number of Fixations DO/PO disambiguation

difficult to hear. This is supported by the finding that for mean number of fixations after the POD for DO/PO there was a three way interaction between group, structure, and plausibility with the SimHL group being more influenced by structure than the NoHL group. Other measurements like reaction time and mean number of fixations after sentence offset for DO/PO, showed that the NoHL group was more influenced by structure. This opposite effect for mean number of fixations after the POD for DO/PO may be an indication that the SimHL group was having more difficulty interpreting POs because in addition to "to" being a reduced word, it was more difficult to hear as a result of the low pass filter. Thus, although this condition contains an "insertion" participants don't hear this word but rather, hear what seems to be a gap in the speech signal. This "gap" in the signal is different from what participants hear in the DO construction because in the DO there is no extended silence between the two noun phrases. Rather, immediately following the second noun phrase participants hear the third noun phrase. In the PO, participants, especially in the SimHL group, may not hear "to" because it has been sufficiently reduced, and as a result, more time would elapse between the two noun phrases. As a result, participants must more seriously consider the possible interpretations of the PO sentence, because they have to determine whether or not the "gap" they heard in the speech signal was because the sentence was a DO, or because they missed a word. This effect might be especially pronounced right after the POD for PO sentences, which is the "to."

It would be interesting to see if individuals with long-term high frequency hearing loss would also show increases in the mean number of fixations following the POD for PO sentences. This may not be the case because individuals with hearing loss are used to missing high frequency information and may have made long-term adaptations to degraded input to their language processing mechanism. As a result, they may be more willing to say that a gap in a speech signal was the absence of the "to" (because it contains high frequency information and is easily reduced) than to consider that the sentence was actually a DO.

Another unexpected effect was evident in the proportion of gazes to the target image measurements both after the POD and sentence-offset. For both measurements, participants showed fewer gazes towards the target image for possible actives and passives than for impossible passives and actives. Thus, participants exhibited more competition for the possible as opposed to impossible sentences. One possible explanation of this effect could be because of the nature of the task. Particularly for the active/passive impossible illustrations, impossible illustrations showed improbable and humorous events—for example—pizza eating a boy or a truck driving a man. Maybe, for sentences that were probable and thus, easier to parse, participants had more time to look around the screen, and, interested by the different illustrations, jumped back and forth more often. The ultimate reason for this effect is mysterious.

Eye-tracking results also showed another indication that individuals with simulated hearing loss may reach the ceiling in terms of processing resources available for expenditure. For the DO/PO condition, in the mean number of fixation measurements for both the POD and sentence-offset, there was a three-way interaction between group, structure, and plausibility. This interaction showed that participants in the NoHL group were more influenced, and able to adapt the number of fixations between the images, than the SimHL group. This is identical to the three-way interaction in the DO/PO reaction time data. Again, individuals with simulated hearing loss have higher numbers of fixations between the two images for *all* conditions. This is because they have higher overall uncertainty and exhibit more competition between the two images. Individuals without simulated hearing loss, on the other hand, are able to adjust the amount of effort for each sentence—when a sentence exhibits more completion, like DO-implausible, where its structure may contain a deletion and it doesn't align with one's semantic knowledge, participants with NoHL gaze more than they did at images in the DO-plausible. Individuals with simulated hearing loss, on the other hand, are exhibiting competition all of the time, not just in the more difficult structures. As a result, the SimHL group doesn't exhibit as much variation between the different conditions as the NoHL group. This is another indication that individuals with simulated hearing loss and real hearing loss expend most of their processing resource perceiving the sentence and analyzing competing interpretations—this leaves less resources available for other processes like the parsing of complex sentence structures. This may explain why individuals with hearing loss and without hearing loss in the face of noise have more difficulty parsing more complex structures (Carroll & Ruigendijk, 2013 and Wingfield et al., 2006).

Another interesting finding was the tendency of the SimHL to be more influenced by plausibility and the NoHL group to be more influenced by structure. Interactions between group and structure were found in three measures: mean number of fixations after sentence-offset, proportion of gazes to the target image after sentence-offset, and the proportion of first gazes to the target after the POD. In all of these three interactions, the NoHL group was more influenced by the structure of the sentence than the SimHL group. On the other hand, interactions between group and plausibility were found in two measures: proportion of gazes after the POD and proportion of gazes after the sentence onset. In these interactions, individuals in the SimHL group were more influenced by plausibility than the NoHL group. This suggests that individuals with simulated hearing loss are less sensitive to syntactic information in a given linguistic signal.

This could because individuals with simulated hearing loss lack available processing resources to further examine the structure of the sentence. Recall that Carroll & Ruigendijk (2013) and Wingfield et al. (2006) found that individuals with and without hearing loss have more difficulty interpreting complex sentences in the face of noise. When participants listen to sentences in noise, they must expend additional processing resources to perceive the study and, as evident through eye-tracking, consider alternate interpretations more. On the other hand, semantic information may be less demanding of processing resources and thus, individuals with simulated hearing loss tend to rely on it more. Semantic information is less demanding because it may be more easily available—when gazing at two images or listening to a sentence, a participant can easily identify which image is possible and which is impossible. It is much more demanding, on the other hand, to identify which image matches with a syntactic representation for a sentence, particularly one that listeners may be uncertain about. Perhaps, because the NoHL group has more processing resources available and tends to rely more on syntactic information, this is the preferred and more reliable cue to the intended meaning of a sentence. On the other hand, perhaps semantic cues are relied on more when syntactic knowledge becomes difficult to access, for example because the words that provide cues to syntactic structure are difficult to perceive (as in simulated hearing loss) or because of a language impairment like aphasia. Thus, this may indicate a general preference for syntactic cues over semantic cues when processing resources are available.

5.4 SIMULATED HEARING LOSS & APHASIA

One of the aims of this study was to examine how individuals with simulated hearing loss would perform on the Gibson task as compared to individuals with aphasia. It was predicted that individual with simulated hearing loss would outperform PWA because the noise to their language processing mechanism is more peripheral. Individuals with simulated hearing loss still have intact syntactic representations and semantic knowledge while individuals with aphasia often have deficits in these areas. Below shows a side by side comparison of the results of the present study and Warren et al. (2015), recall that both studies used the same version of the Gibson task.

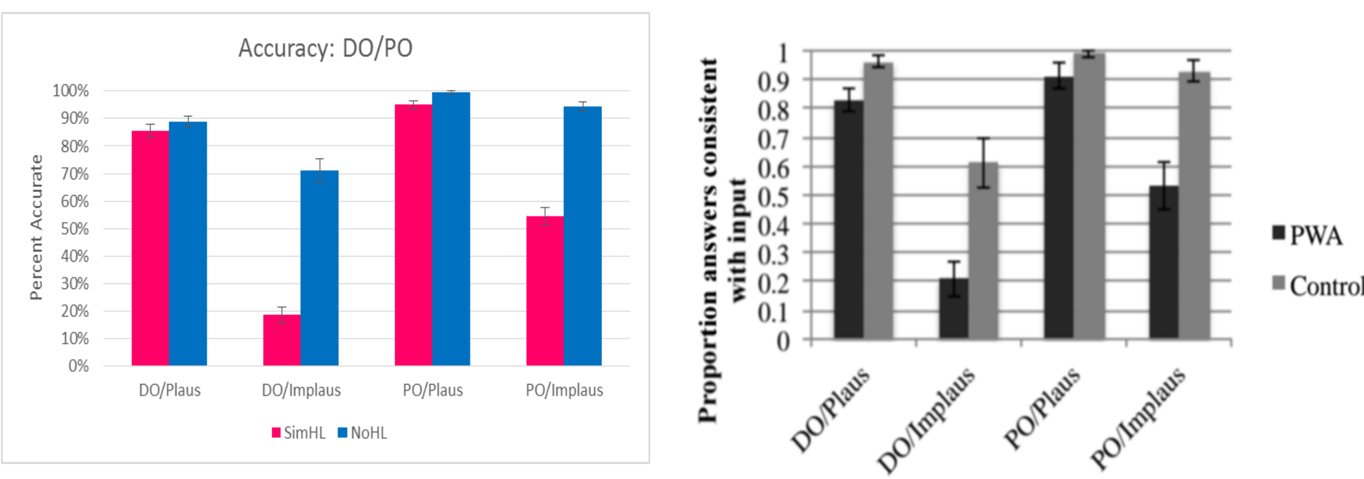

Figure 8: DO/PO, SimHL vs. Aphasia

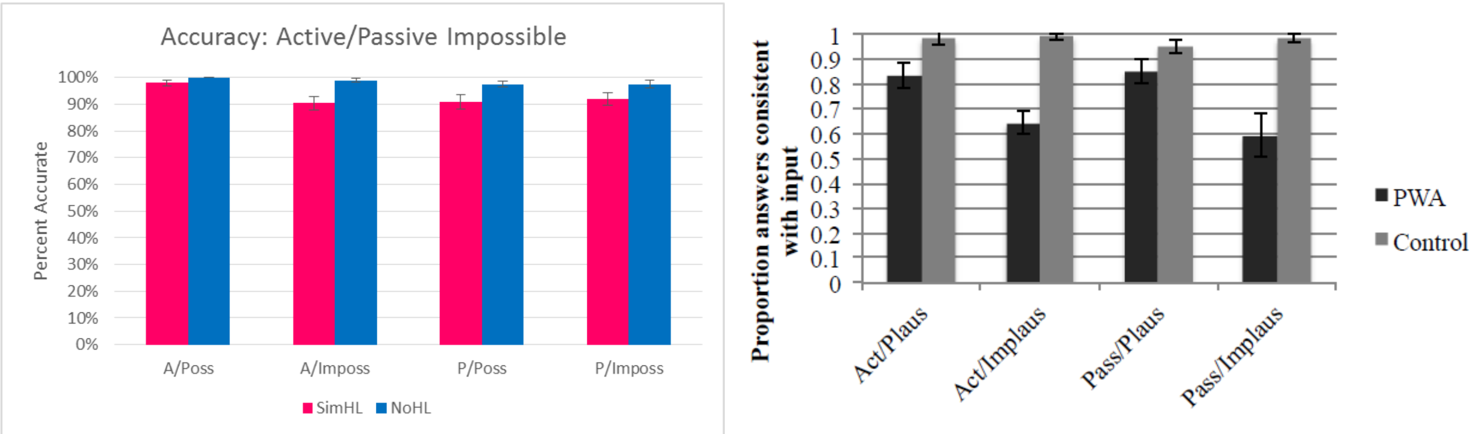

Figure 9: Active/Passive, SimHL vs. Aphasia

The performance of individuals with simulated hearing loss mirrored the performance of PWA in the DO/PO condition, while the simulated hearing loss group outperformed PWA in the active/passion condition. The difference in performance in the active/passive condition aligns with the original predictions of the study. This may relate to the representations of different grammatical construction individuals with simulated hearing loss and PWA have in their memory. Because PWA have consistent noise to their language processing mechanism, their representations of passive sentences may be low quality resulting in less faithful interpretations. For the simulated hearing loss group, on the other hand, they should have high quality representations of passives because prior to the session, as they have previously had typical input to their language processing mechanism. For this reason, we see more fidelity to passives in the simulated hearing loss group as compared to PWA.

However, this does not explain why individuals with simulated hearing loss and PWA performed almost identically on the DO/PO alteration. Perhaps, in conditions where edit distance is small (1 edit), different amounts of noise or different types of noise affect one’s fidelity to a linguistic signal relatively similarly. Warren et al. (2015) examined the relationship between PWAs performance on semantic and syntactic measures and performance on the Gibson task;

they found no significant correlations. Perhaps, certain structures are more susceptible to uncertainty than others. In structures like the DO and PO where one small edit involving an easily reduced word (“to”) can result in a significant meaning difference, only a small amount of noise is needed to cause individuals to be unfaithful to the literal syntax. Thus, it makes no difference if individuals experience peripheral or central noise, or, in the case of Warren et al. (2015), individuals have different degrees of central semantic or syntactic impairment. Because the uncertainty about this structure is already so high, since the two structures are separated by only a single word, any amount of noise may push individuals towards an unfaithful interpretation.

6.0 CONCLUSION

The results of this study were consistent with the predictions set forth by Gibson et al. (2013). They show that individuals with and without simulated hearing loss partake in rational sentence inferencing. Furthermore, participants with simulated hearing loss had lower accuracy scores, indicating that individuals with simulated hearing loss, because of a higher degree of uncertainty, were less faithful to the literal input. Individuals with simulated hearing loss also exhibited longer reaction times, suggesting that more processing resources were necessary to parse the sentences they were listening to. It also appeared that individuals with simulated hearing loss reached a ceiling in terms of available processing resources—reaction times for the simulated hearing loss group were high for all sentence and plausibility conditions, while the no hearing loss group was more able to adapt their expenditure of resources based on a given sentences' complexity. Eye-tracking results revealed that both participants with and without simulated hearing loss showed more competition between the two possible interpretations for more complex conditions (i.e., conditions where participants tended to show lower accuracy scores: DOs, passives, implausible sentences). Individuals with simulated hearing loss showed more competition between interpretations than individuals with no hearing loss. Eye-tracking results also indicated that individuals with simulated hearing loss reached a ceiling in terms of processing resources available to interpret sentences in the face of uncertainty: they were less affected by differences in sentence structure and plausibility than the NoHL group in the number-of-fixations analyses. Finally, while individuals with simulated hearing loss performed better than individuals with aphasia in the active/passive constructions, their performance was mirrored in the DO/PO condition indicating that structures with smaller edit distances may be more susceptible to uncertainty.

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