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Perceptual compensation in individuals with autism spectrum disorders

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PERCEPTUAL COMPENSATION IN INDIVIDUALS WITH
AUTISM SPECTRUM DISORDERS

A Thesis

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of

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by

Elizabeth Anne Langston

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West Lafayette, Indiana

To my family and friends who have always supported me and my trust in the Lord.

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ABSTRACT

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Compensation for coarticulation is the extent in which an individual perceives the contextual variations of speech. When presented with an ambiguous consonant-vowel segment (e.g., a consonant halfway between /sa/ and /fa/) research illustrates that a listener is likely to compensate for coarticulation with the following vowel. Therefore, a listener will be more likely to report an ambiguous speech sound as /s/ when it occurs before [u] than before [a]. Previous results have suggested that, within neurotypical individuals, the degree to which individuals compensate for coarticulation may be related to their Autism Quotient (AQ; Yu, 2010). However, this research did not examine individuals with an autism spectrum disorder (ASD). The current study extends this research by exploring compensation for coarticulation in individuals with an ASD as compared to neurotypical peers in a phoneme classification task (labeling an ambiguous phoneme as either /s/ or /f/). Results from a generalized linear mixed effect model suggest that while there are no differences in how the clinical and neurotypical population compensate for coarticulation, there is a difference in how these two cohorts categorize phonemes. Individuals with an ASD illustrate a gradient categorization slope, while neurotypical individuals show a categorical response curve.

INTRODUCTION

According to the Centers for Disease Control (CDC), the prevalence of autism spectrum disorder (ASD) is approximately one in every sixty-eight individuals (2014). This high rate requires additional research into the understanding of traits and the fundamental differences individuals with autism have when processing speech. The present study focuses on speech perception in order to not only inform theoretical research on ASD but also to expand the knowledge that may help develop clinical trials, modify therapies, and provide better educational experiences for affected individuals. While aspects of speech production may be impaired in individuals with ASD, the ability to process auditory perceptual information may remain intact, if not enhanced (Bonnell et al., 2003).

A variety of theories have been put forth to explain not only deficits, but also areas of strength in ASD. The *Hyper-Systemizing Theory* (HS) suggests perseveration found in individuals with ASD is the result of a better understanding of objects and elements at their most basic level (Baron-Cohen, 2008). The *Weak Central Coherence Theory* (WCC) expands on this idea by suggesting that individuals with an ASD are more likely to focus on the *features* of a perceptual array rather than focus on the *global* configuration of information presented (Baron-Cohen, Ashwin, Ashwin, Tavassoli, & Chakrabarti, 2009). Thus, individuals with ASD may excel in understanding the specific

details of a given stimulus while having difficulty comprehending the generalized meaning of the stimulus or group of stimuli. The *Enhanced Perceptual Functioning* (EPF) and *Neural Complexity* (NC) hypotheses state that individuals with ASD hold an enhanced perception of simple, low level auditory stimuli and impaired perception of complex auditory information (Stewart & Ota, 2008; Mottron, Dawson, Soulieres, Hubert, & Burack, 2006).

Within the current study, several hypotheses exist with regard to the speech perception of the clinical population with an ASD. As suggested in previous research, individuals with ASD may approach a perceptual listening task in a detail-oriented manner. For example, Heaton, Davis, and Happe (2008) presented a case study of an individual with ASD who identified pitches within words at a rate that was 5.92 standard deviations higher than the control group of typically developing individuals. Similarly, in an event related potentials (ERP) study, Ceponiene et al. (2003) found that while individuals with ASD have the auditory capability to process simple and complex tones, these individuals continue to struggle with sequences of complex tones that resemble speech-like variations.

Although Yu (2010) did not examine individuals with ASD, but rather individuals with high or low levels of autistic traits (using the AQ), results indicate a distinct pattern from the results described above. Yu (2010) explored compensation for coarticulation which requires a listener to consider the context of sounds surrounding a given sound or phoneme. Specifically, in order to assess compensation for coarticulation, Yu (2010) presented adults with a phoneme classification task which required participants to

classify the initial phoneme in a consonant-vowel (CV) syllable as either /s/ or /ʃ/. This initial phoneme was pulled from one of seven points on the continuum between the phonemes /s/ and /ʃ/. These graded phonemes were then paired with the vowels [a] and [u] and spoken by either a male or female voice. These pairings resulted in coarticulation, or the blending of a sequence of phonemes, which caused a change in how the phonemes were recognized and impacted the listener's perception. When paired with a rounded vowel like [u], the phoneme /s/ is acoustically more like /ʃ/ (Yu, 2010). Anticipatory coarticulation causes lip rounding in the /s/ phoneme as a strategy to prepare for the production of the rounded vowel [u]. This lip protrusion causes the phoneme to acoustically be more similar to /ʃ/. However, research has shown that when presented with an ambiguous phoneme (between /s/ and /ʃ/), listeners compensate for the occurrence of coarticulation and are thus, more likely to identify the phoneme as /s/ when next to a rounded vowel (e.g., [u]). Specifically, when coarticulation occurs, the listener's perceptual ability compensates by reconstructing the components of the production based on their anticipated knowledge of what requirements are needed in the vocal tract during the production of a specific phoneme sequence (Mitterer, 2006). Yu (2010) found individuals with a high AQ were *more* attentive to the context of a phoneme, and showed greater compensation for coarticulation.

Similarly, Stewart and Ota (2008) presented a word and non-word identification task to a cohort of individuals with high or low levels of autistic traits. Segments included several words which differed solely based on voice onset time. For example, participants selected either /g/ or /k/ when presented with stimuli such as 'giss' versus 'kiss'. They

found that autistic trait level was negatively correlated with the identification shift between real and non-word continuum (Stewart & Ota., 2008). Stewart and Ota (2008) concluded from their results that individuals with higher levels of autistic traits are less affected by the lexical meaning of a given stimulus and reflect more on actual acoustic properties such as voice onset time (VOT).

These results, like those in Yu (2010), suggest individuals with high levels of autistic traits are more sensitive to the phonemic level of speech perception. While Yu (2010) suggests his results relate to the ability individuals with high autistic traits possess when understanding the effects of context on coarticulation, Stewart and Ota (2008) suggests individuals with high levels of autistic traits focus specifically on fine detail in the acoustic signal such as VOT. Both of these results, however, seem to suggest that individuals with high levels of autistic traits perceive speech differently than the neurotypical population with average or low levels of autistic traits. These differences might reside in a difference in the perception of low level acoustic features and may potentially be enhanced in a population with ASD diagnoses.

In sum, given the variety of findings suggested by different studies of speech perception as cited above, the distinct speech perception profiles of individuals with ASD and even those neurotypical individuals with high vs. low levels of autistic traits are far from settled. Specifically, with regard to individuals with an ASD, some research seems to find an overall heightened ability in perception (Stewart & Ota, 2008; Mottron et al., 2006); while others debate results of a heightened ability to perceive the contextual elements of a given target (Yu, 2010); compared with theories which suggest less

sensitivity to this contextual information (Baron-Cohen et al., 2009). Thus, the current study investigates whether the results found in Yu's (2010) study also exists in individuals with an autism spectrum disorder. We ask: When compared with typically developing peers, do individuals with an ASD compensate for the coarticulation of speech, similar to that of individuals with high levels of autistic traits?

METHODS

Participants

Two cohorts were recruited for the present study. The cohort of individuals with an ASD was made up of 9 male native speakers of American English with a mean age of 21.5 years (range = 18 to 26 years). Diagnoses were confirmed by the Autism Diagnostic Observation Schedule – Second Edition (ADOS-2) module 4 (Lord, Rutter, DiLavore & Risi, 2008). The mean ADOS-2 score was 10 (range = 7 to 19). The mean AQ for the ASD population was 31 (range = 29 to 34). This meets to criterion for “borderline” or a “strong likelihood” of an ASD diagnosis. The cohort with ASD was recruited from the greater Lafayette, Indiana area.

The neurotypical comparison group (NT) consisted of 23 male native speakers of American English who were matched on average age and IQ to the ASD group, and were recruited at the University of Chicago. The NT comparison group was further divided into two subgroups based on participants’ AQ scores. The neurotypical-high (NTH) subgroup included 9 individuals (M = 19.8 years, range = 18 to 23 years) who scored above the average score of 21 on the AQ (M = 26, range = 23-31). This places the NTH individuals in the “slightly above average” and “borderline autistic” behavior traits range. The neurotypical-average (NTA) subgroup included 14 individuals (M = 21.4 years,

range =18 to 26 years) who scored within the average range for AQ (M = 17, range = 11-21) (see Table 1).

Table 1. Age and IQ scores of participants divided by cohort

Participant Age and IQ								
	ASD Age	IQ	NTH Age	IQ	NTA Age	IQ	NTA AGE	IQ
1	25	104	18	112	22	122	22	111
2	19	123	19	126	24	100	20	121
3	21	138	19	107	19	129	19	109
4	22	81	19	118	20	108	21	107
5	18	131	18	122	24	116	22	112
6	20	103	20	118	24	98		
7	18	121	22	98	18	125		
8	25	131	21	103	18	128		
9	26	111	23	115	26	126		
AVG	21.5	115	19.8	113			21.4	115

Measures

Language Questionnaire

A short questionnaire was provided to each participant at the beginning of the study. The questionnaire addressed age, diagnosis, participant's dominant hand (left or right handed), and a short history addressing ear infection or hearing loss. The questionnaire also assessed the languages and dialects each participant was previously exposed to.

Hearing Screening

To determine participant's eligibility, air conduction, pure tone stimuli at frequencies of 1, 2, and 4 kHz were presented to participants at a single intensity level

(25 dB HL). Participants were required to pass each frequency in order to meet inclusionary criteria for the present study. If participants did not respond at 25 dB HL, they no longer qualified for the study and were not included in the analysis.

Autism Diagnostic Observation Schedule - Second Edition (ADOS-2)

Autism Diagnostic Observation Schedule - Second Edition is the “gold standard” observational assessment of autism spectrum disorder. The ADOS-2 provides a summary of autistic traits and can be administered to individuals from 12 months of age to adulthood. Assessment includes communication, social interaction, and restricted and repetitive behaviors. Module 4 within the ADOS-2 is designed for verbally fluent adults and was administered to all individuals in the ASD cohort, by a reliable examiner (Lord, Rutter, DiLavore & Risi, 2008).

Autism Quotient (AQ)

The Autism quotient is a short questionnaire that assesses the level of autistic traits present within the typically developing population. Areas assessed include social skills, communication skills, imagination, attention to detail, and attention switching. Participants selected responses of “definitely agree,” “slightly agree,” “slightly disagree,” or “definitely disagree”. Scores are then assigned to each of the 50 questions. Five categories emerge: 0-11 = low AQ, 11-21 = average AQ for the neurotypical population, 22-25 = autistic tendencies slightly above average, 26-31 = borderline likelihood of an ASD, 32-50 = strong likelihood of an ASD (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001).

Wechsler Abbreviated Scale of Intelligence- Second Edition (WASI-II)

IQ was measured using the Wechsler Abbreviated Scale of Intelligence (WASI-II) (Wechsler, 2011). The WASI-II is a standardized assessment which measures a participant's cognitive abilities. The test includes four subsections including vocabulary, similarities, block design, and matrix reasoning. The WASI-II was created in order to assess an individual's behaviors and used to measure an individual's mental capabilities (Wechsler, 2011).

Phoneme Classification Task

In order to identify if participants were able to compensate for the coarticulation of phonemes, a forced choice listening task was administered to each participant using Eprime 1.0. The task was presented using Senheiser headphones (HD280pro, 64 Ω) attached to a Dell Optiplex GX260 (Intel (R) Pentium $\text{\textcircled{R}}$ 4CPU. 2.40 GHz 512 MB of RAM) desktop computer. Participants were asked to identify if the ambiguous speech segment played was either /s/ or /f/. The task included approximately 12 test trials where the individual received immediate feedback on whether their response of which phoneme (either /s/ or /f/) was correct or incorrect. Answers were displayed in two boxes presented on the computer screen with a phoneme labeled in each box. Responses were made via a six button response pad (Cedrus, Model RB-620) with the response in box one corresponding to the first button on the keypad and box two responses corresponding to the second button. The remaining buttons were not used. There were then 84 task trials. The participants were given two breaks at specific points within the trials. At every break, participants were given the choice to remove the headphones for a short period, or

continue the trials. Participants remained seated the entire time and breaks did not exceed three minutes in length.

Stimuli

The phoneme classification tasks included a series of VCV syllables that included a phoneme on a step between /s/ and /ʃ/ paired with canonical vowels [a] or [u]. These stimuli were created from samples of a male native speaker of American English producing clear segments of /sa/ and /ʃa/. These phonemes were then synthesized using PRAAT and mixed with vowels taken from the segments /da/ and /du/. After the speech segments were complete seven native speakers of American English listened to the synthesized speech segments and categorized each as either /s/ or /ʃ/. The results of this task grouped the phonemes into seven steps on the consonant continuum (Yu & Lee, 2014). Overall, the phoneme continuum included seven points between /s/ and /ʃ/ which included the endpoints of the individual /s/ and /ʃ/ phonemes as well as five steps in between (Yu & Lee, 2014).

Procedure

Participants were brought in for three, 40-minute consecutive sessions. In the first session a hearing screening was administered to confirm hearing thresholds of at least 25 dB at 1, 2, and 4 kHz. Participants' data was only included if they met this criteria. Next, the ADOS-2, module 4 was administered to the participants by a reliable examiner in order to classify and confirm their ASD diagnosis. Participants also completed an online version of the autism quotient (AQ). The second visit consisted of a task unrelated to this

thesis (an auditory pitch discrimination task) and administration of the WASI-II. The third visit consisted of two phoneme classification tasks to probe for perception of coarticulation, as well as a digit span memory task to assess the participant's short term memory (also not discussed in this thesis). The results from one phoneme classification task, in which participants were randomly assigned to one of two conditions, are summarized within this thesis.

RESULTS

Data Analysis

A generalized linear mixed effect model was used to evaluate the results of the phonemic classification task. This model specifically looked at the continuous variables within the current study and accounted for the random effects which may be present. Within the model, percent of participant's /j/ responses served as the dependent variable, while vowel and continuum step served as the independent variable. This model illustrated a significant main effect for the vowel [a] ($F(2169) = 2.40, p = 0.0163$) as well as the interaction between cohort and continuum step (ASD $F(2169) = 4.90, p < 0.0001$ and NTA $F(2169) = 1.99, p = 0.0463$). Neither the interaction between continuum step and vowel ($F(2169) = 0.82, p = 0.4141$), nor the interaction between vowel and cohort (ASD $F(2169) = -0.45, p = 0.6497$ and NTA $F(2169) = 0.57, p = 0.5718$) reached significance. Thus, there was no clear compensation for coarticulation for any group of participants here. The following results therefore explore the main effect of vowel and the interaction between continuum step and cohort (ASD, NT) (see table 2).

Table 2. Results of the generalized linear mixed effect model

Solutions for Fixed Effects							
Effect	Vowel	Cohort	Estimate	Standard Error	DF	t Value	Pr > |t|
Step			-5.6038	1.5737	2169	-3.56	0.0004
Vowel	a		10.1206	4.2095	2169	2.40	0.0163*
Vowel	u		0	.	.	.	.
Step*Vowel	a		0.1042	0.1275	2169	0.82	0.4141
Step*Vowel	u		0	.	.	.	.
Step*Cohort		ASD	0.9238	0.1887	2169	4.90	<.0001*
Step*Cohort		NT	0.4242	0.2127	2169	1.99	0.0463
Step*Cohort		NTH	0	.	.	.	.
Vowel*Cohort	a	ASD	-0.1747	0.3847	2169	-0.45	0.6497
Vowel*Cohort	a	NT	0.2292	0.4053	2169	0.57	0.5718
Vowel*Cohort	a	NTH	0	.	.	.	.
Vowel*Cohort	u	ASD	0	.	.	.	.
Vowel*Cohort	u	NT	0	.	.	.	.
Vowel*Cohort	u	NTH	0	.	.	.	.

An additional logistic regression analysis further assessed the significance found within the vocalic context with regard to participants' AQ scores. Here we compared the distance between vowels with that of each cohort's average AQ score. Within the analysis, AQ of each cohort was not found to be significant (NTA $-0.698, p = 0.4852$; NTH $-1.318, p = 0.1875$) (Table 3). An additional analysis was also run in order to assess the effect AQ score has on each participant's use of vocalic context. Here, individual AQ score was found to have a significance with vocalic context ($-2.819, p = 0.00481$) (Table 4). Therefore, the previous analysis is supported, suggesting that within the three cohorts, there is no main effect of autistic traits on the manner in which cohorts use a vocalic context to aid speech perception. Instead when processed across individual AQ scores participant's use of vowel context decreases as AQ increases. This is in contrast to Yu (2010), which suggested that individuals with high AQ process vocalic context to a larger

extent than those with low AQ. The differences between Yu (2010) and the present study, discussed below, could potentially affect the results of the current analysis.

Table 3. Logistic regression of cohort AQ and distance between /a/ and /u/

Results of Logistic Regression				
Coefficients	Estimate	Standard Error	z value	Pr (> |z|)
Step	1.34389	0.05142	26.138	<2e-16**
AQ	-0.03563	0.02113	-1.686	0.0917
NTA	-0.24448	0.35028	-0.698	0.4852
NTH	-0.27548	0.20903	-1.318	0.1875

Table 4. Logistic regression of individual AQ and distance between /a/ and /u/

Results of Second Logistic Regression				
Coefficients	Estimate	Standard Error	z value	Pr (> |z|)
Continuum_Step	1.342514	0.051348	26.145	<2e-16
AQ	-0.026302	0.009329	-2.819	0.00481

Given the finding that ASD participants showed a shallower response slope than NT individuals, we examined whether there was a correlation between individuals' response slopes and their AQ scores, however, these two variables were not correlated ($r = -.056$). This lack of correlation was likely found because the two NT populations patterned differently. Thus, these results suggest that, while within this study the three different cohorts' response slopes differ significantly, this difference is not directly related to their AQ scores. We will later discuss the unique response patterns of the NTH population and how they differ from the ASD and NTA population.

Vowel

To plot the main effect found in vowel, the percentage of /j/ responses were plotted against the seven continuum steps. Figure 1 illustrates the main effect found with regard to vowel pairing. The plot illustrates that the main effect for vowel is found in the middle steps of the consonant continuum. Between steps 3 and 5, there are more /j/ responses for [a] than there are for the vowel [u]. This main effect is not present at either end of the continuum as illustrated by the similar response patterns of vowels in both steps 1 and 2 and steps 6 and 7. This similarity at either end of the continuum and variation within the middle steps is predictable. Yu (2010) reports similar effects of vocalic context and talker voice as a predictor to /j/ response, citing additional research as to why this phenomenon occurs (Mitterer, 2006; Strand, 1999). Similar to Yu's results, the current listeners compensated for the coarticulation of vocalic context most often in the middle of the continuum, where the phonemes are most ambiguous (Yu, 2010).

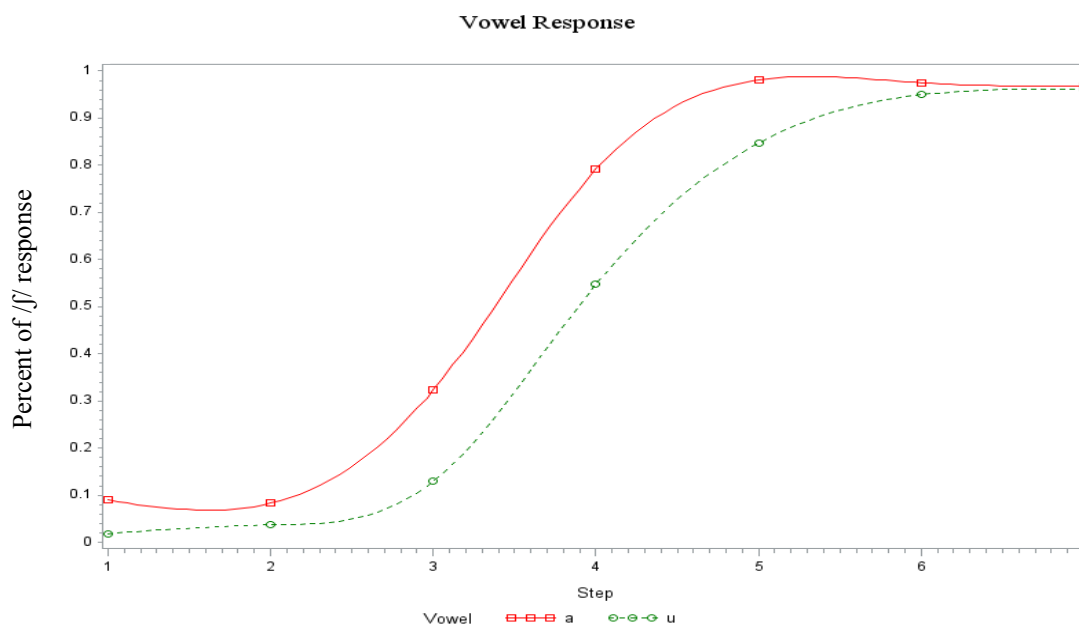


Figure 1. Percent of /j/ responses and continuum step by vowel

Cohort x continuum step interactions

Participants were initially divided into two categories, those with a diagnosis of an autism spectrum disorder (ASD) and those considered neurotypical (NT). As seen in Figure 2, as the consonant continuum increases, the cohort with ASD illustrates a more gradient slope in their /f/ responses as compared to the NT cohort. The NT cohort shows a more categorical response curve where they seem to switch between /s/ and /f/ responses immediately between steps 3 and 4.

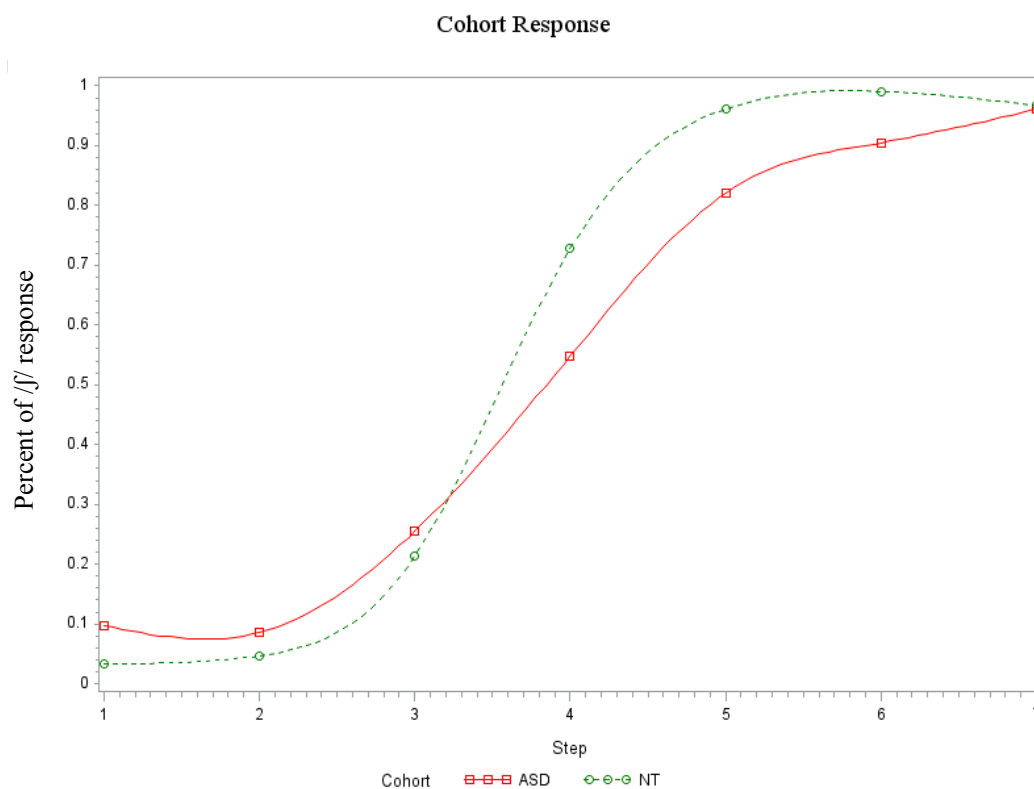


Figure 2. Percent of /f/ response and continuum step by cohort.

It is possible there are gradations within the NT population that may be obscured by grouping them all together in this way. Thus, as planned, in a second analysis the NT

population was divided into two different cohorts based on AQ scores. The cohort was split into those who scored within the average range on the AQ scale, neurotypical-average (NTA), and those whose responses were elevated above the average score for AQ, neurotypical-high (NTH). The percentage of /f/ responses was again plotted against the continuum of steps between /s/ and /f/. The response curves for each of the cohorts illustrates a similar percentage of /f/ responses at the ends of the continuum and variability in responses as ambiguity of the phoneme increases in steps 3 through 5. As seen in Figure 3, the ASD and NTA cohorts illustrate a more gradient response pattern between each of the steps on the consonant continuum. This is specifically shown between the steps 3 and 5 where the NTH cohort illustrates a steeper slope.

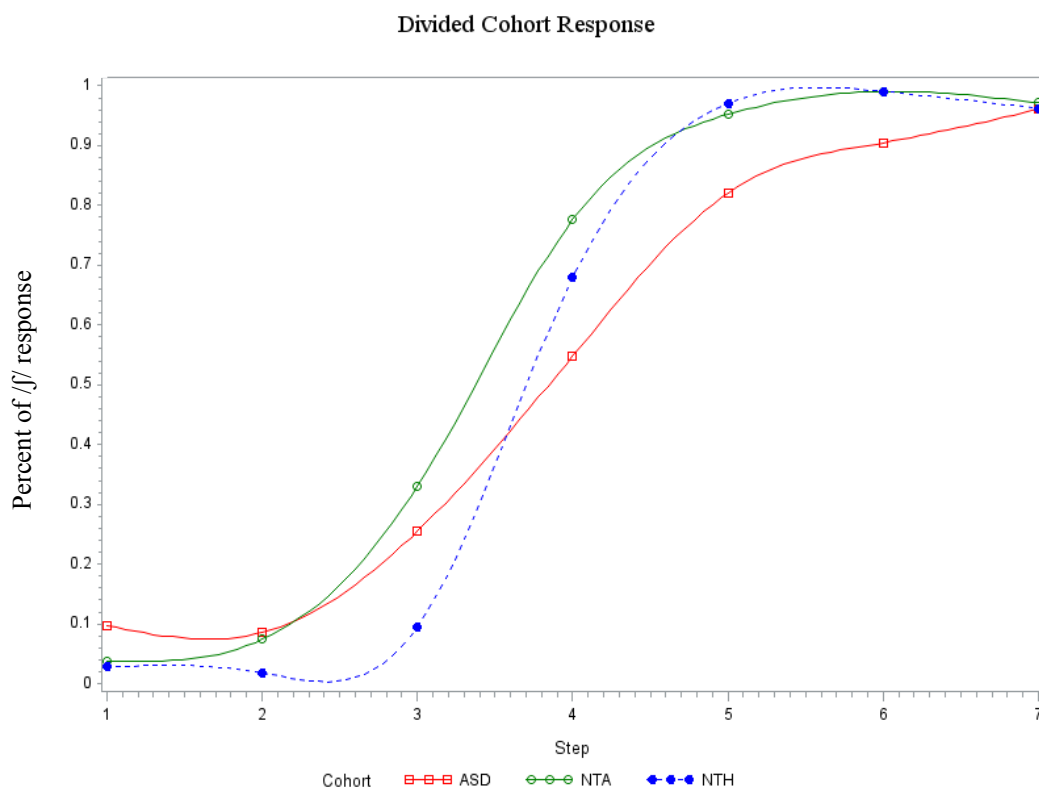


Figure 3. Percent of /f/ response and continuum step by divided cohort

DISCUSSION

The main effect of vowel and /ʃ/ response was similar to that found in previous research. As stated earlier, research suggests individuals are more likely to have a higher response of /ʃ/ when paired with the vowel [a] than with the vowel [u]. When presented with ambiguous phonemes, participants depend on the context of that phoneme (i.e., the vowels) to classify it as either a /s/ or /ʃ/. Although they are not theories of speech perception, theories such as the WCC may predict that individuals with an ASD have greater difficulty in perceiving the effect of vocalic context on a given phoneme due to a perseverative attention to the features of a target consonant phoneme rather than its context. In contrast, speech perception research finds that individuals with high AQ may compensate for coarticulation of the vowel to a *greater* degree than the individuals with low AQ showing a stronger ability to use contextual information (Yu, 2010). The current study explored whether this was also true for individuals with an ASD. We predicted that the population with ASD would show similar response patterns to individuals with high AQ, and thus present with better perceptual compensation when compared to the NTA population. However, neither the population of individuals with ASD, nor the NTH cohort was significantly different in their classification for vowels when compared to NTA individuals. This means that although individuals with ASD may have differences in the manner by which they perceive speech within the current study, it is not due to their sensitivity to the vocalic context. Thus, the differences must reside in other areas of

speech processing (as well as in other areas of communication such as semantics, syntax, and pragmatics).

Additionally, it is worthy of note that there was no significant difference in perception of speech segments between the NTH and NTA cohorts. Recall, that Yu (2010) found that individuals with high AQ were better able to compensate for coarticulation of speech when compared to low AQ individuals. The results of the present study, however, do not pattern with Yu's findings. Not only is there no significance between individuals with ASD and the neurotypical population, there is also no significance found in compensation for coarticulation between individuals with high AQ and average AQ. There are several alternative explanations that may account for this difference. First, in Yu's (2010) study the speech segments presented consisted of similar phonemes, however, the segment in question was placed in a CV syllable instead of a VCV syllable as it was in the present study. It is possible that the context of anticipatory coarticulation, such as the CV segment produced in Yu (2010), may be distinct from that of perseverative coarticulation (occurring in VCV syllables). Second, the level of AQ responses is also distinct between the current study and Yu's study. In the current study we did not enroll participants who scored within the low AQ domain (below a score of 11). Yu, however, compared high with low AQ. In future research it would be of interest to attempt to compare performance of high with low AQ as well as with that of the ASD population. Finally, it may also be that our study does not have sufficient power to pull out rather subtle differences in compensation for coarticulation. Nonetheless, this null result with regard to compensation for coarticulation is interesting as it speaks to

problems in treating neurotypical individuals with high AQ as similar to individuals with ASD diagnoses. While, sometimes these two populations may pattern together, these data suggest that we cannot always assume high AQ individuals (as in Yu's study) process stimuli in a way similar to those with ASD (2010).

A significant interaction was found between continuum step and cohort. As described for the visual domain in Soulieres, Mottron, Saumier, and Laroche (2007) the results illustrated for the ASD cohort in Figures 2 and 3, demonstrate a diminished discrimination peak between two categories. Similar to the HS hypothesis and Soulieres et al. (2007), individuals with ASD appear to carefully discriminate changes in a perceptual segment independently from category influences (Baron-Cohen et al. 2009). The shallow, diminished peak present in the response slope for individuals with ASD is indicative of overlap in the participants' responses of /f/ versus /s/. The HS hypothesis may suggest the detailed-oriented focus that is often present in individuals with ASD, allows the individual to perceive each step of the continuum as an individual sound and thus create categorical markers at each individual step. Entertaining additional categories on the continuum may directly lead to the shallower slope found in figures 2 and 3. This gradient, near absent categorical shift is similar to the findings of Soulieres et al. (2007), and applies their findings to the auditory domain.

According to Depape, Hall, Tillmann, and Trainor (2012) as infants, individuals with ASD require additional time to acquire a specification for their native language. One hypothesis may be that by not specifying a native language within the same timeframe as neurotypical individuals, the infant with ASD is able to explore more variations of the

phonemes in his or her environment. This exploration could potentially lead to the more gradient response pattern we see in this study. Based on an exemplar model, individuals with ASD are able to explore and remember these alternative variations of phonemes, which neurotypical individuals may not explore. If individuals with ASD also score lower in their expressive language abilities, this also reflects difficulty in their early perceptual ability, as the lack of categorical perception may lead to difficulty in word learning and categorization.

Similarly, this gradient perceptual ability may cause differences in the manner in which individual's process language at the semantic level. A gradient response pattern in speech perception may cause an individual some delay or confusion when conversing with others. If the speaker's production of a word is ambiguous at the phonemic level, a gradient listener may be preoccupied attempting to resolve the minimal pair differences and lose the larger message of the word or sentence produced by the speaker. For example, if a speaker states "can you pick up the [ʃɪp]?" with a /ʃ/ produced with a 60% /ʃ/ and 40% /s/ mix. To a categorical listener, this may sound like a clear /ʃ/, and they will continue focusing on the target message. However, to a gradient listener, this phoneme may not be categorized specifically as a /ʃ/, but rather an alternative phoneme between /s/ and /ʃ/. Thus, the gradient listeners may perceive several different categories on the consonant continuum and may not directly categorize here. This leaves a chance that the message "can you pick up the [ʃɪp]?" may be misinterpreted as "can you pick up the X?" where X stands for a non-word. The message is thus lost, or greatly delayed. When this example is extended to other phonemic continuums, additional minimal pairs, and other

ambiguous phonemes; we can observe that the gradient listener may have difficulty or slower responses that result from this simple speech perception difference.

Finally, it is worthy to note that we find distinct patterns within the NT population. Specifically, when we divide the NT population into two subgroups it appears that the NTH population or those neurotypical individuals with high AQ scores differ from the other cohorts in the steepness of their response curve. The steep curve observed in the NTH response indicates that this population was more categorical in responding to the stimuli. This immediate shift between categories can be found within the participants' responses in steps 3 and 5. If individuals rely on two categories and disregard the allophonic level of the speech segment a steeper slope is predicted, like that illustrated by the NTH population. Based on the exemplar model, the NTH individuals may immediately create memories of these categories early on in the study, potentially during the practice trials, when they receive feedback on accuracy of their responses. Additionally, these memories may be brought from their naturalistic experience with the phonemes as well. As found in Yu (2010) the NTH population illustrates characteristics that are independent from the response patterns of the NTA and the ASD population. Although the comparison between NTH and NTA did not reach significance, it is possible that when compared to the other cohorts, this specific categorical memory is unique to the NTH individuals, and not readily found in other cohorts. The steep response curve illustrated in Figure 3 is representative of this uniqueness. Additionally, neurotypical individuals with high AQ may possess an enhanced ability to perceive

speech sounds in their phonetic environment, which may lead to improved ability to categorize phonemes.

Past research has discussed manners by which individuals may approach speech perception and the context of specific phonemes. Yu (2010) suggests coarticulation and the context of a phoneme's environment may affect an individual's ability to categorize phonemes. Others such as Holt, Lotto, and Kluender (2000) suggest identification can be completed based on lower level spectral characteristics of the phonemes presented. As suggested in Soulieres et al. (2007) when participating in classification tasks such as this, the ASD population may illustrate a diminished or nearly absent discrimination peak near the boundary of a given category. All of these theories suggest relevant hypotheses on how an individual categorizes ambiguous phonemes. Within the current study the most interesting results stem from the classification differences found between cohorts. NTH illustrate response patterns that are indicative of being acutely aware of the two mandated phonemic categories. The ASD cohort, and to some extent the NTA cohort, are less categorical, and more sensitive to the consecutive steps that exist on the continuum.

Overall, the predicted response patterns vary from the actual results received from the present study. Yu (2010) found that individuals with higher AQ performed better at compensating for coarticulation than low AQ individuals. While the results of the present study did not reach significance for compensation of coarticulation, this study does support the idea that individuals with high AQ respond to the phoneme classification task in a different manner. However, unexpectedly, individuals with ASD do not follow the NTH response patterns. When applying these results to the greater environment, it is

important to know that individuals with an ASD may not be similar to individuals with high AQ. Speech perception is an important aspect of language development and communication as a whole, and unlike our initial predictions these two cohorts appear to approach the perceptual aspects of speech in two distinct manners. These results suggest that further research and clinical practice must keep in mind these differences when discussing individuals with ASD, individuals with higher autistic traits, and finally individuals with low or average AQ. Just as each individual's approach to speech perception differs, so should the clinical professional's approach when interacting with individuals from each cohort.

The current study, of course, has many limitations. First, individuals regardless of diagnosis will perceive a VCV segment differently than they would natural running speech. Therefore, the results can only speak to that of low level speech segments and cannot be applied to functional communication. Second, the sample population is limited by the small number of participants with ASD who enrolled in the study. Finally, it is possible that the phoneme classification task may only be appropriately testing classification rather than compensation for coarticulation.

In conclusion, while the results of the present study differed from our initial hypothesis, the current study provides interesting data concerning the more gradient perception that exists in individuals with ASD. In addition, typically developing individuals with higher AQ scores appear to perceive speech in a unique manner that differs from both the neurotypical-average population and the population of individuals with an ASD. In the future the uniqueness of individuals with high AQ should continue to

be studied with regard to their speech perception and communicative abilities, not grouped with individuals with ASD. The current results support hypotheses like that in Soulieres et al. (2007) and Baron-Cohen et al. (2009) which continue to suggest that individuals with ASD may be expected to illustrate a more low level, detail oriented approach to processing stimuli than that of typically developing individuals. Future research may explore the differences that exist between the low level enhanced abilities of individuals with ASD and how it affects more complex speech patterns.

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APPENDIX

APPENDIX ADOS-2 SCORES

ADOS-2 Scores					
Subject	Gender	Age	Community Diagnoses	ADOS-2 Score	ADOS-2 Classification
1	M	25	Aspergers	9	spectrum
2	M	19	Aspergers	8	spectrum
3	M	21	Aspergers	7	spectrum
4	M	22	Aspergers	10	autism
5	M	18	Aspergers	19	autism
6	M	20	Aspergers	9	spectrum
7	M	18	Aspergers	7	spectrum
8	M	25	Aspergers	10	autism
9	M	26	Aspergers	13	autism