Department of Modern Languages and Literatures and English Studies

M.A. Thesis

The Impact of Auditory Attention in L2 Vowel Perception and Production by Means of Phonetic Training

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Abstract

A listener must process complicated incoming auditory information and strive to accurately perceive and produce language. High Variability Phonetic Training (HVPT) is used to train the perception and production of L2 speech sounds, improving the learner's perception of a larger amount of contrasting sounds. However, a learner's individual differences when processing this auditory input may explain inequalities in L2 perception and production. Attentional resources may be one source of individual differences in acquiring a L2, where differences in attentional capacity can lead to gains or deficits in learning. The aim of the current thesis was to examine if individual differences in auditory selective attention and auditory attention switching explained differences in gains from HVPT within and across HVPT training sessions. One-hundred and five Catalan/Spanish learners of English participated in four sessions of HVPT over a two-week period. Training consisted of two perception tasks, AX discrimination and Identification, and a production task, Immediate repetition. All the tasks focused on the English vowel contrast /æ/-/ʌ/, which is difficult to Catalan/Spanish learners of English. In the perception tasks accuracy was analyzed and in the production task Bark-converted spectral distance scores were evaluated. Participants were also measured on tasks of auditory selective attention and auditory attention switching and assigned to high and low attention control groups using cluster analysis. General linear mixed models examined gains from HVPT between attention groups, within session and between sessions. Results showed that gains in the perception tasks were significantly greater for the higher than the lower auditory attention group both within sessions and over successive sessions. For the production task there were no gains within the sessions, but attention did explain performance over consecutive sessions. These results suggest that gains made in HVPT are related to auditory attention control, especially in AX discrimination and the Identification perception tasks of the /æ/-/ʌ/ vowel contrast and to a lesser extent the Immediate Repetition production task.

Keywords: High Variability Phonetic Training, L2 vowel contrast, speech perception and production, auditory selective attention, auditory attention switching

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1. Introduction

The goals of learning a second language (L2) are not always to obtain near-native perfection, but to understand and to be understood. The sounds that we perceive and produce are fundamental to understanding and being understood. In other words, input through the auditory channel is the manner that many receive language. The listener must utilize complex auditory evaluation, such as being able to distinguish between the prosodic limits of verbal utterances, using pitch and duration and differentiate between spectral and temporal processing (de Pijper & Sanderman, 1994). As a result, differences in the processing auditory input may explain inter-learner variability in L2 speech perception and production. Resources that influence processing of auditory input can include the functions of attention

The ability to successfully direct attentional resources while using the L2 may be a reason for different outcomes in individual attainment (Segalowitz & Frenkiel-Fishman, 2005). Especially given that these attentional resources have limitations (Petersen & Posner, 2012), even subtle differences in attentional capacity may interact to show improvements, or deficits in acquiring a L2.

During speech perception attentional control has found to be associated with the general mechanisms of speech perception and production by directing auditory processes. While communicating, listeners can focus their processing resources on appropriate acoustic information and select the important information, i.e. selective attention, but difficulties arise within the auditory system when a listener is attempting to comprehend more than one speaker at the same time (Bronkhorst, 2015).

2. Literature Review

A well-studied phenomenon, the cocktail party effect (Cherry, 1953), is an example of the difficulty of attending to a single conversation or hearing a single talker in the distance of a crowded, noisy room (e.g. Kerlin et al., 2010; Gautreau et al.,2013). Many early theories of attention were based on this observation. For example, Treisman´s attenuation theory (Treisman, 1964) states unattended stimuli are filtered by a sensory buffer so that they are attenuated, but not eliminated. This suggests that in real world situations a person has the ability to filter out irrelevant environmental input and attend to necessary information from different sources of auditory input (Bronkhorst, 2015). Two types of attention that may be particularly relevant to L2 acquisition are selective attention and attention switching.

This ability to filter out irrelevant sounds leads to an important aspect of auditory attention, focusing on important factors of speech input within a spatial dimension, allowing comprehension to occur by ignoring superfluous information (Kidd et al.,2005), which some people may be better at than others. In a study by Kidd et al. (2007), 340 normal hearing participants took part in 19 different auditory discrimination and identification tasks, designed to focus on a general auditory ability. The results showed that amongst the participants individual differences were found related to speech recognition in familiar sounds, irrespective of their ability to localize sounds and of intelligence, showing that some individuals have a better overall capability to distinguish between and attend to certain sounds. In another study involving an age range of participants from 18 to 55 years old, using a spatial selective auditory attention task, which asked the participants to report sequence of digits that they heard form a straight ahead position, while competing streams of digits were also heard from a left and right position. The participants showed differences in performance regardless of age (Ruggles & Shinn-Cunningham, 2011). These individual differences may demonstrate an advantage for listeners with better attentional skills and for those with a lesser ability to focus their attention could have difficulty with perception and communication, especially in environments that contain unwarranted noise (Oberfeld & Kloeckner-Nowotny, 2016).

This is equally important in Second Language Acquisition (SLA), where selective attention encourages new information to be comprehended and incorporated with the knowledge a learner has previously obtained from the L1 and the L2, and the ability to use metacognitive learning approaches, where a learner focuses on their own background knowledge to stimulate new learning (Oishi, 2007). Schmidt (1990) maintains that with any new information that is to be learned in a second language, the item first needs to be noticed. Known as the "noticing hypothesis", the learner becomes aware of L2 input in order to direct attention which leads to the ability to comprehend the input so it can then be used (Tomlin & Villa, 1994). A learner with greater auditory selective attention may be better able to perceive this input and determine its relevance compared to a learner that does not have the same ability.

Better selective attention, however, is not sufficient alone for successful performance, perception or production in the lab or in everyday situations. Daily tasks also require a certain level of attention switching – shifting our attentional focus to accomplish cognitive tasks – which is a type of executive control needed to complete a task and disregard others (Monsell, 2003). This pertains to communication as well, which requires enhanced and rapid attentional flexibility control in the form of attentional switching abilities to engage in a relevant task set based on information that is deemed important to the listener and ignore irrelevant input (Safronova, 2016). These abilities have been shown to be linked with more success while performing various phonological tasks, participants showed that having greater attentional switching skills performed with higher accuracy in a perception discrimination task (Darcy et al., 2014) and allowed them to pay more attention to the L2 vowel perception differences (Mora & Mora-Plaza, 2019).

Attention switching may also be beneficial to second language acquisition. Among bilingual children with early contact to more than one language and bilingual adults with a high-level of proficiency, both have been shown to have an increased level of attentional control via the ability to switch between the languages while suppressing the other (Nicolay & Poncelet, 2013). This ability to switch attention may allow the learner to focus on a distinct phonological cue and ignore the non-essential ones, cues with more information compared to ones without (Francis et al., 2000). Given the putative importance for L2 acquisition, a next step for L2 research is to explore the contributions of switching abilities, either alone or with selective attention, to language performance. Other studies have shown that an efficient attentional control is important in the area of speech perception, especially in the tasks that contain listening to differences between speech segments, for example, vowel contrasts (Isaacs & Trofimovich, 2011). Despite this, the role of attention switching has been little studied in L2 acquisition, but rather studied in the context of the development of attentional skills with children with attention deficit hyperactivity disorder (ADHD) (see review by Cubillo et al., 2013). This literature above, nevertheless, suggests auditory attention may influence learning for normal adult learners, even if there is limited research looking at its specific functions during L2 acquisition.

The speech learning model (SLM) by Flege (1995), interprets the differences in a L2 that exist in the levels of learnability of phonetic segments. For adult learners of a second language they have the capability of modifying the categories that contain their current phonetic representations and with the proper input adapt new ones (Moyer, 2009). Best and Tyler (2007) explain that perception of given vowel contrasts may prove to be difficult to learn. The phonological space of the vowel in the L2 may fall in the category of a known L1 phonological space for just one of the vowels and assimilation may occur, this will cause the learner to perceive the sounds as the same. The L2 vowel may also be perceived different than the nearest L1 phonetic category, however, it is still perceived by the learner to fall into the L1 phonological space. Another problem that may occur is that both vowel contrasts of the L2 are perceived as equal in the L1 phonological space, this will also prove to be difficult for the learner in the perception of these distinct vowel sounds and possibly in the production of these given vowel sounds. Overlapping of the phonological space and assimilation of these contrasts between the L2 and L1 could be an obstacle for any language learner. One of the difficulties in the learner's capacity is to realize that these phonological cross-language differences do occur (Flege, 1987). To surpass this, besides a large amount of L2 input, phonetic training can facilitate and shift the learner's attentional resources to the distinctions in these L2 vowel contrasts (Ylinen et al., 2010).

One of the ways to train phonological sounds is with High Variability Phonetic Training (HVPT), this is a method that uses words and or non-words produced by different speakers, to enhance the ability of the learner to recognize a wider range between sound contrasts (Bradlow et al., 1997). Speaker variability is key, as the presentation of varying phonetic stimuli requires the learner's attention to be cued to process speakers under varying contexts, enhancing flexibility of attention and sound processing. This method may be beneficial to the learner in discriminating between difficult sound contrasts and facilitate the acquisition of these sounds (Wade et al., 2007). For example, with Catalan/Spanish learners of English, perception and production inaccuracies may occur with the pairs of vowels, /æ/-/ʌ/ and /iː/-/ɪ/ which have duration differences that do not exist in either language and occupy the vowel space by simply /i/ and /a/ (Aliaga-García & Mora, 2007). The benefits of HVPT are not just limited to the perception of sounds in the L2, but gains can be achieved in production as well (Barriuso & Hayes-Harb, 2018). A vast amount of evidence shows HVPT is useful in differentiating the contrasts between L2 vowels (Aliaga-García & Mora, 2009; Carlet & Cebrian, 2019; Cebrian & Carlet, 2014; Iverson & Evans, 2007, 2009; Mora & Mora-Plaza, 2019; Thomson, 2012; among others). These studies have examined participants' performance at pre- and post-test, but to my knowledge, no HVPT study has observed gains made within each session of training and consecutively between all the sessions of training. This is an analytical method used for other types of cognitive training, practice used to enhance or maintain cognitive abilities (e.g., Friedman & Korman, 2019; Martin et al., 2014, Molloy et al., 2012), which can reveal how efficiently attention interacts with online learning within a single session or from session to session to accrue final post-test benefits. In a study by Atienza et al., (2002), participants were trained on an auditory perception discrimination task using two complex auditory patterns with event-related potentials (ERPs) recorded before and after training. The ERP results indicated that within session improvements were associated with fast neural changes which in turn lead to fast learning, represented by better accuracy and detection at early stages of neural processing immediately after training. This may give the ability to learn rapidly in a generalized manner, by quickly grasping the concept. In contrast, the slow neural changes, i.e. slow learning, distinguished by faster reaction times and stronger neural responses, were shown between the different training sessions. These slower changes led to long term improvements reported to last days to weeks.

The current thesis seeks to examine the effect of group differences in auditory attentional control on perception and production of a difficult L2 vowel contrast during HVPT. In a study by Mora-Plaza et al., (2019), findings show a link between ASA scores and the perception of the vowel contrast, /æ/-/ʌ/, and ASW scores were a strong contributor of gains before and after phonetic training. This thesis aims to extend these previous findings to perception and production tasks during the training sessions. To understand how learners with different attentional abilities benefit from training, differences between blocks, between sessions and gains, (i.e. difference scores) over blocks were examined. This will be carried out by answering the following research questions:

2.1 Research Questions

RQ1. Do differences in auditory attention lead to training gains in terms of L2 perception and production within individual sessions of HVPT?

RQ2. Do differences in auditory attention produce improvements in terms of L2 perception and production between sessions of HVPT?

3. Methods

3.1 Participants

One hundred and five (N=105, 85 females) undergraduate bilingual learners of English participated in this study for course credit. Most of the participants had learned their L2 English in a formal educational setting and had little weekly exposure to the language (Table 1). All of the participants spoke Catalan and Spanish, with different levels of dominance (39 Catalan, 51 Spanish and 15 Balanced). L3s and L4s included French (32), German (16), Italian (7), Arabic (3), Chinese (3), Dutch (2), Swedish (2), Bulgarian (1), Greek (1), Hindi (1), Korean (1), Norwegian (1), Portuguese (1), Romanian (1), Sindhi (1), and Tagalog (1). None of the participants reported having any speech or hearing pathologies

Table 1. Participants' demographics

Measure	***M***	***SD***
Age at testing (years)	22.64	6.92
Age of onset of L2 learning (years)	5.91	2.65
L2 use with Native/Non-natives (hours per week)	7.86	2.36
Self-estimated L2 proficiency - Reading (1=very poor-9=native-like)	7.31	1.27
Self-estimated L2 proficiency - Listening (1=very poor-9=native-like)	7.07	1.33
Self-estimated L2 proficiency - Speaking (1=very poor-9=native-like)	6.58	1.53
Self-estimated L2 proficiency - Writing (1=very poor-9=native-like)	6.87	1.37
Self-estimated L2 proficiency – Pronunciation (1=very poor-9=native-like)	6.23	1.73

Table 2. Participants' level of L2 proficiency

	M	***SD***	***Range Lower***	***Range Upper***
Elicited Imitation Task (0-120)	94.08	15.45	43	116
X/Y Lex Receptive Vocabulary Test (0-10000)	6140.00	1311.10	2550	9650

3.2 Materials and Stimuli

The vowel contrast designed for the training sessions was the English vowels /æ/ and /ʌ/. The training materials comprised of high-variability monosyllabic CVC minimal pairs were produced by four different speakers, two female and two males using the target vowel in different phonetic environments. The word and non-word stimuli used the mirror image of the selected word, having the consonants proceed the target vowel and were matched as close as possible in location of articulation (labial, alveolar, velar) and as well for voicing (e.g. *mad-mud*, *fash-fush*). The recruited speakers of British English were recorded, then excised and normalized for amplitude in Praat (Boerma & Weenink, 2020)**.**

3.3 Measures

3.3.1 Cognitive attention control tasks

3.3.1.1 Auditory selective attention. The auditory selective attention (ASA) task was administered to the participants in their L1 (Catalan) and their L2 (English) and used a single-talker competition method (Humes et al., 2006). The task contained 64 trials of sentences in pairs, one being the target sentence and the other the competitor sentence. The two sentences of each pair always had one spoken by a female and the other by a male and were presented to the participant auditorily and simultaneously. Prior to presentation of the auditory sentence, a call sign appeared on screen to cue the participant to which sentence to attend to with a choice of four colors and eight digits. For example, if the call sign appearing on the screen is *TIGER*, the participant would then hear the male voice say ¨*Ready CHARLIE go to BLUE SIX now*¨ and the female voice would say ¨*Ready TIGER go to RED EIGHT now*¨. The screen would then show the four colors and the eight digits that were produced in the sentences. The participant would use the cued call signal to choose the correct color and digit. Likewise, for both the Catalan and English sentences the duration was normalized to 1700 milliseconds. The individual ASA scores were acquired by summing the correctly identified colors and digits in the two tasks for a maximum score of 128. This task was previously used in Mora and Mora-Plaza (2019).

3.3.1.2 Auditory attention switching. The auditory attention switching (ASW) task is a measure of L1 switching skills, obtained from reaction times and accuracy switching costs, as the participants attend to L1 Catalan vowels for duration (quantity) or voice (quality) that were presented in isolation (Mora & Safronova, 2018; Safronova & Mora, 2012; Safronova & Mora, 2013; Safronova, 2016). This attention switching task is meant to obtain a measure of attentional flexibility of speech dimensions as an auditory version of the Segalowitz and Frenkiel-Fishman´s (2005) paradigm which was a linguistic version of the Monsell (2003) task-switching paradigm. In the task it is necessary for the participants to shift their attention between segmental duration (long vs. short) to voice quality (female vs. male) while using the perception of vowel sounds. The Catalan vowels used /i e ɛ a ɔ o u/ were both spoken by a female and a male on a falling pitch. This was manipulated using a PSOLA (Pitch Synchronous Overlap and Add) algorithm in Praat (Boerma & Weenink, 2020) both to create a long (500 ms) and a short (200ms) version of each of the seven vowels, (7 x 2 x 2) to produce 28 stimuli. The stimuli further copied an additional eight times (28 x 8) to produce a total of 228 trials that were presented to the participants, and were categorized as either long, short, or female, male. A speaker icon appeared and moved in a clockwise motion and was presented in a two by two square framework, with the top two boxes representing the duration and the bottom two boxes representing the voice. Participants used the same labelled keys on a keyboard to choose *long* or *short* while the icon was in the upper two duration boxes and *female* or *male* when it was in the lower two boxes. The trials continued predictably along the framework between the duration and voice quality dimensions, creating a *repeat* when it was within the same dimension and a *switch* when it moved between dimensions. The expectation is to have lower accuracy and speed in a switch trial than in a repeat trial, this is due to the cost of attention being refocused on a different acoustic dimension. The switching cost, which is the difference between switch and repeat reaction times is the measure that is used for attentional control, a smaller number will indicate greater attention control.

Both auditory attention tasks, selective attention and attention switching, showed a weak negative significant correlation, (r=-.196, p=045).

3.3.2 L2 Perception and Production Tasks

In the AX discrimination task, the participants were instructed to choose between the two different items they heard and if they contained the same English vowel or not and to respond as fast and accurately as they possibly could. To make sure the task was understood by the participants, six practice trials were given prior to the start of the task. The participants received visual feedback on the screen in the form of a ¨Correct! ¨ or ¨Wrong! ¨ as well as the response latency in milliseconds (e.g.

¨1270¨). In total, the training sessions for the AX discrimination task contained 96 trials by four sessions (384 trials), which included two words/non-words produced by two of the four different voices offered with a 500-millisecond inter-stimulus interval for each trial. The participants were shown a uniform amount of the same (AA, BB) trials and different (AB, BA) trials, with the four different voices being equally distributed throughout the positions (A and B) of the trials. During each session, the 96 trials contained two minimal pairs, in four different orders, with 12 voice combinations, as well, the trials were split evenly with half starting with a female voice and the other half with a male voice. The responses and reaction times for the participants were recorded. The reaction times were screened for above and below 2.5 SDs form the overall mean of the participants. The percentage of correct responses, accuracy scores, as well as mean reaction times were calculated (see Table 2), this was used as a measure of the participant's L2 vowel discrimination capability. For this task a higher accuracy score and faster reaction times would indicate better performance in the perception of L2 phonological vowel contrasts.

In the identification training task, the participants needed to identify, as fast and accurately as possible the target vowel, either /æ/ or /ʌ/of a single word/non-word that was presented auditorily (e.g. *cap* vs *cup*). At the same time a visual semantic representation was displayed at the left and right of the screen, for example a picture of a *cap* (left) and. a picture of a *cup* (right). The participants were able to choose, through a button on the left or right side of the keyboard, the visual representation that matched the auditory stimuli, visual feedback on error was provided as well as the response latency. Each training session contained 32 trials of two minimal pairs, four words in four different voices, over the four sessions for a total of 128 trials. The responses and reaction times for the participants were recorded. The reaction times were screened for above and below 2.5 SDs form the overall mean of the participants. The percentage of correct responses, accuracy scores, as well as mean reaction times were calculated (see Table 3) and were used as a measure of the participant's L2 vowel identification capability. For this task a higher accuracy score and faster reaction times would indicate better performance in the perception of L2 phonological vowel contrasts.

In the immediate repetition task, the participants were instructed to listen to the native produced word/non-word that they heard and then repeat it as accurately as they could. Each word/non-word was presented two times, with the participant had 2000 milliseconds to repeat it, they would hear the word/non-word produce it and then hear it once more and have 2000 milliseconds to repeat it again. This was done to require a form of self-monitoring on the accuracy of the imitated item, so the participant could perceive and compare the two repetitions. The words/non-words utilized were the same as the previous tasks. They were given 32 trials for repetition with two minimal pairs, presented in four different voices over the four sessions for a total of 128 trials. See data analysis section for a full description of measures used to record the participants data for this task.

3.3.3 Phonetic training

In order of presentation during training within each of the four session, first the AX discrimination task consisted of 96 trials with feedback, then the identification task consisted of 32 trials including feedback and, lastly, the immediate repetition task consisted of 32 trials with two repetitions of each target item. The phonetic training was conducted in a quiet lab with six testing stations. All of stimuli was presented auditorily using closed headphones (Beyerdynamic DT 770 M) in the AX and ID tasks, although for the IR task open headphones (Beyerdynamic DT 990 Pro) were used.
All trials for the AX, ID, and IR tasks within training sessions were given in a completely randomized order for the eight minimal pairs of the words/non-words. The participants were trained on two different word/non-word pairs which were spoken by four different voices (two female), in the four different sessions. All three tasks used the same minimal pair for each of the training sessions (see appendix A) and all four voices were used in each training session.

3.4 Procedure

This study examined the ability of L1 Spanish/Catalan learners of English to perceive and produce the English vowels /æ/ and /ʌ/ through three tasks, the perception tasks of AX discrimination and Identification and the production task, Immediate Repetition during High Variability Phonetic Training (HVPT). HVPT consisted of four training sessions lasting approximately 35 minutes. All the participants came for the four sessions on separate days over two weeks, with a day between the sessions.

The four training sessions consisted of four tasks tapping into perception or production: For perception, (1) AX discrimination task and (2) identification (ID) task and (3) for production an immediate repetition (IR) task, administered in that order. In addition to training, the following questionnaires and tasks were administered. A language background and word familiarity questionnaires were given before the first training session. A pre- and post-test was administered to the participants on the first and last session and were used to evaluate L2 perception using the ABX discriminations and lexical decision (LD) tasks and for L2 production using delayed sentence-repetition (DSR) and word-repetition (DWR). In session two the auditory selective attention task (Humes et al., 2006) and an auditory attention switching task were conducted. In session three a level of proficiency (Table 2) was obtained by using the elicited imitation (EI) task, (Ortega et al., 2002) which is a form of implicit language competency. The EI task involves having the participants listen to a stimulus and repeat it to the best of their ability, with the rationale being that the learners will only have to ability to imitate accurately the sentences they are able to understand, maximum score is 120. As well the receptive vocabulary size using the X/Y Lex, (Meara & Miralpeix, 2006), which tests receptive vocabulary up to the 10,000-word level.

All tasks, except the EI and X/Y Lex, were conducted using *DmDx* software (Forester & Forester, 2003) on laptop computers and participants used noise-cancelling headphones, and for the production tasks, Marantz PMD-661 solid-state digital recorders and external Shure SM58 voice microphones at 44.1 KHz sampling frequency. The present thesis aimed to examine the relationship between performance on the two attention tasks with performance on the four training sessions consisting of the AX discrimination task, the identification task and the immediate repetition task (Figure 1).

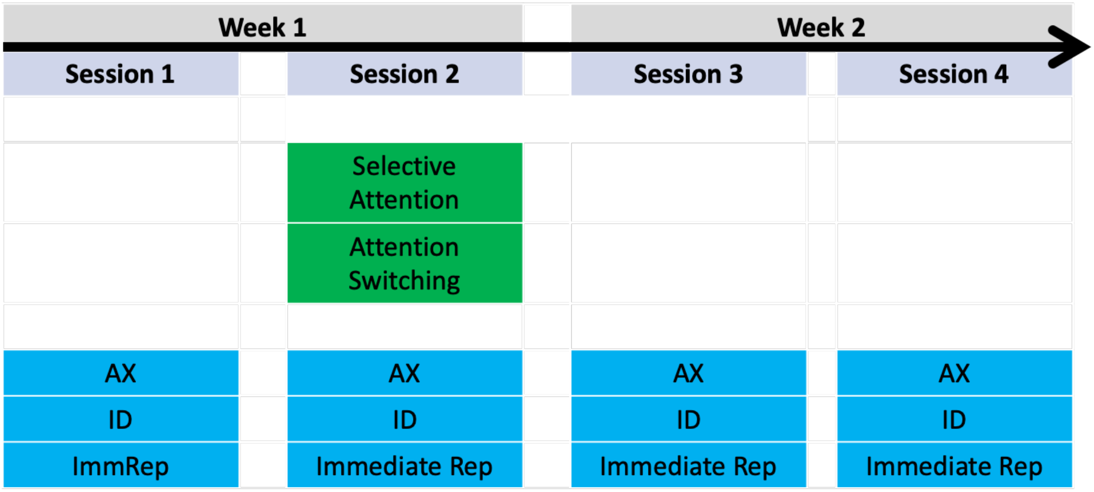

Figure 1: Research design

3.5 Data Analysis

Consistent with the aim of this thesis to examine the role of individual differences in auditory attentional control and improvements in the HVPT of the English vowels /æ/-/ʌ/, the following analysis was intended to answer the research questions proposed. Training gains would take place within each session of HPVT (RQ1), determined by the first half of the training session (Block 1) and compared to the second half (Block 2), and between all four sessions of HPVT (RQ2). For the perception tasks this would be determined by improvements in accuracy. For production gains normalized Bark-converted spectral distance scores (i.e. Euclidean distances) were used from the participants and native speaker produced vowels (N=7) of the same words.

The vowel measurements of the formants (F0, F1, F2, F3) were done in Praat (Boersma & Weenink, 2020) isolated in a 10-millisecond portion by placing a cursor at the midpoint of the steady-state part of each target vowel. All the formant measurements were screened for 2.5 standard deviations from the mean and then replaced with that participant's mean value for the same vowel in that training session. In order to minimize the effects of age, gender and vocal tract size, all frequency values were converted from Hertz (Hz) to Bark (B). The conversion from Hz to B, was accomplished by using the Bark difference Metric, a method modified by a technique developed by Syrdal and Gopal, (1986), with the formula (Traunmüller, 1997):

Zi = 26.81/(1+1960/ Fi) -0.53

In this formula F_i is the value in Hz for a given formant (i) and Z is the value in Bark. To determine an individual speaker´s estimate of vowel quality, a Euclidean distance (spectral distance score, SDS) was calculated. This was established by the use of the formula:

$$\sqrt{((VaB2 - B1) - (VbB2 - B1))^2 + ((VaB1 - B0) - (VbB1 - B0))^2}$$

The two different vowels that the Euclidean distance is measuring is determined by *Va* and *Vb*. As well, the difference in the formants, F1 and F0 is used to estimate the degree of vowel height and the difference between F2 and F1, will estimate the frontness of the vowel (Bohn & Flege, 1990; Baker & Trofimovich, 2005).

To further analyze the immediate repetition production data, the data was prepared to look at a block difference of SDS scores. For each participant the difference between block two and block one was calculated, and a new variable Gain was created. if the number was positive, they had performed better in Block two than in Block one, hence improved in SDS score within the block. Of the participants, fifty-three had gains and fifty-two did not.

4. Results

Table 3 - Descriptives

	M	*SD*	*SE*	*Minimum*	*Maximum*
Identification					
Accuracy	.78	.41	.003	0	1
Reaction Times in Milliseconds	941.15	334.97	3.12	76.30	2486.20
AX Discrimination					
Accuracy	.71	.45	.002	0	1
Reaction Times in Milliseconds	969	307.76	1.76	57.10	2406.60
Immediate Repetition					
SDS	1.60	1.32	.011	.00	10.13
Gains Block 2 – Block 1	-.003	1.16	.014	-9.17	6.99

4.1 Attention Control Tasks

Mean scores for the two auditory attentional control tasks, selective attention (ASA) and attention switching (ASW), can be seen in Table 4. In order to see all the interactions between these attentional variables and other independent variables, they were split into a High/Low group for ASA and Fast/Slow group for ASW. A K-cluster analysis was performed for each variable (Table 5).

Table 4: Mean scores in the attention control tasks: ASA scores (0-128), ASW accuracy (0-.1), RT (adjusted RT in milliseconds)

	M	*SD*	*Min.*	*Max.*
ASA	94.69	15.78	52	125
ASW Accuracy	.905	.080	.50	.99
ASW RT	145.26	81.37	-12.39	440.90
N=105				

Table 5: K-Cluster Analysis Groups

	ASA		ASW	
	High	Low	Fast	Slow
Means	102	74	99.84	236.76
N=105	76	29	74	31

4.2 Perception Results

4.2.1 Identification

In order to see the gains in *Accuracy* for the identification task (ID) a Generalized Linear Mixed Model (GLMM) was used. To examine the role of selective attention the fixed factors were *Block*, (block 1 or block 2), *Session* (session 1, 2, 3, or 4) and *Auditory Selective Attention* (ASA high or ASA low).A separate GLMM analysis was used to examine the effect of attention switching with the fixed factors of *Block*, *Session* and *Auditory Attention Switching* (ASW fast or slow). The random factors for both analyses were *Subjects* and the *Item number* (Table 6 and Appendix B: GLMM1 for parameter estimates).

Table 6: GLMM Analysis Identification

ID Perception	Analysis 1-ASA			Analysis 2-ASW		
	F	*df1, df2*	*p*	*F*	*df1, df2*	*p*
Block	6.097	1, 14.736	.014	5.205	1, 14.512	.023
Session	78.521	3, 14.736	<.001	84.252	3, 14.512	<.001
Attn	6.711	1, 14.736	.010	3.356	1, 14.512	.067
Block*Session	0.252	3, 14.736	.860	0.732	3, 14.512	.533
Block*Attn	0.458	1, 14.736	.499	0.115	1, 14.512	.374
Session*Attn	0.753	3, 14.736	.519	1.040	3, 14.512	.735
Block*Session*Attn	0.253	3, 14.736	.859	2.645	3, 14.512	.047

When first comparing analysis of auditory selective attention, we see three significant main effects of *Block, Session*, as well as the *Selective Attention Group* factors. The Bonferroni-adjusted pairwise comparisons in the main effect of *Block* was driven by the significant improvement in accuracy in block two, (*M* = 0.81, *SE* = .01, *95%CI* = .778-.832). over block one, (*M* = 0.79, *SE* = .01, *95%CI* = .738-.815), *p*= .023. For *Session*, there was a significant main effect similarly there were improvements in each session, increasing from session one, (*M* = 0.71, *SE* = .02, *95%CI* = .675-.748), session two, (*M* = 0.76, *SE* = .02, *95%CI* = .730-.795), session three, (*M* = 0.82, *SE* = .01, *95%CI* = .794-.848), and session four, (*M* = 0.87, *SE* = .01, *95%CI* = .841-.888),. In the Auditory Selective attention group, the main effect was due to a significant difference between the high selective attention group and the low attention group, with the high group, (*M* = 0.83, *SE* = .01, *95%CI* = .804-.854), outperforming the low group, (*M* = 0.76, *SE* = .03, *95%CI* = .704-.807), *p*=.015. None of the other interactions reached significance.

When comparing the analysis of auditory attention switching, there are two main effects for *Block* and for *Session*. The Bonferroni-adjusted pairwise comparisons revealed that the main effect of *Block* was again driven by the improvements in accuracy in block two, (*M* = 0.81, *SE* = .01, *95%CI* = .785-.836). over block one, (*M* = 0.80, *SE* = .01, *95%CI* = .768-.822), *p*= .023. In the main effect of *Session*, also we see this driven by the improvements from session one, *M* = 0.73, *SE* = .02, *95%CI* = .691-.759), session two, (*M* = 0.77, *SE* = .02, *95%CI* = .732-.795), session three, (*M* = 0.83, *SE*

= .01, *95%CI* = .806-.856), and session four, (*M* = 0.87, *SE* = .01, *95%CI* = .847-.888), There was also a three-way interaction of *Block* and *Session* and *Attention Switching Group.*

The three-way interaction can be seen in Figure 1. The effect of attention switching depended on accuracy performance between blocks and sessions. See tables C1 and C2 in Appendix C for means and Bonferroni pairwise comparisons of the three-way interaction. For the fast group, there is an improvement from block one to block two only in session one, two and four. There is also an overall improvement from session to session. In contrast, for the slow group there is a subtle improvement for block one to block two in session two and a steep improvement from block one to block two in session three. Additionally, the improvement between sessions showed a slight improvement for session one to session two, a larger improvement from session two to session three, but the final gains from session three to session four are equal. Lastly, the fast group showed higher overall accuracy across sessions compared to the slow group.

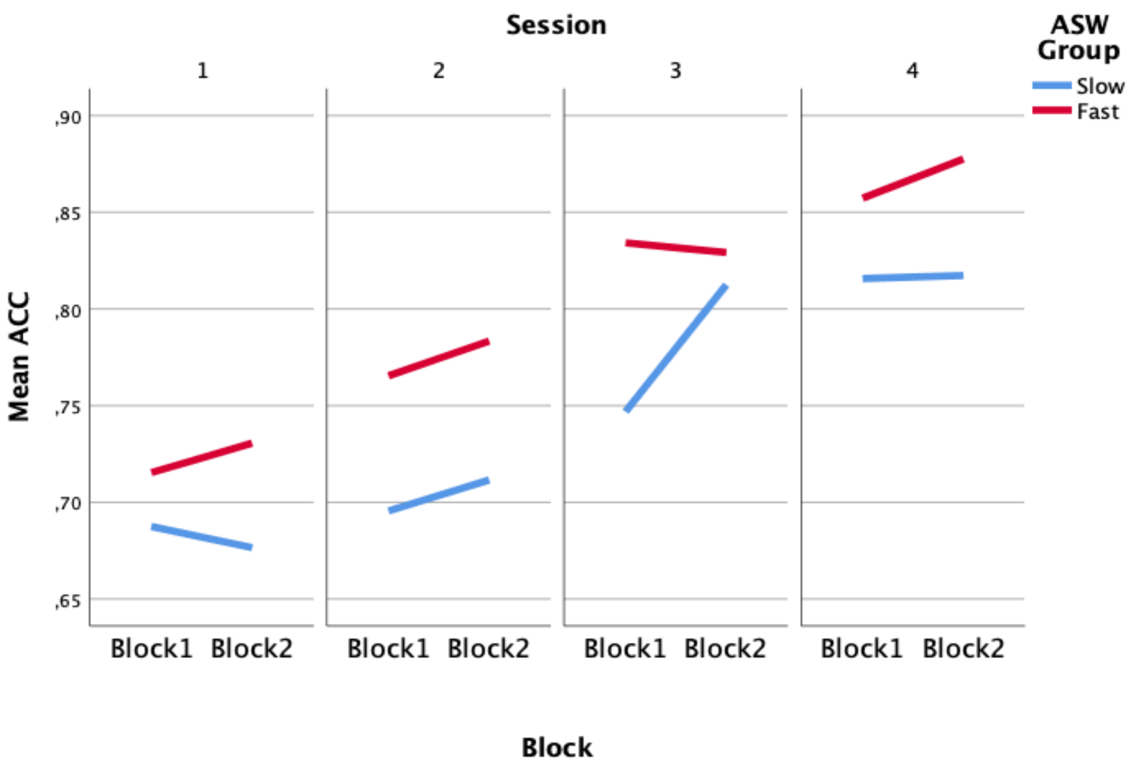

Figure 2: Three-way interaction for Block x Session x ASW Group for Identification Task

4.2.2 AX Discrimination

In the AX discrimination task, the analysis performed to see gains in *Accuracy* was a GLMM with the fixed factors of *Block*, (block 1 or block 2), *Session* (session 1, 2, 3, or 4) and *Auditory Selective Attention* (ASA high or ASA low) and then separately, a GLMM with the same fixed factors of *Block* and *Session, but* with *Auditory Attention Switching* (ASW fast or slow). The random factors were *Subjects* and the *Item number* (Table 7 and Appendix B: GLMM2 for parameter estimates).

Table 7: GLMM Analysis AX Discrimination

AX Perception	**Analysis 3-ASA**			**Analysis 4-ASW**		
	F	*df1, df2*	*p*	*F*	*df1, df2*	*p*
Block	18.66	1, 44.144	<.001	20.489	1, 43.471	<.001
Session	76.437	3, 44.144	<.001	85.997	3, 43.471	<.001
Attn	22.168	1, 44.144	<.001	3.426	1, 43.471	.064
Block*Session	2.360	3, 44.144	.069	2.481	3, 43.471	.059
Block*Attn	0.057	1, 44.144	.812	0.033	1, 43.471	.856
Session*Attn	8.953	3, 44.144	<.001	5.547	1, 43.471	.001
Block*Session*Attn	8.785	3, 44.144	<.001	1.791	3, 43.471	.146

When comparing the analysis of auditory selective attention, there are three main effects, for *Block*, *Session* and *Auditory Selective Attention Group*. The Bonferroni-adjusted pairwise comparisons revealed that the main effect of *Block* was driven by the improvements in accuracy in block two, (*M* = 0.72, *SE* = .003, *95%CI* = .709-.718) over block one, (*M* = 0.70, *SE* = .003, *95%CI* = .686-.699), *p*=.004. In the main effect of *Session*, also we see this driven by the improvements over the sessions, from session one, (*M* = 0.65, *SE* = .01, *95%CI* = .637-.660), session two, (*M* = 0.64, *SE* = .01, *95%CI* = .632-.654), session three, (*M* = 0.75, *SE* = .01, *95%CI* = .743-.761), and session four, (*M* = 0.80, *SE* = .004, *95%CI* = .794-.804, In the Auditory Selective attention group, the main effect was due to a significant accuracy differences between the high selective attention group and the low attention group, with the high group, (*M* = 0.73, *SE* = .002, *95%CI* = .732-.744), outperforming the low group, (*M* = 0.64, *SE* =

.004, *95%CI* = .633-.649), *p*=.002. There was also a two-way interaction between *Session* and *Auditory Selective Attention Group*, see tables C3 and C4 in appendix C. The Bonferroni-adjusted pairwise comparisons revealed an accuracy improvement for each session for both groups, but the high selective attention group showing improved accuracy performance for each session when compared to the low selective attention group. In addition, a significant three-way interaction was found between *Block*, *Session* and *Auditory Selective Attention Group.*

The three-way interaction can be seen in Figure 3 and see tables C5 and C6 in appendix C. The effect of selective attention depended on the accuracy performance between blocks and sessions. For the high group, there is an improvement from block one, to block two only in session one, three and four. There is also an improvement in session one, session three and in session four. In contrast, for the low group there is an improvement for block one to block two in session one and in session two and a large improvement from block one to block two in session three. Additionally, the improvement between sessions showed a slight improvement for session one to session two, a larger improvement from session two to session three, but the final gains from session three to session four are almost equal. Lastly, the high group showed higher overall accuracy performance across sessions compared to the low group.

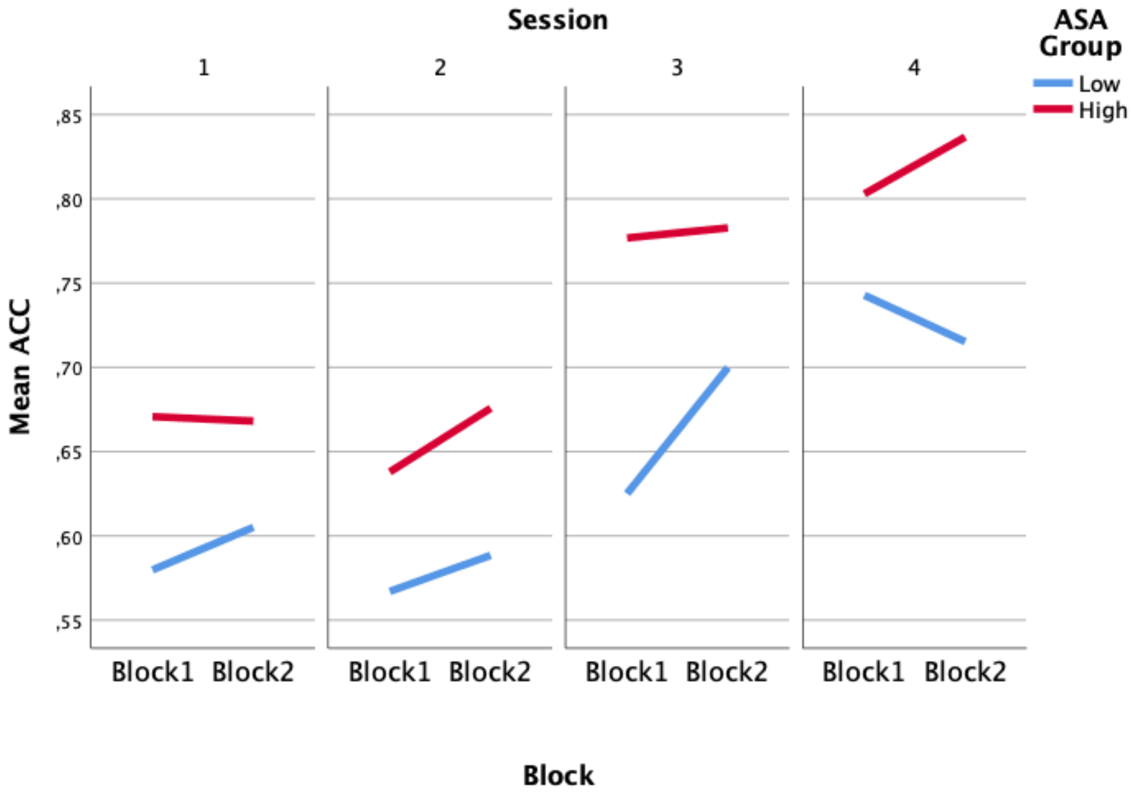

Figure 3: Three-way interaction for Block x Session x ASA Group for AX Discrimination

When comparing the analysis of auditory attention switching, there are two main effects, for *Block* and *Session*. The Bonferroni-adjusted pairwise comparisons revealed that the main effect of *Block* was again driven by the improvements in accuracy in block two, (*M* = 0.72, *SE* = .003, *95%CI* = .709-.718) over block one, (*M* = 0.70, *SE* = .003, *95%CI* = .686-.699), *p*=.004. In the main effect of *Session*, also we see this driven by the improvements over the session from session one, (*M* = 0.65, *SE* = .01, *95%CI* = .637-.660), session two, (*M* = 0.64, *SE* = .01, *95%CI* = .632-.654), session three, (*M* = 0.75, *SE* = .01, *95%CI* = .743-.761), and session four, (*M* = 0.80, *SE* = .004, *95%CI* = .794-.804). There is also a two-way interaction of *Session* and *Attention Switching Group,* see tables C7 and C8 in appendix C. In this two-way interaction, seen in Figure 4, there are overall improvements in accuracy for both the fast and slow groups from sessions two to three and sessions three to four. The fast group had equal performance on session one to two, but the slow group showed worse improvement in session one to two. Lastly the fast group, (*M* = 0.72, *SE* = .006, *95%CI* = .709-.728) showed greater accuracy when compared to the slow group, (*M* = 0.69, *SE* = .008, *95%CI* = .671-.703).

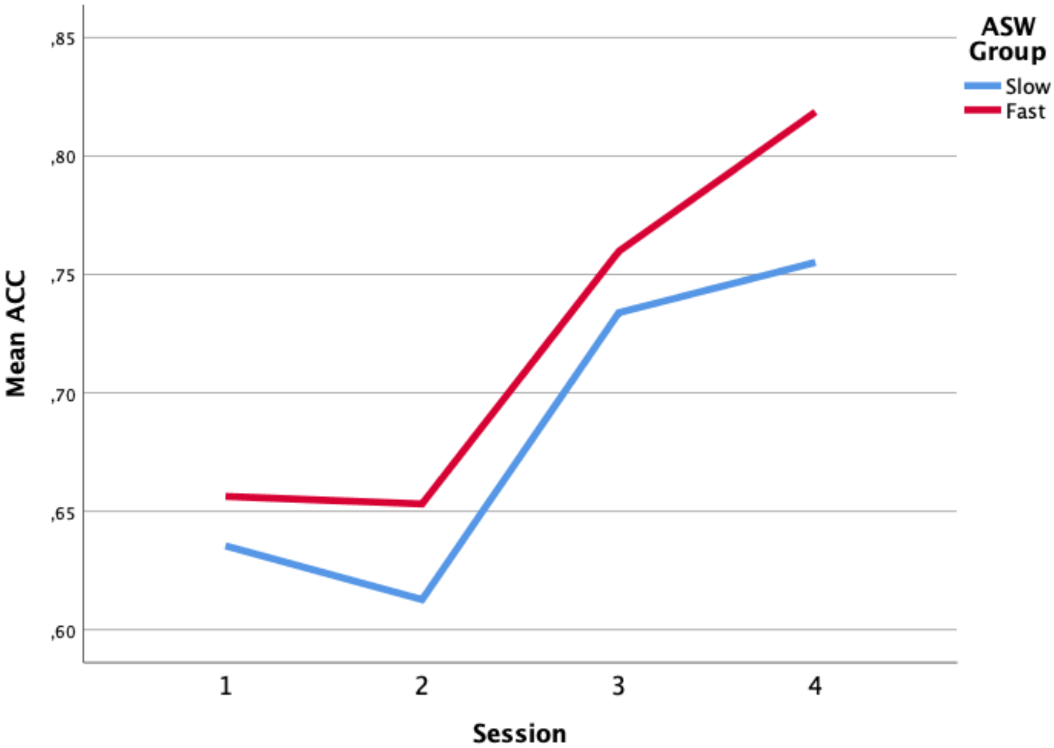

Figure 4: Two-way interaction for Session x ASW Group for AX Discrimination

4.3 Production Results

4.3.1 Immediate Repetition – Spectral Distance Scores

In the immediate repetition task the analysis performed to see gains in *SDS*, gains in SDS would be seen as a lower score, and this was performed by GLMM with the fixed factors being *Block*, (block 1 or block 2), *Session* (session 1, 2, 3, or 4) and *auditory Selective Attention* (ASA high or ASA low) and then separately, the next GLMM had the same fixed factors of *Block* and Session with *Auditory Attention Switching* (ASW fast or slow). The random factors include the *Subjects* and the *Item Number* (Table 8 and Appendix B: GLMM3 for parameter estimates).

Table 8: GLMM Analysis Immediate Repetition for SDS

Production	**Analysis 5-ASA**			**Analysis 6-ASW**		
SDS Scores	*F*	*df1, df2*	*p*	*F*	*df1, df2*	*p*
Block	0.207	1, 13.390	.649	0.019	1, 13.263	.890
Session	5.833	3, 13.390	.001	9.996	3, 13.263	<.001
Attn	3.577	1, 13.390	.059	1.330	1, 13.263	.249
Block*Session	0.895	3, 13.390	.443	0.474	3, 13.263	.700
Block*Attn	1.893	1, 13.390	.169	3.226	1, 13.263	.073
Session*Attn	3.712	3, 13.390	.011	5.060	1, 13.263	.002
Block*Session*Attn	1.746	3, 13.390	.155	0.074	3, 13.263	.979

When comparing the analysis of auditory selective attention, there is only a main effect found for *Session*. The Bonferroni-adjusted pairwise comparisons revealed that the main effect of *Session* was driven by the overall lower performance of SDS scores during the sessions, session one, (*M* = 1.45, *SE* = .02, *95%CI* = 1.41-1.49), session two, (*M* = 1.62, *SE* = .02, *95%CI* = .1.58-1.67), session three, (*M* = 1.59, *SE* = .02, *95%CI* = 1.54-1.63), and session four, (*M* = 1.76, *SE* = .02, *95%CI* = 1.71-.1.81). There was a two-way interaction between *Session* and *Selective Attention*, see Tables C9 and C10 in appendix C. This can be seen in Figure 5, for the low group there is a steady loss (upward trend) in performance of SDS scores through all the sessions, with a steep decline from session three to four. In the high group there is a decline from session one to two and sessions three to four, with a slight improvement in SDS scores for session two to three. Overall the high selective attention group performs worse, with higher mean SDS scores, when compared to the low selective attention group.

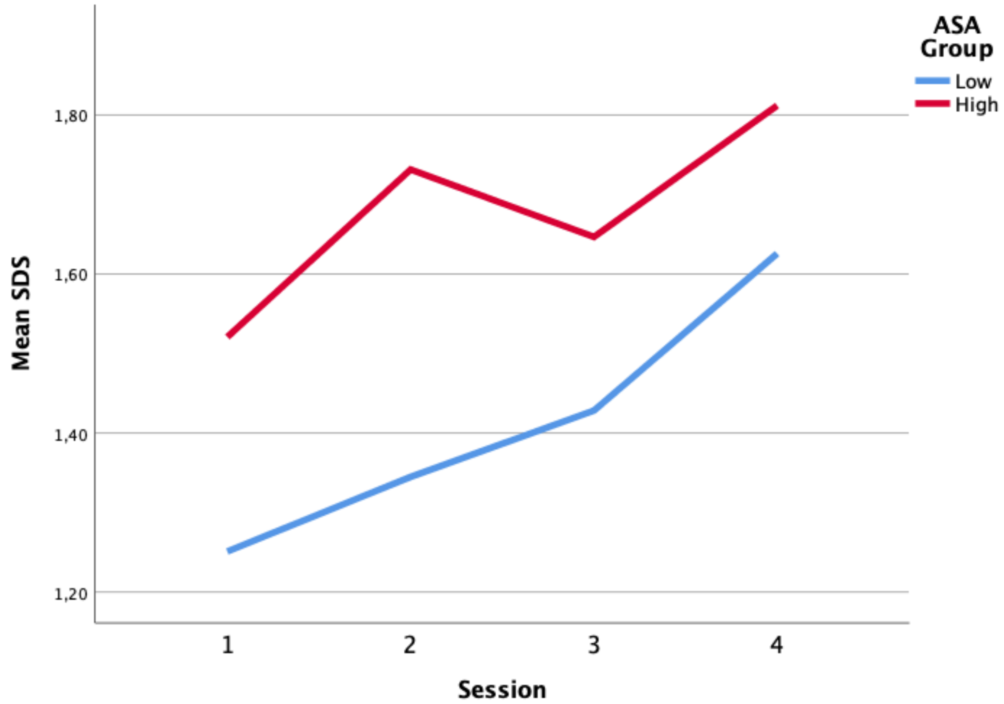

Figure 5: Two-way interaction for Session x ASA Group for Immediate Repetition

When observing the analysis of auditory attention switching, there is one main effect, for *Session,* as well. The Bonferroni-adjusted pairwise comparisons revealed that the main effect of *Session* was driven by the overall worse improvement of SDS scores during the sessions, session one, (*M* = 1.45, *SE* = .02, *95%CI* = 1.41-1.49), session two, (*M* = 1.62, *SE* = .02, *95%CI* = .1.58-1.67), session three, (*M* = 1.59, *SE* = .02, *95%CI* = 1.54-1.63), and session four, (*M* = 1.76, *SE* = .02, *95%CI* = 1.71-.1.81).. There was a two-way interaction between *Session* and *Attention Switching,* see Tables C11 and C12 in appendix C. This can be seen in Figure 6, for the slow group there is a steep decline in performance of SDS scores in sessions one to two and three to four, with a slight improvement from session two to three. In the fast group there is a decline in all the sessions, more pronounced from session one to two and three to four, with almost even performance from session two to three. Overall the fast attention switching group, (*M* = 1.67, *SE* = .03, *95%CI* = 1.61-1.73) performs worse when compared to the slow attention switching group, (*M* = 1.52, *SE* = .03, *95%CI* = 1.46-1.58).

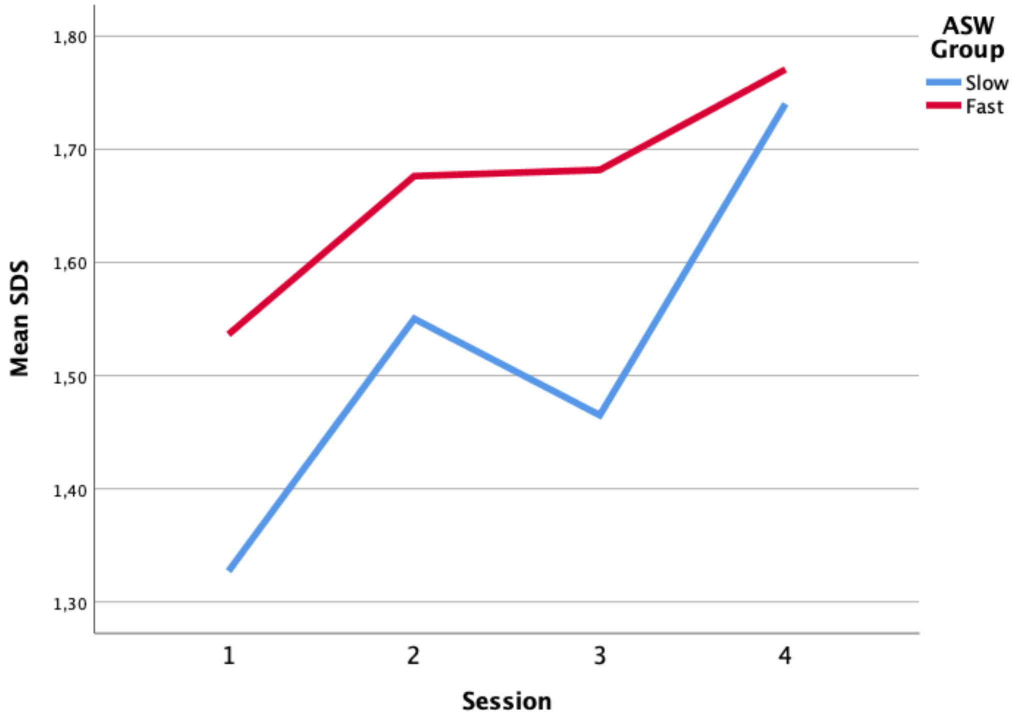

Figure 6: Two-way interaction for Session x ASW Group for Immediate Repetition

4.3.2. Immediate Repetition – Block Gains

The new *Gain* variable was now used in a GLMM analysis, with the fixed factors being *Session* (session 1, 2, 3, or 4) and *Auditory Selective Attention* (ASA high or ASA low) and then separately, the next GLMM had the same fixed factors of *Session* with *Auditory Attention Switching* (ASW fast or slow). The random factors include the *Subjects* and the *Item Number* (Table 9 and Appendix B: GLMM4 for parameter estimates).

Table 9: GLMM Analysis Immediate Repetition for Gains

Production	**Analysis 7-ASA**			**Analysis 8-ASW**		
Gains	*F*	*df1, df2*	*p*	*F*	*df1, df2*	*p*
Session	0.947	3, 6.712	.417	0.340	3, 6.648	.796
Attn	1.595	1, 6.712	.207	4.325	1, 6.648	.038
Session*Attn	3.008	3, 6.712	.029	0.069	3, 6.648	.977

When comparing the analysis of auditory selective attention, there were no main effects. There was a two-way interaction between *Session* and *Selective Attention* see Tables C13 and C14 in appendix C. The Bonferroni-adjusted pairwise comparisons revealed that the interaction is driven by the differences between the low, (*M* = .10, *SE* = .04, *95%CI* = -.012-.183) and the high ASA group, (*M* = -.05, *SE* = .04, *95%CI* = -.114-.024), p = .039 during session two. As seen in Figure 7, the low ASA group initially starts with higher within block gains, in session one and session two, with equal performance in session three and they continue to decline in session four. For the high ASA group, they start initially with higher SDS levels, worse performance, this continued for each session until session four, where they had within block gain improvements.

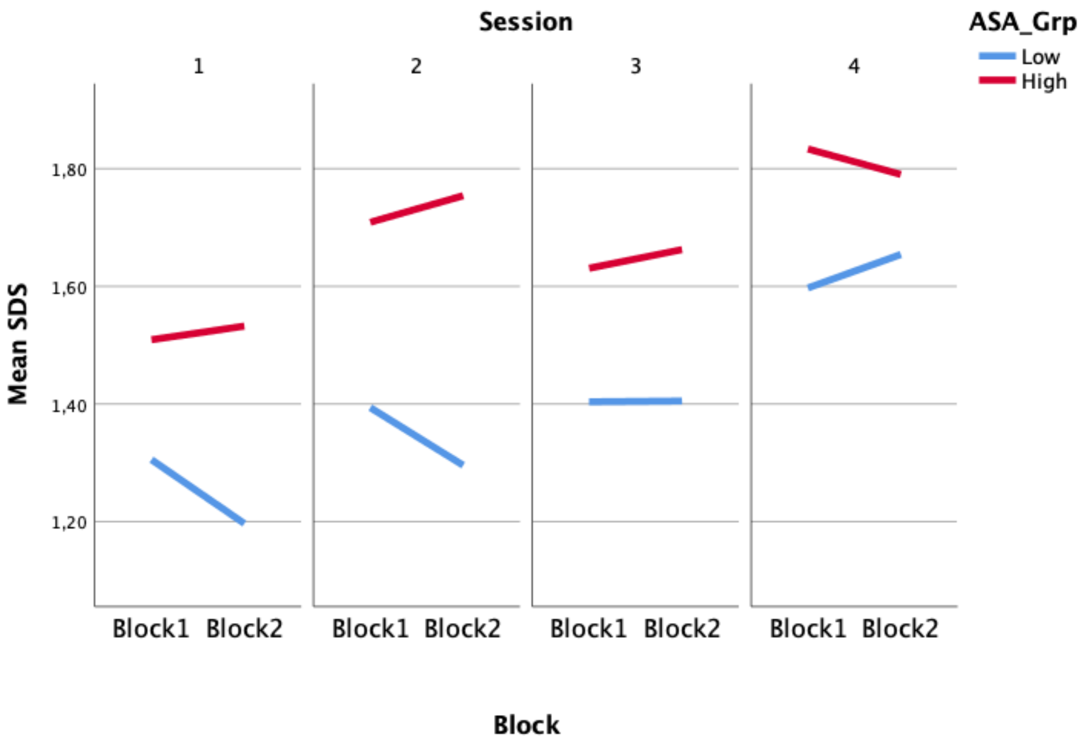

Figure 7: Two-way interaction for Session x ASA Group with Block gains for Immediate Repetition

In the case of auditory attention switching a significant main effect of attention switching was found. This was driven by the slow attention switching group (*M* = .03, *SE* = .02, *95%CI* = -.013-.073). performing at a higher level than the fast attention switching group (*M* = -.03, *SE* = .02, *95%CI* = -.064-.009), *p* = .043. No other interactions were found to be significant.

5. **Discussion**

The aim of this thesis intended to focus on two types of auditory attentional control, selective attention and attention switching and to compare the individual differences of the group of L1 Catalan/Spanish bilingual learners of English and the relationship between improvements within the HVPT sessions and between HVPT training sessions, with these sessions consisting of perception tasks and a production task.

Previous training studies (e.g., Aliaga-García & Mora, 2009; Cebrian & Carlet, 2014; Iverson & Evans, 2007) have shown improvements in L2 perception and production. Most studies have used a pre-, post-test design to elicit gains, and very few have examined gains from within and between the training sessions in a L2 setting in order to observe the learning conditions of the participants (e.g., Perrachione et al., 2011). As well, in a study by Mora and Mora-Plaza (2019), auditory selective attention and auditory attention switching tasks were combined with four sessions of HVPT. In line with the results from this thesis, they found that there was a significant relationship with gains in perception of the vowel contrast /æ/-/ʌ/ and auditory selective attention. The results in this thesis show that with the perception task there are significant interactions with auditory attentional control.

The identification task has a significant main effect of auditory selective attention, overall explaining that gains in this task were significantly related to selective attention. This increase in selective attention skills allows a focus on different speech dimensions, and for learners the acquisition of phonology in the L2 (Darcy et al., 2014). Interestingly, a three-way interaction between block, session and auditory attention switching occurred. The identification task is a multimodal task, containing phonetic, orthographic and visual representations, in the form of line drawings, of the auditorily presented words. Increased performance in attention switching skills could facilitate the transition between the auditory and visual domains (Lukas et al., 2014). Even though this interaction demonstrated differences between the groups, and improved results for the faster attention switching group, there was no clear relationship with improvements over blocks or sessions with attentional control being the factor.

In the AX discrimination task there was a significant main effect of auditory selective attention, also showing that selective attention and gains in this perception task were related, the high ASA group showing improvements over the low ASA group. This suggests that when acquiring this new contrast, e.g. the vowels /æ/-/ʌ/, the learners may have to restructure their previously obtained phonetic space and use attention skills to perceive and divide auditory dimensions or attend to new sounds that may have not been used as phonetic contrasts (Francis & Nusbaum, 2002). Again, a two-way, session and selective attention and a three-way interaction of block, session and auditory selective attention and alludes to the relationship between the improvements throughout these domains, but although the group of high ASA did show more gains in blocks and over the training session, there is no clear difference linking attentional skills to the improvements.

Previous studies that have used a production task together with the HVPT paradigm have shown improvements from pre-test to post-test (e.g. Aliaga-García & Mora, 2009; Carlet & Cebrian, 2019). In a study by Iino and Thomson (2018), Japanese learners of English were tested on perception and production of English phonemes with HVPT, both perception and production produced gains, but only slight gains for production compared to very high gains for perception. In the study by Darcy et al., (2014) no clear link between attention control skills and vowel production were found. For this thesis initially looking at production gains within the blocks and over the sessions, revealed no gain in any of the blocks and worse performance in the consecutive sessions. These findings may suggest that first, for many learner's perception proceeds production, so even though the participants were intermediate learners this is a reason some may have less gains than in perception tasks. Next is the concept of automaticity, which is the lack of attentional control while executing a cognitive function (Segalowitz & Hulstijn, 2005), with speech production the more proficient the more automatic speech becomes. During the immediate repetition production task, the instructions are to repeat the word as the native speaker just produced it. This may cause a possible awareness and attentional focus on the word and the attempt to produce a native like representation, hence less automaticity and worse performance. Lastly the immediate repetition task was the last of the training tasks, and most likely for some learners the most difficult, as the session of HVPT continued fatigue could have been a factor of the subsequent worse performance, especially knowing that the training sessions were training and the testing sessions were different.

In order to see possible gains of higher attentional control, participants were separated into groups that made gains within the blocks and those that did not. When this was done the participants were separated into a group that had gains and one that lacked gains., this showed no significant interaction with either of the auditory attention scores. A significant main effect of auditory attention switching was found, driven by the slow attention group performing much higher in gains between blocks than the fast attention switching group. It was posited that overly attending to production may actually lead to a lowering in performance, the group that has slower attention switching skills may in fact be essential to not focus on form and be automatic in production. A significant interaction was found between session and auditory selective attention. Interestingly, the high and low group for selective attention showed a similar pattern to the attention switching (fast and slow) groups. At the start in session one the low ASA group had higher mean block differences than the high ASA group, as sessions progressed the high group steadily improved, but the low ASA group dropped in gains and ended session four at a lower level than the high ASA group. Once again for the immediate repetition task auditory selective attention skills are a principal mechanism needed to perceive, and to eventually learn the vowel contrasts that are heard. In the immediate repetition task, a word is heard, it is produced by the learner, it is repeated and produced again, selective attention is needed to sustain and attend to each new word pair and perform well over the sessions, even if initially production gains were lower.

5.1 Limitations

All of the sessions had specific words, two minimal pairs per session, the words were produced by different speakers as well, some of the participants may have found a block of words easier than another. This may have occurred in session three where the words were easier to perceive than in session one. In future studies it may be important to match words on level of perception as well as production ease.

For L2 learners an already established phonological representation is difficult, HVPT has shown it can assist in this and help to correct these phonological misrepresentations, it may be a challenge in just four sessions of HVPT, further research may need to address this.

The analysis of the immediate repetition production task was limited to the second of the two repeated words, 16 out of the 32 words for each session. In future studies focusing on the immediate repetition production task may need to assess both words to see gains in the blocks and especially to be able to perceive relationships with attentional control.

6. **Conclusion**

This thesis showed that gains made in HVPT, within session blocks and over distinct consecutive sessions, are related to auditory attention control. The type of perception task will determine which type of auditory attention control will be more utilized, selective attention or attention switching. Previous research has shown that attentional control will correlate with gains made in perception (Darcy et al., 2014; Mora & Mora-Plaza, 2019), but here higher attentional control shows improved overall gains, with attention to the phonetic vowel contrast can assist learners in perceiving difficult L2 sounds that may not exist in their L1. The type of attention has been shown to determine improvements in the perception tasks, whereas auditory selective attention leads to gains in the AX discrimination task, and auditory attention switching will lead to gains in the identification task. Further studies to clearly link attentional control and the type of perception task used in phonetic training will need to be explored, this can include length of training and longer within sessions as well.

L2 production and auditory attentional control has been seen in this thesis to have some effect on gains, with improvement over sessions but not over blocks. Overall using spectral distance scores did not show any improvement over blocks or sessions. Production seems to lag behind perception, and some learners may have to attend to lower level skills and automatization has not yet occurred. Future studies may need to examine the type of training to enhance phonetic skills, to assess gains in production after training and gains related to within the training tasks. Better attention to the phonetic differences in the vowel contrast may lead to improved production. The HVPT already helps to stimulate selective attention with the use of variability in place of say just one speaker. Perhaps more variability in training may increase gains in production. Future studies may focus on the distinctive orientations of attention and effectiveness of varying paradigms.

Word Count: 9275

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Appendix A – Words/Non-words

List of words and non-words in the training tasks

Words		**Non-words**	
/æ/	**/ʌ/**	**/æ/**	**/ʌ/**
cat	cut	datt	dutt
match	much	fash	fush
mad	mud	thatt	thutt
ban	bun	tazz	tuzz
cap	cup	mab	mub
sack	suck	tam	tum
bag	bug	thack	thuck
mag	mug	chang	chung

Appendix B – Parameter Estimates

GLMM 1	Analysis 1 – ASA				Analysis 2 - ASW			
	β	*SE*	*t*	*95% CI*	*β*	*SE*	*t*	*95% CI*
Intercept	2.096	0.120	17.454	1.861-2.332	2.152	0.130	16.558	1.897-2.407
Session1	-0.929	0.106	-8.723	-1.138-0.720	-1.043	0.114	-9.128	-1.267--0.819
Session2	-0.713	0.109	-6.552	-0.926-0.500	-0.729	0.118	-6.202	-0.959--0.499
Session3	-0.048	0.114	-2.009	-0.452-0.006	-0.418	0.121	-3.454	-0.655--0.181
Block	-0.048	0.117	-0.410	-0.278-0.182	-0.187	0.125	-1.496	-0.432-0.058
Attn	-0.332	0.222	-1.496	-0.768-0.103	-0.425	0.211	-2-013	-0.839--0011
Session1 x Block	0.001	0.149	0.008	-0.291-0.294	0.104	0.158	0.658	-0.206-0.413
Session2 x Block	-0.037	0.152	-0.242	-0.335-0.262	0.075	0.162	0.463	-0.243-0.393
Session3 x Block	-0.101	0.159	-0.636	-0.412-0.219	0.225	0.168	1.337	-0.105-0.556
Session1 x Attn	-0.123	0.190	-0.657	-0.498-0.248	0.174	0.181	0.963	-0.181-0.529
Session2 x Attn	0.013	0.195	0.069	-0.370-0.396	0.038	0.185	0.204	-0.325-0.401
Session3 x Attn	-0.191	0.201	-0.948	-0.585-0.204	0.357	0.193	1.845	-0.022-0.736
Block x Attn	0.210	0.206	-1.019	-0.615-0.194	0.175	0.197	0.890	-0.211-0.562
Session1 x Attn x Block	0.193	0.264	0.731	-0.324-0.710	-0.035	0.254	-0.139	-0.532-0.462
Session2 x Attn x Block	0.180	0.270	0.666	-0.350-0.710	-0.150	0.258	-0.581	-0.657-0.357
Session3 x Attn x Block	0.221	0.278	0.794	-0.324-0.766	-0.636	0.268	-2.373	-1.162--0.111

GLMM 2	Analysis 3 - ASA				Analysis 4 - ASW			
	β	*SE*	*t*	*95% CI*	*β*	*SE*	*t*	*95% CI*
Intercept	-0.653	0.147	-4.448	-0.941-0.365	-0.733	0.151	-4.843	-1.030--0.436
Session1	1.064	0.124	8.598	0.822-1.307	1.092	0.126	8.702	0.846-1.338
Session2	0.406	0.091	4.469	0.228-0.584	0.411	0.093	4.436	0.230-0.593
Session3	0.308	0.065	4.706	0.179-0.436	0.306	0.067	4.538	0.174-0.438
Block	-0.234	0.061	-3.840	-0.353-0.114	-0.153	0.064	- 2.392	-0.279--0.028
Attn	-0.780	0.120	-6.490	-1.016-0.545	-0.427	0.121	-3.526	-0.665--0.190
Session1 x Block	0.246	0.079	3.129	0.092-0.400	0.143	0.083	1.724	-0.020-0.305
Session2 x Block	0.054	0.079	0.689	-0.100-0.208	0.063	0.083	0.760	-0.100-0.226
Session3 x Block	0.194	0.083	2.354	0.033-0.356	0.000	0.086	0.005	-0.168-0.169
Session1 x Attn	0.472	0.088	5.355	0.299-0.645	0.336	0.086	3.924	0.168-0.504
Session2 x Attn	0.384	0.089	4.325	0.210-0.557	0.323	0.086	3.745	0.154-0.492
Session3 x Attn	0.305	0.091	3.335	0.126-0.484	0.292	0.089	3.270	0.117-0.467
Block x Attn	0.390	0.105	3.700	0.183-0.597	0.139	0.102	1.358	-0.061-0.339
Session1 x Attn x Block	-0.508	0.139	-3.645	-0.782-0.235	-0.152	0.135	-1.128	-0.416-0.112
Session2 x Attn x Block	-0.306	0.140	-2.190	-0.581-0.032	-0.308	0.135	-2.280	-0.572--0.043
Session3 x Attn x Block	-0.700	0.143	-4.882	-0.980-0.419	-0.129	0.140	-0.921	-0.403-0.145

GLMM 3	Analysis 5 - ASA			
	β	*SE*	*t*	*95% CI*
Intercept	1.592	23.480.51	0.000	-47.983.66-47.986.85
Session1	-0.180	22.815.27	-0.000	-44.721.33-44.720.97
Session2	-0.111	22.815.27	-0.000	-44.721.27-44.721.04
Session3	-0.365	22.815.27	0.584	-44.721.52-44.720.79
Session4	-0.408	22.815.27	-0.000	-44.721.56-44.720.75
Block	0.027	0.047	0.584	-0.064-0.119
Attn1	-0.113	33.813.49	-0.000	-66.279.32-66.279.10
Attn2	0.024	33.813.49	0.000	-66.279.19-66.279.24
Session1 x Block	-0.028	0.066	-0.430	-0.158-0.101
Session2 x Block	-0.082	0.066	-1.251	-0.211-0.047
Session3 x Block	-0.080	0.066	-1.216	-0.209-0.049
Session1 x Attn	-0.195	0.088	-2.206	-0.369--0.022
Session2 x Attn	-0.334	0.089	-3.771	-0.507-0.160
Session3 x Attn	-0.124	0.089	-1.395	-0.299-0.050
Block x Attn	-0.099	0.088	-1.117	-0.272-0.075
Session1 x Attn x Block	0.223	0.125	1.783	-0.022-0.468
Session1 x Attn x Block	0.266	0.125	2.128	0.021-0.512
Session1 x Attn x Block	0.150	0.126	1.192	-0.097-0.397

GLMM 3	Analysis 6 – ASW			
	β	*SE*	*t*	*95% CI*
Intercept	1.694	24.724.83	0.000	-46.462.57-48.465.84
Session1	0.232	0.112	2.077	0.013-0.452
Session2	0.239	0.085	2.814	0.073-0.405
Session3	0.100	0.063	1.584	-0.024-0.223
Block	-0.024	0.053	-0.454	-0.127-0.079
Attn1	-0.477	24.724.83	-0.000	-48.463.68.46.463.73
Attn2	-0.420	24.724.83	-0.000	-48.463.68.63.463.79
Session1 x Block	0.036	0.075	0.485	-0.110-0.182
Session2 x Block	-0.021	0.074	-0.284	-0.167-0.124
Session3 x Block	-0.054	0.074	-0.724	-0.199-0.092
Session1 x Attn	-0.177	0.081	-2.199	-0.335--0.019
Session2 x Attn	.0.112	0.081	-1.389	-0.270-0.046
Session3 x Attn	-0.220	0.081	-2.712	-0.378--0.061
Block x Attn	0.055	0.081	0.685	-0.103-0.213
Session1 x Attn x Block	-0.003	0.114	-0.027	-0.227-0.220
Session1 x Attn x Block	0.033	0.114	0.286	-0.191-0.256
Session1 x Attn x Block	0.040	0.114	0.348	-0.184-0.264

GLMM 4		Analysis 7 - ASA				Analysis 8 - ASW			
		β	***SE***	***t***	***95% CI***	***β***	***SE***	***t***	***95% CI***
Intercept		-0.057	0.058	-0.985	-0.171-0.057	-0.024	0.040	-0.598	-0.103-0.055
Session1		0.166	0.075	2.196	0.018-0.314	0.012	0.053	0.232	-0.091-0.115
Session2		0.155	0.075	2.056	0.007-0.303	-0.022	0.053	-0.420	-0.125-0.081
Session3		0.047	0.075	0.626	-0.101-0.195	-0.036	0.053	-0.684	-0.139-0.067
Attn		0.089	0.068	1.306	-0.045-0.233	0.070	0.062	1.133	-0.051-0.191
Session1 x Attn		-0.221	0.089	-2.492	-0.395--0.047	-0.008	0.081	-0.105	-0.167-0.150
Session2 x Attn		-0.232	0.089	-2.618	-0.406--0.058	0.026	0.081	0.326	-0.132-0.185
Session3 x Attn		-9.111	0.089	-1.251	-0.285-0.063	0.011	0.081	0.131	-0.148-0.169

Appendix C- Extra Tables

Table C1- Three-Way interaction – Session x Block x ASW – Identification Task

Session	*Block*	*ASW Group*	*M*	*SE*	*95%CI - Lower*	*95%CI - Higher*
1	1	Slow	.71	.03	.648	.772
		Fast	.74	.02	.690	.777
	2	Slow	.70	.03	.635	.762
		Fast	.75	.02	.708	.799
2	1	Slow	.72	.03	.655	.778
		Fast	.78	.02	.747	.824
	2	Slow	.73	.03	.674	.793
		Fast	.81	.02	.767	.840
3	1	Slow	.78	.03	.718	.826
		Fast	.86	.02	.822	.882
	2	Slow	.84	.02	.793	.880
		Fast	.85	.02	.817	.878
4	1	Slow	.85	.02	.800	.885
		Fast	.88	.01	.848	.901
	2	Slow	.85	.02	.802	.886
		Fast	.90	.01	.870	.917

Table C2: Pairwise Comparisons - Three-Way interaction – Session x Block x ASW – Identification

Pairwise Contrasts

Block	*ASW_Grp*	*Session Pairwise Contrasts*	*Contrast Estimate*	*SE*	*t*	*df*	*Adj. Sig.*	*95% CI Lower*	*95% CI Upper*
1	Slow	1 - 2	-.007	.026	-.262	14512	.793	-.058	.045
		1 - 3	-.062	.025	-2.468	14512	.041	-.122	-.002
		1 - 4	-.133	.025	-5.345	14512	.000	-.199	-.068
		2 - 1	.007	.026	.262	14512	.793	-.045	.058
		2 - 3	-.055	.025	-2.189	14512	.057	-.112	.001
		2 - 4	-.127	.025	-5.074	14512	.000	-.191	-.062
		3 - 1	.062	.025	2.468	14512	.041	.002	.122
		3 - 2	.055	.025	2.189	14512	.057	-.001	.112
		3 - 4	-.071	.022	-3.186	14512	.006	-.127	-.015
		4 - 1	.133	.025	5.345	14512	.000	.068	.199
		4 - 2	.127	.025	5.074	14512	.000	.062	.191
		4 - 3	.071	.022	3.186	14512	.006	.015	.127
	Fast	1 - 2	-.052	.018	-2.864	14512	.008	-.092	-.011
		1 - 3	-.119	.018	-6.707	14512	.000	-.164	-.073
		1 - 4	-.141	.018	-7.871	14512	.000	-.188	-.094
		2 - 1	.052	.018	2.864	14512	.008	.011	.092
		2 - 3	-.067	.016	-4.154	14512	.000	-.106	-.028
		2 - 4	-.089	.016	-5.532	14512	.000	-.130	-.049
		3 - 1	.119	.018	6.707	14512	.000	.073	.164
		3 - 2	.067	.016	4.154	14512	.000	.028	.106
		3 - 4	-.022	.014	-1.630	14512	.103	-.049	.005
		4 - 1	.141	.018	7.871	14512	.000	.094	.188
		4 - 2	.089	.016	5.532	14512	.000	.049	.130
		4 - 3	.022	.014	1.630	14512	.103	-.005	.049
2	Slow	1 - 2	-.036	.026	-1.363	14512	.346	-.094	.023
		1 - 3	-.139	.025	-5.476	14512	.000	-.204	-.073
		1 - 4	-.147	.025	-5.767	14512	.000	-.214	-.080
		2 - 1	.036	.026	1.363	14512	.346	-.023	.094
		2 - 3	-.103	.024	-4.258	14512	.000	-.161	-.045
		2 - 4	-.111	.024	-4.578	14512	.000	-.172	-.050
		3 - 1	.139	.025	5.476	14512	.000	.073	.204
		3 - 2	.103	.024	4.258	14512	.000	.045	.161

		3 - 4	-.008	.020	-.402	14512	.688	-.047	.031
		4 - 1	.147	.025	5.767	14512	.000	.080	.214
		4 - 2	.111	.024	4.578	14512	.000	.050	.172
		4 - 3	.008	.020	.402	14512	.688	-.031	.047
	Fast	1 - 2	-.054	.017	-3.077	14512	.004	-.093	-.015
		1 - 3	-.098	.017	-5.699	14512	.000	-.141	-.055
		1 - 4	-.144	.018	-8.179	14512	.000	-.190	-.097
		2 - 1	.054	.017	3.077	14512	.004	.015	.093
		2 - 3	-.044	.016	-2.827	14512	.005	-.075	-.014
		2 - 4	-.090	.016	-5.806	14512	.000	-.130	-.050
		3 - 1	.098	.017	5.699	14512	.000	.055	.141
		3 - 2	.044	.016	2.827	14512	.005	.014	.075
		3 - 4	-.046	.014	-3.376	14512	.002	-.078	-.013
		4 - 1	.144	.018	8.179	14512	.000	.097	.190
		4 - 2	.090	.016	5.806	14512	.000	.050	.130
		4 - 3	.046	.014	3.376	14512	.002	.013	.078

Table C3: Two-way Interaction - ASA x Session – AX Discrimination Task

Session	ASA	*M*	*SE*	*95%CI-Lower*	*95%CI-Upper*
1	Low	.60	.009	.58	.61
	High	.67	.005	.66	.68
2	Low	.58	.009	.56	.60
	High	.66	.005	.65	.67
3	Low	.67	.008	.65	.69
	High	.78	.005	.77	.79
4	Low	.73	.008	.71	.74
	High	.82	.004	.81	.83

Table C4: Pairwise Comparisons - ASA x Session – AX Discrimination Task

ASA	Session Pairwise Contrasts	Contrast Estimate	SE	t	df	Adj. Sig.	95% CI Lower	95% CI Upper
Low	1 - 2	.179	.015	11.684	44144	.000	.139	.219
	1 - 3	.243	.019	12.707	44144	.000	.194	.292
	1 - 4	.307	.022	13.996	44144	.000	.252	.362
	2 - 1	-.179	.015	-11.684	44144	.000	-.219	-.139
	2 - 3	.064	.013	4.810	44144	.000	.038	.090
	2 - 4	.128	.015	8.409	44144	.000	.092	.165
	3 - 1	-.243	.019	-12.707	44144	.000	-.292	-.194
	3 - 2	-.064	.013	-4.810	44144	.000	-.090	-.038
	3 - 4	.064	.011	5.625	44144	.000	.039	.090
	4 - 1	-.307	.022	-13.996	44144	.000	-.362	-.252
	4 - 2	-.128	.015	-8.409	44144	.000	-.165	-.092
	4 - 3	-.064	.011	-5.625	44144	.000	-.090	-.039
High	1 - 2	.186	.013	14.797	44144	.000	.153	.220
	1 - 3	.193	.020	9.496	44144	.000	.141	.246
	1 - 4	.286	.026	11.181	44144	.000	.222	.350
	2 - 1	-.186	.013	-14.797	44144	.000	-.220	-.153
	2 - 3	.007	.013	.538	44144	.591	-.018	.032
	2 - 4	.100	.017	5.790	44144	.000	.061	.139
	3 - 1	-.193	.020	-9.496	44144	.000	-.246	-.141
	3 - 2	-.007	.013	-.538	44144	.591	-.032	.018
	3 - 4	.093	.011	8.373	44144	.000	.067	.120
	4 - 1	-.286	.026	-11.181	44144	.000	-.350	-.222
	4 - 2	-.100	.017	-5.790	44144	.000	-.139	-.061
	4 - 3	-.093	.011	-8.373	44144	.000	-.120	-.067

Table C5: Three-Way interaction – Session x Block x ASA – AX Discrimination Task

Session	*Block*	*ASA Group*	*M*	*SE*	*95%CI - Lower*	*95%CI - Higher*
1	1	Low	.58	.014	.55	.61
		High	.67	.008	.65	.69
	2	Low	.61	.011	.58	.63
		High	.67	.007	.65	.68
2	1	Low	.57	.014	.54	.60
		High	.64	.009	.62	.65
	2	Low	.59	.012	.57	.61
		High	.68	.007	.66	.69
3	1	Low	.63	.014	.60	.65
		High	.78	.007	.76	.79
	2	Low	.70	.011	.68	.72
		High	.78	.006	.77	.79
4	1	Low	.74	.013	.72	.77
		High	.80	.007	.79	.82
	2	Low	.72	.011	.69	.74
		High	.84	.005	.83	.85

Table C6: Pairwise Comparisons - Three-Way interaction – Session x Block x ASA – AX Discrimination

Session	*Block*	*ASA Pairwise Contrasts*	*Contrast Estimate*	*SE*	*t*	*df*	*Adj. Sig.*	*95% CI Lower*	*95% CI Upper*
1	1	Low - High	-.104	.030	-3.458	44144	.001	-.163	-.045
		High - Low	.104	.030	3.458	44144	.001	.045	.163
	2	Low - High	-.074	.028	-2.636	44144	.008	-.130	-.019
		High - Low	.074	.028	2.636	44144	.008	.019	.130
2	1	Low - High	-.071	.027	-2.581	44144	.010	-.124	-.017
		High - Low	.071	.027	2.581	44144	.010	.017	.124
	2	Low - High	-.093	.027	-3.490	44144	.000	-.145	-.041
		High - Low	.093	.027	3.490	44144	.000	.041	.145
3	1	Low - High	-.167	.025	-6.567	44144	.000	-.217	-.117
		High - Low	.167	.025	6.567	44144	.000	.117	.217
	2	Low - High	-.108	.026	-4.137	44144	.000	-.159	-.057
		High - Low	.108	.026	4.137	44144	.000	.057	.159
4	1	Low - High	-.072	.024	-3.019	44144	.003	-.119	-.025
		High - Low	.072	.024	3.019	44144	.003	.025	.119
	2	Low - High	-.148	.023	-6.378	44144	.000	-.194	-.103
		High - Low	.148	.023	6.378	44144	.000	.103	.194

Table C7: Two-Way interaction – Session x ASW – AX Discrimination

ASW	*Session*	*M*	*SE*	*95%CI- Lower*	*95%CI- Upper*
Slow	1	.64	.008	.62	.65
	2	.61	.008	.60	.63
	3	.73	.007	.72	.75
	4	.76	.007	.74	.77
Fast	1	.66	.006	.65	.67
	2	.65	.006	.64	.66
	3	.76	.005	.75	.77
	4	.82	.005	.81	.83

Table C8: Pairwise Comparisons - Two-Way interaction – Session x ASW – AX Discrimination

ASW	*Session Pairwise Contrasts*	*Contrast Estimate*	*SE*	*t*	*df*	*Adj. Sig.*	*95% CI Lower*	*95% CI Upper*
Slow	1 - 2	.197	.015	13.401	43475	.000	.158	.236
	1 - 3	.217	.021	10.458	43475	.000	.164	.271
	1 - 4	.327	.023	14.261	43475	.000	.270	.385
	2 - 1	-.197	.015	-13.401	43475	.000	-.236	-.158
	2 - 3	.020	.014	1.415	43475	.157	-.008	.049
	2 - 4	.130	.016	8.243	43475	.000	.095	.166
	3 - 1	-.217	.021	-10.458	43475	.000	-.271	-.164
	3 - 2	-.020	.014	-1.415	43475	.157	-.049	.008
	3 - 4	.110	.012	9.147	43475	.000	.081	.139
	4 - 1	-.327	.023	-14.261	43475	.000	-.385	-.270
	4 - 2	-.130	.016	-8.243	43475	.000	-.166	-.095
	4 - 3	-.110	.012	-9.147	43475	.000	-.139	-.081
Fast	1 - 2	.180	.013	13.970	43475	.000	.146	.214
	1 - 3	.211	.020	10.567	43475	.000	.159	.262
	1 - 4	.279	.026	10.892	43475	.000	.215	.342
	2 - 1	-.180	.013	-13.970	43475	.000	-.214	-.146
	2 - 3	.031	.013	2.485	43475	.013	.007	.056
	2 - 4	.099	.017	5.698	43475	.000	.060	.138
	3 - 1	-.211	.020	-10.567	43475	.000	-.262	-.159
	3 - 2	-.031	.013	-2.485	43475	.013	-.056	-.007
	3 - 4	.068	.011	5.942	43475	.000	.040	.095
	4 - 1	-.279	.026	-10.892	43475	.000	-.342	-.215
	4 - 2	-.099	.017	-5.698	43475	.000	-.138	-.060
	4 - 3	-.068	.011	-5.942	43475	.000	-.095	-.040

Table C9: Two-Way interaction – Session x ASA – SDS

Session	*ASA*	*M*	*SE*	*95%CI-Lower*	*95%CI-Upper*
1	Low	1.25	.028	1.19	1.30
	High	1.52	.025	1.47	1.57
2	Low	1.34	.030	1.28	1.40
	High	1.73	.030	1.67	1.78
3	Low	1.42	.038	1.35	1.50
	High	1.64	.026	1.59	1.69
4	Low	1.62	.046	1.53	1.71
	High	1.81	.029	1.75	1.86

Table C10: Pairwise Comparisons - Two-Way interaction – Session x ASA – SDS

							95% CI	
Session	*ASA Pairwise Contrasts*	*Contrast Estimate*	*SE*	*t*	*df*	*Adj. Sig.*	*Lower*	*Upper*
1	Low - High	-.279	.145	-1.916	13394	.055	-.564	.006
	High - Low	.279	.145	1.916	13394	.055	-.006	.564
2	Low - High	-.395	.145	-2.719	13394	.007	-.680	-.110
	High - Low	.395	.145	2.719	13394	.007	.110	.680
3	Low - High	-.255	.146	-1.748	13394	.080	-.540	.031
	High - Low	.255	.146	1.748	13394	.080	-.031	.540
4	Low - High	-.195	.145	-1.340	13394	.180	-.480	.090
	High - Low	.195	.145	1.340	13394	.180	-.090	.480

Table C11: Two-Way interaction – Session x ASW – SDS

Session	*ASA*	*M*	*SE*	*95%CI- Lower*	*95%CI-Upper*
1	Slow	1.33	.027	1.27	1.38
	Fast	1.54	.029	1.48	1.59
2	Slow	1.55	.032	1.49	1.61
	Fast	1.68	.034	1.61	1.74
3	Slow	1.47	.032	1.40	1.53
	Fast	1.68	.030	1.62	1.74
4	Slow	1.74	.039	1.66	1.81
	Fast	1.77	.032	1.71	1.83

Table C12: Pairwise Comparisons - Two-Way interaction – Session x ASW – SDS

Session	*ASW Pairwise Contrasts*	*Contrast Estimate*	*SE*	*t*	*df*	*Adj. Sig.*	*95% CI Lower*	*95% CI Upper*
1	Slow - Fast	-.220	.134	-1.637	13265	.102	-.483	.043
	Fast - Slow	.220	.134	1.637	13265	.102	-.043	.483
2	Slow - Fast	-.137	.134	-1.017	13265	.309	-.400	.127
	Fast - Slow	.137	.134	1.017	13265	.309	-.127	.400
3	Slow - Fast	-.255	.134	-1.896	13265	.058	-.518	.009
	Fast - Slow	.255	.134	1.896	13265	.058	-.009	.518
4	Slow - Fast	-.041	.134	-.304	13265	.761	-.304	.222
	Fast - Slow	.041	.134	.304	13265	.761	-.222	.304

Table C13: Two-Way interaction – Session x ASA – SDS Gain

Session	*ASA*	*M*	*SE*	*95%CI-Lower*	*95%CI-Upper*
1	High	-.023	.032	-.087	.040
	Low	.109	.042	.025	.191
2	High	-.045	.035	-.114	.024
	Low	.098	.043	.012	.183
3	High	-.032	.034	-.098	.035
	Low	-.010	.051	-.111	.092
4	High	.032	.035	-.037	.101
	Low	-.057	.052	-.161	.047

Table C14: Pairwise Comparisons - Two-Way interaction – Session x ASA – SDS Gain

Session	*ASA Pairwise Contrasts*	*Contrast Estimate*	*SE*	*t*	*df*	*Adj. Sig.*	*95% CI Lower*	*95% CI Upper*
1	High - Low	-.131	.069	-1.898	6712	.058	-.266	.004
	Low - High	.131	.069	1.898	6712	.058	-.004	.266
2	High - Low	-.142	.069	-2.060	6712	.039	-.277	-.007
	Low - High	.142	.069	2.060	6712	.039	.007	.277
3	High - Low	-.026	.069	-.371	6712	.711	-.161	.110
	Low - High	.026	.069	.371	6712	.711	-.110	.161
4	High - Low	.090	.069	1.309	6712	.191	-.045	.225
	Low - High	-.090	.069	-1.309	6712	.191	-.225	.045