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Relationship Between Intelligibility and Response Accuracy of the Amazon Echo in Individuals with Amyotrophic Lateral Sclerosis Exhibiting Mild-Moderate Dysarthria

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Relationship Between Intelligibility and Response Accuracy of the Amazon Echo in Individuals with Amyotrophic Lateral Sclerosis Exhibiting Mild-Moderate Dysarthria

by

Caroline A. Layden

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science with a concentration in Speech Language Pathology Department of Communication Sciences and Disorders College of Behavioral and Community Sciences University of South Florida

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ABSTRACT

There is an ever-growing and increasing amount of technology options that use speech recognition software. Currently, the market includes smartphones, computers, and individual smart home personal assistants that allow for hands-free access to this technology. Research studies have explored the utility of these assistive devices for the completion of activities of daily living; however, there is limited research looking at the accuracy of voice recognition software within smart home personal assistants in populations with disordered speech. In persons with amyotrophic lateral sclerosis (ALS), symptoms include changes to motor functions, speech in particular, and it is unknown how some of these devices may respond to their disordered speech. The present study aimed to examine the accuracy of the Amazon Echo to respond appropriately to commands given by dysarthric patients with ALS. Participants were asked to read a variety of commands to an Amazon Echo. The sentences and responses by the Amazon Echo were audio-recorded for transcription and intelligibility ratings, which were then analyzed to look for relationships between intelligibility, auditory-perceptual features of speech, and sentence type. Results revealed there was no significant relationship between command intelligibility and accuracy of response by the Amazon Echo, nor was there a significant relationship between any of the auditory-perceptual ratings and accuracy of response. There was, however, a significant and positive association between conversational intelligibility and accuracy of responses by the Amazon Echo. This study provides support for use of hands-free assistive technology in patients with ALS to aid in the maintenance of quality of life and activities of daily living.
INTRODUCTION

Amyotrophic lateral sclerosis (ALS) is the most prevalent motor neuron disease in the U.S. population, affecting nearly 5.0 individuals per 100,000 (Metah et al, 2016). ALS results in the progressive degeneration of both upper motor neurons in the cerebral cortex and lower motor neurons in the brainstem and spinal cord (Rowland & Schneider, 2001). The initial onset of symptoms may present as a spinal onset, bulbar onset, or a mixture of both. Despite onset type, the degeneration of motor neurons leads to muscular weakness, paralysis, and atrophy of vital systems throughout the body, which will inevitably lead to death as the respiratory system becomes compromised (Wijesekera & Leigh, 2009). To date, there is no known cure for ALS, which leaves symptom management and compensation as the only treatment options. Collaboration between the patient, caregivers, and medical care team is essential in order to maintain quality of life and plan for/select various management options.

Spinal vs. Bulbar Onset

Of onset types, spinal onset, or limb onset, is the most common, with the incidence ranging from approximately 65%-70% of cases (Hardiman, Van Den Berg, & Kiernan, 2011; Kiernan et al., 2011). A key feature of this onset type is the initial degeneration of lower motor neurons of the spinal cord. Notable differences in presentation include more marked changes to, and difficulties with, appendicular motor control and movement (Rowland & Schneider, 2001). Over time, symptoms associated with bulbar dysfunction will begin to become apparent as well (Kiernan et al., 2011). While this is not the case for everyone, a person with spinal onset ALS may not experience a significant decline in speech intelligibility until an average of 34 months
post diagnosis (Beukelman & Ball, 2002). They are more likely to rely on their speech while completing and participating in their activities of daily living (ADLs) such as maintaining a home, daily social routines, or work-related activities, for a longer amount of time than an individuals with bulbar onset ALS.

In contrast to spinal onset, bulbar onset ALS targets lower motor neurons in the brainstem controlling corticobulbar functions first (Wijesekera & Leigh, 2009). As such, early symptoms of a bulbar onset ALS may be dysarthric speech characterized by changes in vocal quality, resonance, and articulatory precision, or some degree of dysphagia (Wijesekera & Leigh, 2009). Individuals with a bulbar onset ALS will likely have a more advanced form of dysarthria or reduced intelligibility closer to the initial onset of symptoms. The characteristic vocal features of persons with bulbar ALS may include spastic, flaccid, or mixed dysarthria with reduced loudness, labored breathing, increased nasality, reduced rate of speech, and reduced intelligibility (Ng & Khan, 2012).

Dysarthria in ALS

Dysarthria is one of the most common symptoms in ALS and is one of the earliest symptoms in approximately 25% of cases (Tomik & Guiloff, 2010). While there is not a single type of dysarthria seen in ALS, or even in onset type, there are several types that are more commonly found in ALS including spastic, flaccid, and mixed spastic-flaccid. The presentation of dysarthric symptoms largely depends on the progression of the disease and the proportion of lower motor neuron damage to upper motor neuron damage (Darley, Aronson, & Brown, 1969), and diagnosis may change as the disease progresses (Duffy, 2013). Spastic dysarthria is typically characterized by a strained or harsh vocal quality, monopitch, monoloudness, slowed rate of speech, reduced range of motion of articulatory structures, reduced maximum phonation time,
imprecise consonants, and incomplete velopharyngeal movement (Duffy, 2013). Flaccid dysarthria is typically characterized by breathiness, short phrases, audible inspirations, hypernasality, imprecise consonants, nasal emissions, short phrases, harsh voice, monoloudness, and monopitch (Duffy, 2013). Mixed flaccid-spastic dysarthria would include symptoms of both of the above mentioned dysarthrias (Darley, Aronson, & Brown, 1969).

As ALS is a progressive neurological disease, dysarthria severity will change over time. To determine the severity level, various vocal characteristics and speech subsystems are assessed, including the respiratory, phonatory, resonatory, articulatory, rate of speech, prosody, stress, and intelligibility, to name a few (Darley, Aronson, & Brown, 1969). Rating scales provide clinicians quantifiable subjective measures to track these characteristics. Anchors such as “normal functioning” and “severely impaired” define ratings at both ends of a rating scale. While this has raised concerns about both inter-rater and intra-rater reliability, Bunton and colleagues (2007) found that experienced clinicians demonstrated good inter- and intra-rater reliability when rating dysarthrias using the various auditory-perceptual characteristics laid out by Darley, Aronson, and Brown (1969).

**Cognitive Functioning**

Difficulties with motor and speech coordination are not the only symptoms present in ALS. There have been many behavioral and cognitive changes noted as well. Frontotemporal dementia is a comorbid disease found in 5-15% of persons with ALS (Kiernan et al., 2011). Characteristics of frontotemporal dementia associated with ALS may include problems with executive functioning, changes in behavior, and increased impulsivity. These changes can contribute to difficulties following routines and completing activities of daily living. Not all persons with ALS will develop dementia, but some may demonstrate a mild-moderate cognitive
impairment (Raaphorst et al., 2010). Rippon and colleagues (2006) estimated the percentage of persons with ALS having some amount of cognitive impairment to be 30%. Another study estimated that percentage to have an even greater range, approximately 33-51% (Ringholz et al., 2005). In yet another study, it was suggested that mild cognitive impairment may be even more prevalent than previously suspected, and due to biases in published literature, methods used when testing, and stage of severe motor and speech impairment at testing, may contribute to the widely varying ranges presented in the literature (Raaphorst et al., 2010). As there is such variability in the current literature, it suggests the need for further research into the type and extent of cognitive dysfunction found with ALS to better serve this population.

Regardless of exact numbers, it is clear that mild cognitive impairment is a possible symptom in at least a proportion of patients with ALS. Mild cognitive impairment has been found across both onset types (Raaphorst et al., 2010). Although many studies have investigated the correlation between onset type and cognitive impairment, no correlation has been found to suggest that cognitive impairment will occur more frequently based on spinal or bulbar presentations (Beeldman et al., 2016; Massman et al., 1996; Raaphorst et al., 2010).

**Activities of Daily Living and Assistive Technology**

As the disease progresses, many aspects of one’s life can be affected, but a focus of intervention should be on maintaining independence and continuing one’s desired routines and interactions through whatever means possible, including use of assistive technology. Assistive technology (AT) is much like the name suggests; it is, any sort of device or program that is designed with the aim of meeting and assisting the needs of an individual. This could be through supporting mobility and ambulation, communication, vision, or cognition (Mendohlson & Fox, 2002). One type of AT frequently used with individuals with ALS is augmentative and
alternative communication (AAC). AAC can aid and support communication, and help to prevent and remediate communicative breakdowns. The most common reasons for AAC use among individuals with ALS, as indicated by caregivers, include communication and clarification of basic wants and needs, transmission of information, and maintenance of social interactions (Fried-Oken et al., 2006). Although the symptoms of ALS create new barriers and challenges for these individuals, they are capable of maintaining and engaging in meaningful social interactions with the support of AAC technologies throughout the disease course.

Speech Language Pathologists (SLPs), just one of many on the multidisciplinary team working with these individuals, are key players in finding a device or tool to suit the immediate needs of the individual, as well as providing instruction to the individual and caregiver in regards to using the assistive technology. Ball and Beukelman (2004) found that 90% of individuals with ALS accepted the use of AAC, with an additional 6% eventually accepting the use of AAC following some delay after the recommendation. Only 4% of those included in the study chose not to accept the use of AAC (Ball & Beukelman, 2004). These numbers show the prevalence and importance of assistive technology in the lives of these individuals, but it is key that in implementing assistive technology, adequate support and instruction is provided to receive the maximum benefits. It has been observed that when clinicians focus treatment on maintaining ADLs, as well as supporting communication with others, individuals with ALS report a higher the quality of life (Light & McNaughton, 2015).

The choice of device is dependent on the individual and what would best meet their needs to engage actively in activities of daily living (Brown-Triolo, 2002). This means the individual’s likes and dislikes, wants and needs, physical capabilities and challenges are considered in device selection. There are low-tech devices, such as a notepad, boogie board, laser pointer, and
communication boards (Beukelman, Garrett, & Yorkston, 2007). These aids can be considered to support both communication and cognition. All of these examples are lightweight and portable, so they can be used within the home or taken out into the community. They do require that the individual using them has sufficient motor control to hold and manipulate a pen, write using a finger, or point to a word or picture. Alternatively, low-tech devices can be utilized with caregiver assistance or partner assisted visual scanning. High-tech options can include a smartphone, iPad or tablet, computers, and specialized speech generating devices (SGDs) (Beukelman, Garrett, & Yorkston, 2007). These options can greatly enhance a person’s independent communication success with many of the features and applications allowing utilization of a computerized voice for novel speech output. Although they were not created as a tool specific for enhancing cognition and supporting memory, with some adaptations the devices can function as such as well.

**Smart Home Personal Assistant**

As technology advances and becomes more ingrained in today’s society, a new and more commonplace item being marketed is that of the Smart Home Personal Assistants (Chan, Campo, Estève, & Fourniols, 2009). These devices are accessed hands-free through voice control and have the capability to perform many tasks for the user. These tasks may include playing music, telling a joke, or answering a question. By performing a quick internet search the device can answer such things as “What’s the weather like?” “How long will it take me to get to school?” and much more. These devices also have many features that can assist an individual in completing tasks of daily living, such as setting timers, reminders, and appointments. Currently there are many different types of Smart Home Personal Systems available to the public. These include Google Corporation’s Google Home (Google Corporation, 2017), the Amazon Echo
(Amazon.com, Inc, 2018), Microsoft’s Invoke (Microsoft Corporation, 2017), and the recently announced Apple Home Pod (Apple Corporation, 2017). All of these Smart Home Personal Assistants are created very similarly and perform similar tasks. The differences lie in the price of the devices, software used in each device, as well as in speaker and microphone quality.

Amazon manufactures the Amazon Echo, which is currently available in five different models, the Echo Dot, Echo, Tap, Echo Spot, and Echo Show, which offer increased quality in technology used, respectively. The personal assistant is referred to as Alexa, and this name is used as a “wake phrase” to activate the device and begin a command. These devices remain running in the background, but they will be in sleep mode until the waking phrase is spoken. The company boasts that the device can be used from across the room from up to twenty feet away (“Amazon Alexa Voice Service: Learn,” 2017). This feature can be beneficial for an individual who may require increased respiratory effort to maintain speech loudness or experience increased difficulty with ambulation. Another helpful function of the Amazon Echo is its ability to recognize the voice of multiple speakers. This feature is helpful because it can connect information to that individual’s voice, such as their own personal messages, emails, online calendars, and playlists. The Amazon Echo also has the ability to connect to other smart devices throughout the home such as a smart TV, lamps, and other environmental controls (“Connect Your Device to Alexa,” 2017). This allows an individual to access and control their environment hands-free, using only their voice. If an individual can still use their voice, while having poor motor control, they could still control their environment and participate in many common ADLs.

**Smart Technology Use in Other Populations**

As automatic speech recognition is refined and included in more common household products, it has the potential to be used in therapeutic and clinical settings. These products are
becoming increasingly sensitive and refined to accurately recognize and respond to differences in speech sound productions. Speech-language pathologists and health care clinicians have been taking notice of these developments, and current trends suggest that smart technology is being incorporated in both research settings and clinical settings, with a focus on increasing one’s access to household objects and increasing participation in activities of daily living (Boster, & McCarthy, 2017). Many studies have looked into the efficacy of using smart technology as an external memory aid (EMA) and found evidence to support its usage with a variety of patient populations. Svoboda and colleagues (2012) found that 10 individuals, all with a moderate-severe memory impairment, successfully utilized and generalized the use of their smartphone as an EMA to their daily lives to increase participation in ADLs. Similar results were found in a randomized controlled trial with 42 individuals with TBI; a statistically significant difference was found between the groups using a personal digital assistant (PDA) and the control group on functional memory tasks (Lannin et al., 2014). These studies have looked at enhancing the individual's ability to complete a specific action at a specific time, or reminders to enhance the individual’s ability to successfully follow multi-step directions in completing tasks (Lancioni et al., 2014). Some researchers have investigated the use of specific smartphone applications (apps), such as Google Calendar (Google Corporation, 2017), a free app to organize appointments and easily set up reminders and alarms, which can be used on any of the owner’s devices. Haj et al (2017) found that persons with Alzheimer’s disease demonstrating difficulty with prospective memory, or tasks and sequences that will occur in the future, benefited from the instruction and use of the Google Calendar app (Haj et al., 2017). Another study compared the use of Google calendar to traditional use of a paper-and-pencil diary in patients with acquired brain injury, such as TBI, anoxia, CVA, or arteriovenous malformation. The authors found that
the group using Google Calendar kept track of the appointments more successfully than the group relying on a diary (McDonald et al., 2011). Evidence continues to support the efficacy and use of smart technologies, such as an EMA. The above-mentioned studies utilized the various smartphone technologies through texting, or manual input; however, if necessary, these features can be accessed hands-free with the voice recognition software that comes standard on smart devices such as smartphones or Smart Home Personal Assistants. This allows individuals with limited motor control to access and utilize common household technologies such as an EMA, if needed.

There is currently limited research to examine the use of a Smart Home Personal Assistant as an EMA in persons with dysarthria. One potential reason for this lack of research may be due to the limited evidence that these devices can accurately interpret disordered speech and speech errors. The first step to add to this research area would be to begin to examine how effective a Smart Home Personal Assistant is at recognizing and interpreting disordered speech. While there are many different potential populations of persons with disordered speech, as well as different brands, and versions of Smart Home Personal Assistants to investigate, the purpose of this study was to evaluate the relationship between dysarthria in ALS and effective interpretation of commands of the Amazon Echo. The research questions were as follows: What is the relationship between intelligibility of speech command and accuracy of response by the Amazon Echo? Are any auditory-perceptual characteristics (e.g., prosodic deficits, velopharyngeal mechanism insufficiency, respiratory mechanism insufficiency, etc.) related to accuracy of response by the Amazon Echo? It was hypothesized that as intelligibility decreased the number of misperceptions would increase. It was also hypothesized that there would be
increased difficulty and misperceptions with complex stimuli as intelligibility typically declines with increased sentence length.
METHODS

Study Design

This research study was a descriptive study of the effects of dysarthria on the Amazon Echo’s response to verbally produced stimuli by persons with varying severity and types of dysarthria due to ALS.

Setting

Participants were recruited and evaluated in treatment rooms at the University of South Florida ALS multidisciplinary clinic (USF-ALS) in the Morsani Center. The treatment rooms were approximately 8 ft. x 10 ft. and included a sink and cabinetry, an examination table, two chairs, and a tiled floor. All treatment rooms were roughly identical to one another in layout, and participants were all positioned identically, seated 3 ft. from the Amazon Echo.

Study Participants

Participants were recruited from the University of South Florida ALS multidisciplinary clinic (USF-ALS) in the Morsani Center. The study underwent the necessary review by the USF Institutional Review Board (see Appendix A for approved consent form). Six individuals with Amyotrophic Lateral Sclerosis (ALS) exhibiting mild to moderate dysarthria were recruited and participated in this study. Using the Demographic data form (Appendix B), participant characteristics were documented. Table 1 displays participant demographics including age range, dysarthria type, time since onset of symptoms, onset type, and gender. Five participants were male, and only one participant was female. Severity and types of dysarthria included, 1 mild spastic dysarthria, 3 mild-moderate mixed flaccid-spastic dysarthria, and 2 moderate mixed
spastic-flaccid dysarthrias. Three participants presented with bulbar onset and three participants presented with spinal onset of symptoms. Participants reported experiencing onset of their symptoms ranging from 1-5 years prior to this study. Inclusionary criteria included a medical diagnosis of ALS (spinal or bulbar), and documented mild to moderate dysarthria as determined by an experienced movement disorders speech-language pathologist using a perceptual motor speech evaluation (see Appendix C), adapted from the Darley et al. (1969) study investigating differential diagnosis patterns of dysarthria and the Bunton et al. (2007) study of interrater reliability of perceptual analysis of dysarthria, which found that experienced raters had good interrater reliability when rating acoustic characteristics of speech. Respiratory, phonatory, resonatory, articulatory, rate, prosody, stress, and naturalness were rated on a scale of zero to seven, representing no impairment to severe impairment, respectively. Conversational intelligibility was also measured during the motor speech evaluation by calculating the percentage of intelligible words to unintelligible words during conversational speech sample. Table 2 displays the individual auditory-perceptual results of the motor speech evaluation. Exclusionary criteria for this study was a severe dysarthria as determined during screening measures.

Table 1. Participant Demographics.

<table>
<thead>
<tr>
<th>Participants</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age range</td>
<td>75 years+</td>
<td>65-74</td>
<td>45-54</td>
<td>55-64</td>
<td>55-64</td>
<td>75+</td>
</tr>
<tr>
<td>Gender</td>
<td>Male</td>
<td>Male</td>
<td>Female</td>
<td>Male</td>
<td>Male</td>
<td>Male</td>
</tr>
<tr>
<td>highest level of education</td>
<td>Some college</td>
<td>Some college</td>
<td>Bachelor's</td>
<td>Some college</td>
<td>High school</td>
<td>Graduate</td>
</tr>
</tbody>
</table>
Table 1. Continued

<table>
<thead>
<tr>
<th>Onset type</th>
<th>Spinal</th>
<th>Spinal</th>
<th>Bulbar</th>
<th>Spinal</th>
<th>Bulbar</th>
<th>Bulbar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time since onset of Symptoms</td>
<td>5 years</td>
<td>1 year</td>
<td>1 year</td>
<td>1 year</td>
<td>2 years</td>
<td>4 years</td>
</tr>
<tr>
<td>Current meds</td>
<td>Riluzole</td>
<td>Riluzole</td>
<td>Riluzole</td>
<td>None</td>
<td>Riluzole</td>
<td>Dextrometorphen</td>
</tr>
</tbody>
</table>

Table 2. Auditory Perceptual Ratings gathered during the motor speech evaluation.

<table>
<thead>
<tr>
<th>Participants</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Respiratory Mechanism Severity</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Max Phonation</td>
<td>13 sec</td>
<td>14 sec</td>
<td>13 sec</td>
<td>11 sec</td>
<td>7 sec</td>
<td>21 sec</td>
</tr>
<tr>
<td>Max loudness</td>
<td>Adequate</td>
<td>Adequate</td>
<td>Inadequate</td>
<td>Inadequate</td>
<td>Inadequate</td>
<td>Adequate</td>
</tr>
<tr>
<td>Loudness in conversation</td>
<td>Adequate</td>
<td>Inadequate</td>
<td>Inadequate</td>
<td>Adequate</td>
<td>Adequate</td>
<td></td>
</tr>
<tr>
<td>Laryngeal Mechanism Severity</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Vocal Quality</td>
<td>Hoarse</td>
<td>Hoarse, Harsh</td>
<td>Hoarse, Harsh</td>
<td>Strained; Harsh</td>
<td>Harsh; Rough</td>
<td>Rough; Strained; Harsh</td>
</tr>
<tr>
<td>Pitch range</td>
<td>Inadequate</td>
<td>Adequate</td>
<td>Inadequate</td>
<td>Inadequate</td>
<td>Inadequate</td>
<td></td>
</tr>
<tr>
<td>Vocal tremor</td>
<td>Flutter</td>
<td>No</td>
<td>Flutter</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>Velopharyngeal Mechanism Severity</td>
<td>3</td>
<td>0</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Table 2. Continued</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Resonance</strong></td>
<td><strong>Hyponasal</strong></td>
<td><strong>Normal</strong></td>
<td><strong>Normal</strong></td>
<td><strong>Hyponasal</strong></td>
<td><strong>Hyponasal with nasal emission</strong></td>
<td><strong>Hyponasal</strong></td>
</tr>
<tr>
<td>Orofacial Mechanism</td>
<td>4</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>Severity</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conversation</td>
<td>Imprecise</td>
<td>Imprecise</td>
<td>Imprecise</td>
<td>Imprecise</td>
<td>Imprecise</td>
<td>Imprecise</td>
</tr>
<tr>
<td>Diadocokinesis</td>
<td>Imprecise</td>
<td>Precise</td>
<td>Imprecise</td>
<td>Imprecise</td>
<td>Imprecise</td>
<td>Imprecise</td>
</tr>
<tr>
<td>Rate Severity</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Speed</td>
<td>Slow</td>
<td>Normal</td>
<td>Slow</td>
<td>Slow</td>
<td>Slow</td>
<td>Slow</td>
</tr>
<tr>
<td>Pace</td>
<td>Slow</td>
<td>Consistent</td>
<td>Consistent</td>
<td>Consistent</td>
<td>Consistent</td>
<td>Consistent</td>
</tr>
<tr>
<td>DDK rate</td>
<td>Slow</td>
<td>Normal</td>
<td>Slow</td>
<td>Slow</td>
<td>Slow</td>
<td>Slow</td>
</tr>
<tr>
<td>Prosody Severity</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Intonation in</td>
<td>Normal</td>
<td>Monotonous</td>
<td>Monotonous</td>
<td>Monotonous</td>
<td>Monotonous</td>
<td></td>
</tr>
<tr>
<td>conversation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stress in</td>
<td>Normal</td>
<td>Reduced</td>
<td>Reduced</td>
<td>Equal and excess</td>
<td>Reduced</td>
<td>Equal and excess</td>
</tr>
<tr>
<td>conversation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fluency Severity</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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</tr>
<tr>
<td>Naturalness Severity</td>
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<td>3</td>
<td>4</td>
<td>4</td>
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<td>4</td>
</tr>
<tr>
<td>Conversational</td>
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<td>98%</td>
<td>95%</td>
<td>85%</td>
<td>75%</td>
<td>95%</td>
</tr>
<tr>
<td>Intelligibility</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Procedures

At a pre-scheduled appointment in the ALS Clinic, the Speech Language Pathologist (SLP) collected the necessary pre-screening information, evaluated the person for inclusion and exclusion criteria, and reviewed the consent form with each eligible participant. Next, the principal investigator explained the study procedures to participants who then completed the study in their individual treatment rooms. They were seated 3 feet away, facing the Amazon Echo, which was placed on a counter-top just below the level of their mouth. The principal investigator held the audio recorder directly in the middle of the participant and Amazon Echo, or one and half feet between each. Participants were shown 10 sentences individually typed on an 8 x 11-inch piece of paper, in a large, easily readable font (i.e. Times New Roman, font size 30) (Appendix D). They were instructed to read aloud the sentences one at a time. Additionally, they were told if the Echo does not understand on the first attempt, they should repeat it a second time, and if it still does not understand, then move on to the next sentence. After reading the sentences, the patient completed a final exit survey (see Appendix E), which included questions regarding the perceived amount of effort required to produce the sentences, and external memory aid usage. Responses generated were on a scale of 1-10. The scale anchors used to describe 1 and 10 were, “no effort at all/extremely poor” and “extremely effortful/excellent,” respectively.

Materials

Materials included the consent form (See Appendix A for approved IRB Approval Form), the demographic survey form (Appendix B), motor speech evaluation form (Appendix C), Amazon Echo device, the list of ten sentences (i.e., functional wake phrases) (Appendix D) printed out on individual pieces of paper, a Sony ICD- UX560 audio recorder, and an exit survey (Appendix E). The list of ten sentences (functional wake phrases) were adapted from frequently
message banked phrases (Costello, 2016) and ordered by length. Six sentences were simple and 4 sentences were complex. Complex sentences were sentences with greater than two elements of information. For example, “Set appointment for Doctor’s appointment Monday at 2:00 pm” includes an action (set appointment), a title, and a specific time/date. A simple sentence was defined as sentences with fewer than three elements such as “what time is it?” Complex vs. simple sentences are displayed in Appendix D.

**Measures**

The dependent measure was Amazon Echo’s response to the participant’s spoken sentence. Each sentence required the Amazon Echo to perform a certain task or action. The device’s response on any given sentence, or dependent measure, was audio-recorded for analysis. An accurate response consisted of the Amazon Echo’s completion of the requested task (See Appendix D for acceptable responses for each sentence). A list of potential responses was collected prior to the experiment by the examiner repeatedly asking the Amazon Echo the same stimuli questions. Each response was coded 1 for correct/accurate or 0 for requests for more information or requests for repetition. If a participant required two trials for the Echo to respond, the scores were averaged together for the two trials for a single data point per sentence; for example, if a participant required two trials, data was coded with “0” for trial one and “1” for trial two, which were averaged for a final score of .5.

The intelligibility of the individual stimuli sentences was used as the independent measure. The participant’s spoken stimuli questions were audio-recorded to determine intelligibility of the sentences. Each word spoken by the participant was compared with the sentence written on the list and accuracy was calculated by dividing the number of words correctly spoken with the words for that sentence. Intelligibility scores on a sentence requiring
two trials were averaged together for a single data point. A total of 100% of spoken sentences were transcribed at the word level by the primary investigator and by a listener unfamiliar to the study to calculate intelligibility. By comparison of the two transcripts, the inter-rater reliability was calculated to be 96% agreement (84%-100%).

Each of the overall eight severity ratings and conversational intelligibility from the auditory-perceptual measures that were collected during the motor speech evaluation pre-screening were extracted and used for comparison with the accuracy of responses by the Amazon Echo. This included: respiratory mechanism severity, laryngeal mechanism severity, velopharyngeal mechanism severity, orofacial mechanism severity, rate severity, prosody severity, fluency severity, naturalness severity, and conversational intelligibility.

The Exit survey given at the conclusion of testing was also analyzed for the mean effort level, likely future use, and most commonly used external memory aids of the participants.

**Data Analysis**

The scored audio recordings were transferred from the data sheets to an excel spreadsheet and uploaded into JMP Data Analysis Software (SAS Institute, 2018).

A multi-level mixed modeling approach was utilized in order take into account all of the available data for each participant. Specifically, this allowed for each command (both intelligibility and Echo response) to be nested within individual participants such that every participant had 10 cases (one for each command). Consequently, the data analyses for each research question have a combination of fixed effects (participant level characteristics) and random effects (effects related to the command that vary within a participant).
RESULTS

In order to answer the first research question, a bivariate regression was conducted with the Echo response (the dependent variable) regressed onto the individual command intelligibility. The results revealed there was no significant relationship found between the intelligibility of a command and the accuracy of response by the Amazon Echo, $b = -0.69$, $t(57) = -0.68$, $p = .50$.

To investigate the relationship between conversational intelligibility, measured during the pre-screening motor speech evaluation, and the accuracy of the Amazon Echo’s responses, the data were analyzed using two bivariate regressions. First, the data were analyzed to determine if there was an association between conversational intelligibility and intelligibility of commands. There was a positive association between the two, $b = .38$, $t(4) = 2.82$, $p < .05$, meaning that participants who had higher conversational intelligibility also had higher command intelligibility. Next, using a mixed model, it was determined that conversational intelligibility and accuracy of the Amazon Echo’s responses were significantly and positively associated, $b = 2.41$, $t(4) = 3.80$, $p < .05$. Interpreting this in the original scales of the measures, this means that every 10-percentage point increase in intelligibility was associated with an increase of .24 in accuracy of response by the Amazon Echo.

To investigate the effect of length and complexity of the command sentences on the response of the Amazon Echo, sentence commands were coded into categories of either simple or complex; simple commands were defined as a command with fewer than three elements. An element was determined as key pieces of information such as action, item/title, time, etc. To determine the answer, a t-test was used and found a significant difference between the accuracy
of responses to simple commands as compared to complex questions, \( t(52) = 3.21, p < .01 \). Alexa responded appropriately to, on average, 89% of simple commands and only 63% of complex commands.

Table 3 displays the individual auditory-perceptual severity ratings, average command intelligibility, average Amazon Echo response, and conversational intelligibility used for data analysis. To answer the question, “What auditory-perceptual characteristics (Prosodic deficits, velopharyngeal mechanism insufficiency, respiratory mechanism insufficiency, etc.) are related to accuracy of response by the Amazon Echo?” the data was analyzed using bivariate regressions to estimate associations between the scores from the auditory-perceptual measures and the accuracy of the Amazon Echo’s responses. There were no significant associations between any of the perceptual measures and accuracy of responses. One finding of note was that the Amazon Echo responded significantly worse to one participant as compared to the other participants. Participant #5 had an average score of accurate responses of .3 (95% CIs .19 to .57), while the other participant’s scores ranged from .80 to .95 (Lowest 95% CI = .60).

Table 3. Auditory-Perceptual Ratings/Intelligibility ratings used for data analysis

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
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</tr>
<tr>
<td>Respiratory Mechanism</td>
<td>2</td>
</tr>
<tr>
<td>Severity</td>
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</tr>
<tr>
<td>Laryngeal Mechanism</td>
<td>4</td>
</tr>
<tr>
<td>Severity</td>
<td></td>
</tr>
<tr>
<td>Velopharyngeal</td>
<td></td>
</tr>
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<td>Mechanism</td>
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<tr>
<td>Severity</td>
<td></td>
</tr>
<tr>
<td>Oral Mechanism</td>
<td>4</td>
</tr>
<tr>
<td>Severity</td>
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<tr>
<td>Rate Severity</td>
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Table 3. Continued

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<tbody>
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<td>Prosody Severity</td>
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<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Fluency Severity</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Naturalness Severity</td>
<td>0</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Conversational Intelligibility</td>
<td>98%</td>
<td>98%</td>
<td>95%</td>
<td>85%</td>
<td>75%</td>
<td>95%</td>
<td>95%</td>
<td>95%</td>
</tr>
<tr>
<td>Average Command Intelligibility</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>89%</td>
<td>97%</td>
<td>97%</td>
<td>97%</td>
</tr>
<tr>
<td>Average Accuracy Of Response by Amazon Echo</td>
<td>89%</td>
<td>100%</td>
<td>90%</td>
<td>95%</td>
<td>30%</td>
<td>80%</td>
<td>80%</td>
<td>80%</td>
</tr>
</tbody>
</table>

Ratings on a scale of 0-7; normal-profoundly severe

Table 4 lists the individual ratings of the Exit Survey questions. This information will help with interpretation of individuals’ performance on study tasks.

Table 4. Summary of Participants’ Survey of Technology Usage

<table>
<thead>
<tr>
<th>Participant</th>
<th>Experience</th>
<th>Effort</th>
<th>Likely Use</th>
<th>Current Memory Aids</th>
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<tbody>
<tr>
<td>1</td>
<td>10</td>
<td>2</td>
<td>5</td>
<td>None</td>
</tr>
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<td>2</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>Cellphone</td>
</tr>
<tr>
<td>3</td>
<td>8</td>
<td>1</td>
<td>5</td>
<td>Cellphone; Notebook</td>
</tr>
<tr>
<td>4</td>
<td>9.5</td>
<td>3</td>
<td>7</td>
<td>Cellphone; Large Calendar</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>7</td>
<td>5</td>
<td>Cellphone; Day planner</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td>3</td>
<td>10</td>
<td>Cellphone; Day Planner</td>
</tr>
<tr>
<td>Mean score per category</td>
<td>8.25</td>
<td>2.8</td>
<td>7</td>
<td></td>
</tr>
</tbody>
</table>
DISCUSSION

The purpose of this study was to examine the relationship between speech intelligibility in persons with ALS exhibiting mild to moderate dysarthria and the accuracy of interpretation by the Amazon Alexa. It was hypothesized that with decreased intelligibility of speech commands, there would be an increase in misperceived responses by the Amazon Echo. However, there were no statistically significant relationships between command intelligibility and accuracy of response. This may be due to the restricted variability that is seen in both the intelligibility of the commands and within the Alexa responses. There was a significant relationship found between conversational intelligibility and accuracy of the Amazon Echo’s response. There was also no relationship found between various auditory-perceptual ratings and accuracy of response by the Amazon Echo. When comparing the types of stimuli spoken, such as a simple sentence as compared to a complex sentence, there was a significant difference between complex sentences as compared to simple sentences. This may be due to the fact that the Amazon Echo must identify more specific elements within the sentence to accurately complete a task correctly.

This study had a relatively small data set generated from only six participants who were all similarly intelligible, 75%-100% at the conversational level. These participants all had high intelligibility ratings when producing the stimuli sentences, averaging between 89%-100%. Their conversational intelligibility ratings (see Table 3) did have a greater degree of variability, which is what prompted the additional comparison. A statistically significant association was found between conversational intelligibility and accuracy of response by the Amazon Echo. It is possible the command intelligibility ratings for each individual sentence were not representative.
of conversational intelligibility because the participants were not self-generating these sentences and they were aware of the purpose of the study, which may have impacted their sentence productions (i.e. attempted to increase volume, over-articulate).

Another potential explanation for the lack of findings may be that the sentence stimuli were relatively easy for Amazon Echo to interpret. It seemed reasonable to hypothesize that longer utterances would have decreased intelligibility, but some utterances required the Amazon Echo to pick up on more pieces of information than others. For instance in the sentence, “Alexa, what time is it?”, if the Amazon Echo identifies “time” it would likely produce a correct response. However, “Alexa, set an alarm every day at 8:00 am for medicine,” would require the Amazon Echo pick up on an “alarm,” “every day,” “8:00 am,” and “medicine.” These “elements” or pieces of information were defined as the key pieces of information including action, title, time, and location. Simple sentences were considered a sentence with fewer than 3 elements to be identified by the Amazon Echo. There was a significant difference found between the accuracy of responses on simple sentences vs. complex sentences. As previously mentioned, these sentences were longer and would require adequate breath support by the participants. While some participants were successful given a second attempt, others were unsuccessful. Given this information, individuals with ALS and dysarthria who may experience difficulty with coordinating respiratory support for similarly longer commands, may be more successful by simply shortening commands.

The final question to be answered: “Were any auditory-perceptual characteristics related to the accuracy of responses by the Amazon Echo?” was more of a challenge. Unlike the command intelligibility scores, the various auditory-perceptual scores found in the motor speech evaluation had a very large degree of variability. This variability likely contributed to the fact
that no significant association could be found. It was also mentioned above that one participant, participant 5, scored particularly low on average response by the Amazon Echo. This prompted further investigation into his auditory-perceptual rating scale scores and his specific command intelligibility scores. This participant had very similar scores and difficulties when compared to the other participants, which can be seen in Table 3. Anecdotally, this participant had increased difficulty in speaking longer, or more complex utterances on a single breath. He was noted to exhibit reduced volume, require a breath, or display a pause in speaking, which the Amazon Echo appeared to interpret as the end of the phrase and was unable to recognize the command after only a few words were spoken. While other participants may have had similar experiences, participant 5 had this occur more frequently and was unsuccessful on second attempts. This was not anticipated to be a significant factor when designing the study, therefore, no specific recordings of sound levels (in decibels) were planned to be measured. Interestingly, participant 5 rated the amount of effort to complete the speaking tasks to be 7/10, while the average effort rating was 2.8, which is much lower (see Table 4 above).

**Limitations and Future Research**

Because there is no existing literature with which to compare the results of this study, this study has generated preliminary findings that require further investigation. There are several limitations of this study that have implications for future research. First, this study had a small number of participants with ALS, the majority of whom were diagnosed with flaccid-spastic dysarthria. Additionally, all of the participants were seated only 3 ft. away from the Amazon Echo for consistency, however, no other distances were tested, which would be important if reduced volume is one of the key features of an individual’s speech. In fact, the sound level of the spoken sentences was not measured at all in this study, which may be a good factor to
measure in future studies. While the design of this study was purposeful as it was an exploratory study, it does limit generalization of results. A study with larger numbers of participants with varying types of dysarthria may be warranted. Additionally, the design of this study strictly looked at intelligibility of stimuli sentences chosen for the participants. They did not correct or make suggestions for changing the way sentences were spoken, shorten sentences, or create their own sentences. For the participants who experienced the greatest difficulty with the longer, more complex stimuli, a potential solution could be to shorten their sentences or stimuli while completing a desired task. For example, when scheduling appointments, the patient could shorten “Alexa, schedule an appointment next Tuesday 2:00 pm with Susan” to “Alexa set appointment”, and would then be prompted with “what day”, and then “what time”, and finally “what title.” The patient could follow the prompts, which would decrease demands on the respiratory system by producing shorter utterances.

The Exit survey reported that 5/6 participants were already using smartphones as a memory aid, typically in conjunction with some type of planner. The Amazon Echo has the potential to be used to enhance activities of daily living or be used as an external memory aid; but to be used effectively individuals must be able to independently recall or generate the commands. Because this study excluded participants with documented cognitive impairments, another study looking at independently generated commands when given suggestions or rules of what could be used with the Amazon Echo would give more information related to use of this device as a memory aid in individuals with cognitive impairments.

While this study focused on use of the Amazon Echo, there are many other device types from different manufacturers. These devices run different speech software and may have
different outcomes from this study. Other potential studies could use these devices or compare performance across devices.

**Clinical Implications**

A few key pieces of information can be gathered from this study with respect to clinical implications. The first implication is the idea of enhancing one’s access to various technologies. A major concern with ALS is the loss of access, be that to communication or environmental controls, through the loss of motor function. The Amazon Echo has the ability for these individuals to maintain access to environmental controls, such as controlling lights, air conditioning, music, locks and security, provided they have the necessary add-ons. As mentioned above, some individuals can experience changes to cognition and would likely benefit from use of a memory aid; however, options become limited as the disease progresses. In this study several participants reported that they already used external memory aids. The Amazon Echo would allow them access to an EMA as the disease progresses. The Amazon Echo also recognizes synthesized speech, so it would function well if a patient transitioned to use of a speech generating device for communication purposes as well.

Secondly, a clinician may choose to suggest this device as a helpful option by examining the results of a motor speech evaluation. Taking into consideration the participants’ conversational intelligibility would be important, as a relationship was found between conversational intelligibility and accuracy of response. If a patient has a relatively high intelligibility rating, they are likely to be understood. Even if their intelligibility rating is lower, such as the case with participant 5 who averaged 75% intelligibility, speaking in short commands and following prompts would still likely have a positive outcome. While there was not a specific feature of the auditory perceptual evaluation that was associated with increased misperceptions,
things to consider clinically are the patient’s vocal loudness and their respiratory status. If a patient has increased respiratory compromise they may not be strong candidates for use of the device. However, as mentioned above as a potential study, training these patients or any other patients to use these devices, by providing short phrases and following prompts would likely ensure success with use.
REFERENCES


APPENDICES

Appendix A: IRB Approved Consent Form

April 1, 2018

Caroline Layden
Communication Sciences and Disorders
Tampa, FL 33612

RE: Expedited Approval for Initial Review
IRB#: Pro00034022
Title: Relationship Between Accuracy of the Amazon Echo at interpreting of Dysarthric Speech and Severity of Dysarthric Speech in Individuals with Amyotrophic Lateral Sclerosis

Study Approval Period: 4/1/2018 to 4/1/2019

Dear Ms. Layden:

On 4/1/2018, the Institutional Review Board (IRB) reviewed and APPROVED the above application and all documents contained within, including those outlined below.

Approved Item(s):
Protocol Document(s):
Protocol, Version #1, 3.29.18.docx

Consent/Assent Document(s)*:
Patient Consent, Version #1, 3.16.18.docx.pdf

*Please use only the official IRB stamped informed consent/assent document(s) found under the "Attachments" tab. Please note, these consent/assent documents are valid until the consent document is amended and approved.

It was the determination of the IRB that your study qualified for expedited review which includes activities that (1) present no more than minimal risk to human subjects, and (2) involve only procedures listed in one or more of the categories outlined below. The IRB may review research through the expedited review procedure authorized by 45CFR46.110. The research proposed in this study is categorized under the following expedited review category:
Appendix B: Demographic Survey

1. What is your age range?
   a. 35-44 years old
   b. 45-54 years old
   c. 55-64 years old
   d. 65-74 years old
   e. 75 years or older

1. What is the highest level of education you have received?/Occupation
   a. Elementary up through the 8th grade
   b. Some high school, no diploma
   c. High School Diploma or equivalent (GED)
   d. Some College
   e. Bachelor’s Degree
   f. Graduate or Professional Degree

1. Type of Onset (Collected from medical chart in initial screening)
2. Time Post Onset (Collected from medical chart in initial screening)
3. Current Medications (Collected from medical chart in initial screening)
Appendix C: Auditory-Perceptual Motor Speech Evaluation (adapted from Darley, 1969).

**Motor Speech and Voice Ratings:** Perceptual speech evaluation is rated on a 0-7 point scale, with 0 indicating normal function and 7 indicating a profound dysfunction.

A. Speech: Perceptual speech evaluation is rated on a 0-7 point scale, with 0 indicating normal function and 7 indicating a profound dysfunction.
   a. **Respiratory mechanism is involved with a severity rating of:**
      Maximum phonation duration:
      Maximum loudness: ☐ Normal ☐ Adequate ☐ Inadequate
      Loudness in conversation: ☐ Normal ☐ Adequate ☐ Inadequate
   b. **Laryngeal mechanism is involved with a severity rating of:**
      Vocal quality: ☐ Normal ☐ Hoarse ☐ Breathy (continuous)
      ☐ Breathy (transient) ☐ Strained-strangled ☐ Harsh ☐ Rough ☐ Pressed
      Pitch range: ☐ Normal ☐ Adequate ☐ Inadequate
      Vocal tremor: ☐ Yes ☐ No
   c. **Velopharyngeal mechanism is involved with a severity rating of:**
      Resonance: ☐ Normal ☐ Hypernasal ☐ Hyponasal
      Nasal emission: ☐ Yes ☐ No
      Nasal assimilation: ☐ Yes ☐ No
   d. **Orofacial mechanism is involved with a severity rating of:**
      Conversation: ☐ Precise ☐ Imprecise
      Diadochokinesis: ☐ Precise ☐ Imprecise
   e. **Rate is involved with a severity rating of:**
      Speed: ☐ Normal ☐ Fast ☐ Slow
      Pace: ☐ Consistent ☐ Variable
      DDK rate: ☐ Normal ☐ Fast ☐ Slow
   f. **Prosody is involved with a severity rating of:**
      Intonation in conversation: ☐ Normal ☐ Variable ☐ Monotonous
      Stress in conversation: ☐ Normal ☐ Equal and excess
      ☐ Reduced stress ☐ Excess loudness variation
   g. **Fluency is involved with a severity rating of:**
      Neurogenic stuttering: ☐ Yes ☐ No
      Palilalia: ☐ Yes ☐ No
   h. **Naturalness is involved with a severity rating of:**
   i. **Intelligibility in connected speech is:**
**Appendix D: Question Stimuli**

<table>
<thead>
<tr>
<th>Stimulus Sentences</th>
<th>Allowable Responses</th>
</tr>
</thead>
</table>
| 1. Alexa, what time is it? | It’s ________  
The time is _______. |
| 2. Alexa, when is my next appointment? | Your next appointment is _____. |
| 3. Alexa, what is the weather like today? | Currently it is_______.  
In Tampa it is_______.  
Right now it is_______. |
| 4. Alexa, add bread to my shopping list | I added bread to your shopping list.  
I’ve put bread on your shopping list. |
| 5. Alexa, set a timer for ten minutes | Ten minutes starting now. |
| **6. Alexa, set a reminder for doctor’s appointment tomorrow** | Okay, when would you like to be reminded? |
| **7. Alexa, remind me to call mom tomorrow morning** | Sure, what time would you like me to remind you? |
| 8. Alexa, add grocery shopping to my to do list. | Okay, I added grocery shopping to your to do list.  
Sure, I’ve added grocery shopping to your to do list. |
| 9. Alexa, set an alarm for medicine at 8:00am every day. | Okay, I set an alarm for 8:00. |
| 10. Alexa, set an appointment next monday 2:00 pm with Susan. | Okay, I put the appointment in the calendar. |

**Bolded responses correspond to Complex Stimuli**
**Appendix E: Exit Survey Questionnaire**

1. How would you rate your experience using the Amazon Echo device

   1  2  3  4  5  6  7  8  9  10

2. On the scale below please indicate how much effort these tasks involved.

   1  2  3  4  5  6  7  8  9  10

3. How likely would you be to use the Amazon Echo to help you with everyday tasks?

   1  2  3  4  5  6  7  8  9  10

4. If you would not use this device to help with everyday tasks, would you be likely to use any of the following (circle all that may apply)

   Notebook  
   Cellphone  
   Voice recorder  
   Large Calendar  
   Daily Planner  
   Other