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The effects of augmentative and alternative communication cursor click modality on language complexity and user perceptions

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THE EFFECTS OF AUGMENTATIVE AND ALTERNATIVE COMMUNICATION CURSOR CLICK MODALITY ON LANGUAGE COMPLEXITY AND USER PERCEPTIONS

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ABSTRACT

Purpose: Surface electromyography (sEMG) provides an alternative method for individuals with severe motor impairments to use the voluntary contractions of sparred musculature as inputs into an alternative and augmentative communication (AAC) device. Current research suggests that individuals with typical motor control prefer a sEMG-based click mechanism over a dwell-based click mechanism to operate an on-screen cursor. However, there is no existing data on the effects of cursor click modality on language production in AAC users with motor impairments. The goal of this study was to evaluate the communicative abilities of individuals with neuromuscular disorders when using an AAC device with two different cursor click modalities.

Method: Twelve individuals with neuromuscular disorders produced synthetic language samples via an on-screen keyboard using an sEMG/accelerometer system with two different click modalities: dwell-based clicking and sEMG-based clicking. A third language sample via natural speech was also recorded. Language sample analysis was used to evaluate language complexity at syntactic, semantic, and ideational levels. To analyze syntactic complexity, language samples were examined for clausal density, conjunction usage, phrase expansions (noun phrase, verb phrase, and prepositional phrase), and mean length of utterance. Semantic complexity was analyzed using measures of moving-average type token ratio, abstract noun usage, metacognitive verb usage, and usage of morphologically complex words. Ideational complexity was analyzed in terms of the extent to which the responses conveyed the participant's ideas. A questionnaire was used to measure the participants' perceptions of usefulness for each modality.

Results: Mean length of utterance was shorter in the dwell-based click modality than in the sEMG-based click and natural speech modalities. In the sEMG-based click modality the majority of sentences were complex sentences, whereas simple sentences made up the majority in the dwell-based click modality. Morphologically complex word usage was used more frequently in the natural speech modality than in the sEMG-based click modality and used most frequently in the dwell-based click modality. There were no modality-specific trends for ideational complexity. Measures from the questionnaire showed that participants ranked natural speech as being more useful than either of the cursor-click modalities, but all three modalities were rated as at least somewhat useful (5 out of 7 on a rating scale of usefulness).

Conclusion: This study is the first to evaluate the effects of cursor-click modality on the communicative abilities of individuals with neuromuscular disorders. Despite differences in language complexity on some measures, participants were able to use all three modalities to accurately respond to the language prompt with similar ideational scores. These results support both sEMG and dwell as alternative access methods for controlling a cursor-click system for individuals with neuromuscular disorders in future AAC applications.

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Introduction

Neuromuscular Disorders

Neuromuscular disorders (NMDs) are a broad category of conditions that affect the peripheral nervous system by disrupting nerve and muscle activity in the body (McDonald, 2012). Consequently, these disruptions can cause individuals to have difficulty with the precise motor movements required for speech production, which can negatively impact an individual's ability to communicate independently. Neurological speech disorders that arise from irregularities in the speed, strength, range, steadiness, tone, or accuracy of the movements required for the breathing, phonation, resonation, articulation, or prosody necessary for speech production, are collectively called dysarthria (Duffy, 2013). The abnormalities that arise from dysarthria result in a variety of deficits that impact speech and can negatively impact an individual's intelligibility. Difficulty executing the motor movements of the speech articulators can lead to misarticulated words and slurred speech, and abnormalities affecting the phonation system can lead to weak phonation and changes in vocal quality (Chiara, Martin, & Sapienza, 2007; Neel, Palmer, Sprouls, & Morrison, 2015; Schölderle, Staiger, Lampe, Strecker, & Ziegler, 2016). Dysarthria can also negatively impact the respiration system, which is another essential subsystem involved in speech production (Schölderle et al., 2016). As a result, individuals with neuromuscular disorders may face communication challenges that impact their ability to participate in everyday social contexts (Ball, Fager, & Fried-Oken, 2012).

Approximately 600 diseases are classified as either congenital or acquired neuromuscular disorders, with the manifestation of communication difficulties varying across diseases (Knuijt et al., 2011). Congenital disorders are present at or before birth, whereas acquired disorders develop at some point over an individual's life (Duffy, 2013). One common congenital neuromuscular disorder that can negatively impact speech is Cerebral Palsy (CP). CP is the most common motor disability in childhood and affects nearly 2 out of every 1000 children that are born (Haak, Lenski, Hidecker, Li, & Paneth, 2009). Speech can also be negatively impacted by acquired neuromuscular disorders such as Muscular Dystrophy, Multiple Sclerosis (MS), and Spinal Cord Injury (SCI). Muscular dystrophies encompass a broad range of diseases with varying incidence rates, but one of the most common types, Duchenne/Becker Muscular Dystrophy, affects approximately 1 in 3500 male children that are born (Cruz Guzmán, Chávez García, & Rodríguez-Cruz, 2012). MS, with a reported incidence of 3.6 females and 2.0 men per 100,000, and SCI, with an annual incidence rate of 3 per 100,000 in socioeconomically advanced countries, are two other common NMDs (Alonso & Hernán, 2008; Dilokthornsakul et al., 2016; Kurtzke, 1975). A far more rare acquired disorder is Guillain-Barré Syndrome (GBS), affecting 1.7 people per 100,000, but it poses similar communication challenges (Alter, 1990). Given the high incidence rate of many neuromuscular disorders, understanding the impact they can have on communication ability is critical.

Neuromuscular Disorders and Communication

Given the high incidence of many neuromuscular disorders, and the essential role that communication plays in everyday life, it is important to understand the speech characteristics that are often present in individuals with neuromuscular disorders. CP is a common NMD that affects an individual's ability to communicate clearly. CP results from damage to the motor cortex of the developing brain, and is characterized by gross motor function (Schölderle et al., 2016). The gross motor dysfunction of the oral muscles causes reduced articulatory precision, and as a result, decreased speech intelligibility (Schölderle et al., 2016). As the linguistic demands and complexity of an individual's communicative intents increase, the implications of oral motor dysfunction increase. Allison & Hustad (2014) found that the intelligibility of individuals with CP decreased as utterance length and phonetic complexity of words increased. In addition to decreased intelligibility, individuals with CP also tend to have slow, monotonous speech that may lead to an overall reduction in the naturalness of their speech (Schölderle et al., 2016).

Muscular Dystrophy is a subcategory of NMD that can also have negative effects on an individual's communication abilities. Muscular Dystrophy is categorized by progressive weakness and loss of muscle mass. Oculopharyngeal muscular dystrophy (OPMD) is a subtype of muscular dystrophy that causes the weakness and loss of muscle mass in many structures involved in speech, including tongue muscles, the pharyngeal wall, and the diaphragm. These muscle weaknesses can lead to dysphonia, vocal fatigue, hypernasality, and overall reduced intelligibility of speech (Neel et al., 2015). Another subtype, Facioscapulohumeral muscular dystrophy (FSHD), causes weakness specifically to the facial muscles. Individuals with FSHD often experience communication difficulties related to decreased cheek compression strength and capacity, as well as reduced endurance of anterior tongue movements (Mul et al., 2019). These weaknesses could lead to fatigue and decreased articulatory accuracy. Consequently, individuals with FSHD may exhibit reduced speech intelligibility.

GBS is a rare NMD that occurs when the body's immune system attacks the nerves in the body. It is characterized by ascending weakness, tendon areflexia, paresthesia, and an aluminocytologic dissociation in the cerebrospinal fluid (Abbassi & Ambegaonkar, 2019). Miller-Fisher syndrome (MFS), the most common variant of GBS, is characterized by deficits in cranial neuropathy and its communication challenges often manifest as dysphonia and dysarthria, which can have negative implications for an individual's speech intelligibility (Howell et al., 2010).

MS is a progressive NMD that typically affects the expiratory muscles and the laryngeal muscles due to demyelination and axonal damage (Chiara, Martin, & Sapienza, 2007). Individuals with MS tend to have inadequate subglottal pressure for speech production and have particular difficulty sustaining phonation and using connected speech (Chiara et al., 2007). In addition to difficulty with phonation and lung pressure, individuals with MS may also have motor impairment of the muscles involved in speech articulation, which may further affect speech intelligibility (Chiara et al., 2007).

Individuals with SCIs can also experience speech difficulties, often related to impairment of the respiratory function, depending on the location of the injury. For individuals with cervical SCIs, vital capacity volumes are often smaller than normal, and respiratory-phonatory control for speech is negatively impacted. This can result in fewer syllables per breath, reduced sustained phonatory duration, impacted prosody, reduced vocal loudness, and reduced voice quality (Ward, Jarman, Cornwell, & Amsters, 2016). These effects are exacerbated when speech utterances are long (Ward et al., 2016).

Augmentative and Alternative Communication

Due to the negative effects that these neuromuscular disorders have on communication, a need for alternative communication methods exists. For individuals with impaired spoken language**,** alternative modes of communication such as gesture or augmentative and alternative communication (AAC) can supplement or replace speech. AAC is defined by the American Speech Language-Hearing Association as “an area of clinical practice that attempts to compensate (either temporarily or permanently) for the impairment and disability patterns of individuals with severe expressive communication disorders” (American Speech Language Hearing Association, n.d.). Individuals with a variety of communication challenges, including those secondary to neuromuscular disorders, can benefit from alternative communication methods.

Many types of AAC rely on an individual’s gross or fine motoric abilities for access. Low tech AAC options such as communication picture boards often rely on an individual using their finger or another body part to point at the target item (Fager, Bardach, Russell, & Higginbotham, 2012). For an individual to make a selection, they must have strong motor control of the body part. Other AAC technology relies on computer typing or physical writing, which also requires strong motor control of the limbs (Treviranus, 1994). High-tech AAC options often utilize touch screen manipulation, which is also frequently performed with the user’s limbs (van der Meer, Sigafoos, O’Reilly, & Lancioni, 2011).

Individuals with motor impairments can face challenges using AAC technology with access methods that rely on gross and fine motor movements. Many of the common access methods like touch screen and finger pointing require motoric control that some

AAC users do not have. However, some AAC technology utilizes alternate access methods that capitalize on an individual's intact voluntary muscle movements such that individuals with limited motor movement may use the technology.

Current Alternative Access Methods

Over the past few decades, AAC technology has expanded to include a wider range of options for individuals with unique motor access challenges. These access technologies include adapted keyboards, computer and mobile technology touch screen adaptations, switch scanning, head tracking, eye tracking, and brain-computer interfaces (Koch Fager, Fried-Oken, Jakobs, & Beukelman, 2019). Keyboards can be adapted in a number of ways to make access to AAC technology easier for an individual with motor impairments. For example, expanded keyboards require a large range of motion, but are practical for users with limited fine motor skills who have difficulty targeting a small key. Alternatively, contracted keyboards are practical for users with fine motor skills, but limited range of motion, as the keys are compacted into a smaller area (Brodwin, Star, & Cardoso, 2004). Switch scanning is an alternative access method that was designed for individuals with complex motor challenges. This method allows individuals to use a part of their body with good motor control to manipulate a switch to scan through a set of targets, and then again to select the target (Bueklman & Miranda, 2005). While this method capitalizes on a user's remaining motor ability, it can be slow and fatiguing since a user must wait for the device to scan through many undesired targets before reaching the desired item (Bueklman & Miranda, 2005).

Although these alternative access methods address many of the needs that individuals with motor challenges face, they still do not adequately serve users with significantly limited motor functioning in their arms and hands. As a result, some AAC devices incorporate access methods that utilize minimal movement and do not require strong motor abilities of the user's limbs. Current AAC strategies utilizing minimal movement have focused on head and eye movement tracking and brain-computer interfaces.

Eye-Tracking Systems

Significant improvements have been made in eye-tracking systems with the use of infrared technologies (Fager, Beukelman, Fried-Oken, Jakobs, & Baker, 2012). These systems rely on computer tracking of infrared light reflection from the surface of the user's eye. As a user is presented with symbols, words, or letters, a user selects their desired content by dwelling (pausing) the cursor, blinking, or activating a switch when the cursor is in the desired place (Fager et al., 2012). In a study following 15 individuals with Amyotrophic Lateral Sclerosis (ALS) who used eye-tracking systems, a wide range of communication functions were met using the systems. These functions included communicating in group social contexts, communicating on the phone, e-mailing, using the internet, and communicating in face-to-face interactions with others (Ball et al., 2010). Although the use of eye-tracking technologies pose many communication benefits for individuals with complex motor challenges, the sensitivity of the device to environmental conditions creates practical limitations (Fager et al., 2012). Eye-tracking technology requires a well-lit environment with precise positioning. An unstable environment or frequent position changes of the user can interfere with the devices utility (Fager et al., 2012). Additionally, eye-tracking systems can be fatiguing as they require users to fixate on a given target to keep the cursor aligned in the desired spot on the screen, which raises questions about the implications of long-term use with this technology (Fager et al., 2012). Given the practical limitations of eye-tracking technology, other access methods such as head-tracking systems may be more beneficial for some users.

Head-Tracking Systems

Head-tracking systems use video or infrared cameras to track movements of specific body features and translate the movements into cursor control. Communication content is presented on a screen, similarly to the presentation method used by eye-tracking devices. Users select their desired content by dwelling the cursor on the content or by using an alternate movement to activate a switch (Fager et al., 2012). Like eye-tracking technology, head-tracking systems can be strenuous after long periods of use given the extreme head movements that are often required to hold the cursor in alignment. Head-tracking technology is also sensitive to the environmental conditions and requires high levels of clinical training to support the advanced technology (Fager et al., 2012). Head-tracking systems also have practical limitations and require at least minimal head movement ability. This has led to the exploration of brain-computer interface technology as an alternative access method.

Brain-Computer Interface Technology

An alternative access method for individuals with little to no reliable motor function is brain-computer interface (BCI) technology. BCI technology utilizes recorded brain signals to extract features and convert them into specific commands that can control technology (Gosmanova et al., 2017). BCI provides an alternative means to control communication assistive technology, without the use of neuromuscular output. BCI devices that are used for communication can be classified as noninvasive or invasive, with most communication devices relying on noninvasive options such as electroencephalography (Brumberg, Nieto-Castanon, Kennedy, & Guenther, 2010). BCI technology is a beneficial option for individuals with extreme motor impairments, because it bypasses the neuromuscular pathways that are typically involved in controlling a system and uses brain signals directly. However, BCI systems rely on slow typing, making them unpractical for long conversations at natural rates (Brumberg et al., 2010; Peters et al., 2015). Other uses of BCI cited concerns with inconvenience, discomfort with wet electrodes, portability, reliability, and dependability, and high out-of-pocket costs. Some users had concerns about the complex, time-consuming nature of the set-up of the system, and the intensity of caregiver training (Peters et al., 2015). Overall, future research is needed to improve the feasibility of BCI as a form of AAC technology. Given the practical limitations of eye and head tracking technology and the additional work needed to make BCI a reliable option, sEMG access methods have been explored as an alternative method requiring limited movement.

sEMG Access Methods

The motor challenges of individuals with neuromuscular disorders and the limitations of other access methods suggests that surface electromyography (sEMG) may be a useful access method for individuals with limited motor control. sEMG allows individuals to control a human-machine interface such as a computer cursor by using voluntary muscle contractions. Electrodes that are placed on the surface of the skin are used to detect the electrical activity of the user's facial muscles (Vojtech, Cler, & Stepp, 2018). Whereas eye and head tracking systems require well-lit environments, sEMG is unaffected by lighting condition. Additionally, sEMG systems do not require the user to be directly in front of the computer screen, as many head- and eye-tracking systems do, which allows for more flexible positioning of the user (Cler, Nieto-Castañón, Guenther, Fager, & Stepp, 2016). sEMG systems also do not require a stable head position, as eye-tracking and some head-tracking systems do. Facial EMG can be used as an access method with a wide range of different coordinated facial muscles, allowing for user specific optimization. Although this individualized process requires the timely efforts of a trained operator with knowledge of potential sensor configurations, the individualized sensor location optimization makes this system a practical access method for a heterogenous population of users with diverse motor challenges (Vojtech et al., 2018). Research has shown that sEMG can recognize activity in muscles that are innervated but do not support movement, suggesting that sEMG systems may benefit individuals who do not possess the strength to produce limb or facial movements required for other access methods, but can still produce reliable muscle activity (Saxena, Nikolic, & Popovic, 1995).

Cler et al. (2016) compared the performance of sEMG to other access methods available to individuals with motor impairments using a measure called information transfer rate that investigates both the speed at which a user makes selections and the accuracy of those selections. The sEMG system had higher information transfer rates than BCI systems and comparable information transfer rates to head- and eye-tracking systems

(Cler et al., 2016). Given these factors, sEMG access serves as a strong alternative access method for individuals with limited motor function.

Cursor Click Modality

Successful AAC devices must not only provide a reliable access method that meets the unique needs of the user, but also must provide an easy and efficient way to select content on the device. With some high-tech AAC devices, the user makes content selections by utilizing a cursor click mechanism. Some systems have utilized mechanical switches, but for users with complex motor challenges this may not be an efficient system. New technological advances have focused on alternative cursor clicking systems that accommodate users with limited mobility.

Dwell time selection is a promising alternative to traditional mouse clicks that rely on additional motor function or actions. Dwell time selection occurs when a system user points or holds the cursor in a particular place for a designated amount of time. Within the designated dwell time, a user can readjust, change, or refine their selection (Hansen, Johansen, Hansen, Itoh, & Mashino, 2003). A shorter dwell time allows a user to make faster clicks, but it could lead to more unintentional clicks. A longer dwell time reduces the likelihood of accidental clicks, but it leads to slower and less frequent clicks that reduces the efficiency (Groll, Hablani, Vojtech, Stepp, 2020). Although dwell time selection requires less motoric output than manual selection systems, it can be difficult for users to maintain a stable cursor position long enough to activate the click and can be fatiguing due to the increased amount of concentration needed to achieve activation.

Another alternative cursor click method is sEMG-based clicking, which utilizes sEMG from voluntary intentional muscle movements such as blinking, smiling, eyebrow raising, frowning, and teeth clenching (Groll, Hablani, Vojtech, Stepp, 2020). In studies investigating the reliability of sEMG-based cursor clicking, it was found that sEMG-based cursor clicking allowed for more reliable and intentional clicks than an alternative system using vision-based head movement (Magee, Felzer, & MacKenzie, 2015; Vojtech, Hablani, Cler, & Stepp, 2020).

The effects of dwell and sEMG-based cursor click modalities on computer access has previously been investigated in individuals who are neurotypical, but these cursor click systems have not been compared in AAC users with neuromuscular disorders. In the previous study with individuals who were neurotypical, it was found that sEMG-based clicking allowed for quicker more accurate cursor clicks when compared to dwell-based clicking (Groll, Hablani, Vojtech, Stepp, 2020). However, given the unique motor challenges that individuals with neuromuscular disorders may experience, such as muscle weakness and involuntary spasms, some users in a patient population may find dwell-based cursor clicking to be more comfortable. Therefore, additional research is needed to compare dwell and sEMG-based cursor click systems in individuals with neuromuscular disorders.

The efficiency of a device's cursor click system has implications on the user's success with the device. In order for an AAC device to assist a user in achieving communication competence, both the access method and the content selection method must meet the user's unique challenges to assist them in communicating efficiently in multiple contexts. Given the importance of content selection on the successfulness of a device, there is a need to explore how differences in clicking modality can affect an individual's communication ability.

Evaluating AAC Communicative Abilities

Many factors contribute to an AAC system's effectiveness in helping an individual with communication challenges achieve the overarching goal of successful communication. One way to evaluate an AAC system is in terms of the overall usefulness of the device. The following factors have been found to be relevant when examining a system's usefulness: the ability to successfully get wants and needs met, convey a variety of messages, communicate clearly, communicate quickly, and communicate effortlessly (Calculator, 2013a, 2013b, 2014).

In order to be an effective device, an AAC system must also allow an individual to achieve communicative competence (Light & McNaughton, 2014). It is essential to the quality of life of an individual to have communicative competence to achieve their social, educational, personal, and vocational goals (Lund & Light, 2007). The exact definition of communication competence varies across individuals according to their own goals, but achieving linguistic competence is an important factor (Light & McNaughton, 2014). For an AAC system to be effective, a user must be able to use high-level language to successfully meet complex communication demands. The inability to use complex morphological and syntactical forms in their language can impact a user's ability to succeed academically, secure and maintain employment, and clearly convey their communicative messages to others (Binger & Light, 2008). In order for an AAC device to be a practical communication support for an individual with complex communication needs, a system must allow an individual to produce high-level complex language. Collectively, measures of usefulness and language complexity can be used to evaluate the effect on communication that different AAC devices have, in order to optimize device design and input modalities.

Research Statement

The purpose of this project was to compare the communicative abilities of individuals with neuromuscular disorders when using two different cursor click modalities (dwell-based and sEMG-based) in an AAC device, and to investigate how these differences compared to communicative abilities when using natural speech. Communicative abilities were analyzed in terms of language complexity as well as the users' perceptions of usefulness, which were determined from user ratings of successfulness, effort, speed, ability to communicate clearly, and ability to communicate a variety of messages.

It was hypothesized that the language of participants would be less complex when using the dwell-based click modality compared to the sEMG-based click modality because dwell-based cursor control requires users to maintain a stable position, which can be especially fatiguing for users with muscle weakness and limited motoric control. It was further hypothesized that the language of participants would be less complex using both the dwell-based and sEMG-based click modalities when compared to their natural speech. Moreover, it was hypothesized that participants' perceptions of usefulness would mirror language complexity findings, with the highest usefulness ratings for natural speech and the lowest for the dwell-based click modality.

Methods Section

Participants

Fourteen adults with neuromuscular disorders participated in this study. Twelve of the participants were recruited from the Madonna Rehabilitation Hospital in Lincoln, Nebraska and two participants were recruited from Boston University in Boston, MA. Informed consent was obtained, and the study was carried out in compliance with the Boston University Institutional Review Board. When participants were unable to provide written consent, verbal consent was provided in front of at least two witnesses. Two participants were excluded from participation after demonstrating difficulty during system optimization and practice, resulting in a final total of twelve participants with recorded data.

Participant demographics can be found in Table 1. The neuromuscular disorders consisted of spinal cord injury, cerebral palsy, muscular dystrophy, multiple sclerosis, and Guillain-Barré Syndrome. All twelve participants used speech as their primary modality of communication. Nine participants reported having prior experience with AAC technology. One participant reported cognitive impairment and two participants reported a history of speech and/or language impairment. The mean age of the participants was 44.4 years (range = 23–73). American English was the primary language for all participants.

Procedures

Overview

The current study was part of a larger session with additional tasks that lasted 2-2.5 hours. Participants were seated in front of an adjustable table with a laptop. The table was adjusted such that the laptop was at a comfortable eye level for the participant.

Participants completed an experimental task in which they were asked to listen to a fable and respond by retelling the moral in their own words. Participants completed this task using three different communication modalities: two different cursor click modalities to control a sEMG/accelerometer (ACC) system (dwell-based click and sEMG-based click) and natural speech. Following the task, the participants responded to a 5-question questionnaire to assess their experience during the task. An optional break was provided between cursor click modalities to mitigate physical and mental strain/fatigue. In the dwell-based click modality, participants used an optimized dwell time to cause a cursor click by hovering over a fixed position on the screen for a set period of time. In the sEMG-based click modality, a sEMG sensor was placed in an optimized location on the participant's face and a click was activated by a voluntary muscle contraction of a facial muscle. The optimized dwell time and optimized sEMG sensor location for each participant were determined during a calibration process prior to completion of the task for each modality as described below in the *calibration* section. The order of the click modality was randomized and counter-balanced across participants, but all participants completed the task with their natural speech last to provide a comparison of their natural language ability

Overview of System

In both the dwell-based click and sEMG-based click modalities the Delsys Trigno™ Wireless EMG System (Delsys, Boston, MA) was utilized to control an on-screen cursor. Cursor movement was always controlled by accelerometer inputs from the system, whereas cursor click used either sEMG or dwell timing. The system consisted of two sensors; a MiniHead sensor (25×12×7mm) and a main sensor body (27×37×15 mm). The MiniHead Sensor recorded sEMG signals and the main sensor body established a local reference to the signals from the MiniHead sensor and recorded accelerometer signals for cursor movement.

Sensor Preparation and Placement

Prior to the placement of either sensor, the participant's skin was cleaned with alcohol wipes and exfoliated using tape to remove excess skin cells, oils, and hairs (Stepp, 2012). The main body sensor was placed on the participant's glabella and the MiniHead sensor was placed on one of several muscle groups to measure voluntary muscle contractions during a specific facial movement: the orbicularis oculi for the wink or blink, the risorius and orbicularis oris for the smile, the frontalis for the eyebrow raise, and the mentalis for the chin contraction (Vojtech et al., 2018). During the calibration process, this optimized location for the MiniHead sensor was determined for each participant based on which facial muscles the participant could easily and voluntarily contract.

Cursor Movement

For both click modalities, participants controlled the cursor movements using the same procedure as described in Vojtech, Hablani, Cler, and Stepp (2020). The cursor was controlled by tilting the head in the direction of the desired cursor movement. Specifically, the angle of the head tilt was used to compute the cursor angle in the x-y plane, in which head roll and head pitch (Eq. 1 & 2) were computed and mapped to move the cursor in the corresponding directions. The combination of head roll and head pitch measurements allowed the cursor to move two-dimensionally on the screen using small, comfortable sized movements. The use of larger head tilt movements caused the cursor to move faster.

$$\text{Head Roll } (\theta, \text{deg}) = \frac{360}{2\pi} \times \text{atan2}\left(\frac{y}{z}\right) \quad (1)$$

$$\text{Head Pitch } (\rho, \text{deg}) = \frac{360}{2\pi} \times \text{atan2}\left(\frac{-x}{\sqrt{y^2 + z^2}}\right) \quad (2)$$

Cursor Click

In the dwell-based click modality, participants clicked by hovering the cursor in a relatively still position (i.e., within a small radius of 21.2 pixels from a fixed point) for an optimized length of time. If the cursor moved outside the radius before the dwell time was reached, a new fixed point was set and the current dwell time was reset. The length of dwell time was optimized for each participant during the calibration process.

In the sEMG-based click modality, participants clicked by making a voluntary facial muscle contraction. The root-mean-square (RMS) of the sEMG was computed over a window of 54 ms to calculate a threshold during the calibration process. The system registered a muscle contraction as an intentional click when RMS exceeded this set threshold. The optimized sEMG sensor location for each participant was also determined during the calibration process.

Calibration

A calibration process occurred prior to each click modality. Overall, the calibration process took approximately 45 minutes, with the majority of the time spent on the main sensor body placement and the first calibration for cursor movements. The modality specific calibrations were typically quicker. The first calibration for cursor movements remained the same for both modalities. Participants were instructed to tilt their heads left and right twice, and up and down twice, using small comfortable movements. From these movements, minimum and maximum RMS values were calculated from the accelerometer signals and assigned to each movement. During cursor control, RMS values were normalized to these values. When movements were made with RMS values that exceeded those obtained during calibration, these values were scaled to the maximum and minimum limits.

After this, participants were instructed to perform a short calibration task in which they moved the cursor to target circles in each of the four corners of the screen. If the participant was unable to easily navigate the cursor, recalibration was performed until the researcher determined they were comfortably able to complete the task.

After the first calibration for cursor movement, modality-specific calibration occurred. Prior to completion of the dwell-based click task, participants completed a calibration process to determine optimal dwell time. The initial dwell time was set at 1.5 seconds, because individuals with typical neuromuscular control were previously shown to have the most control at this dwell time (Groll, Hablani, Vojtech, Stepp, 2020). Participants completed a calibration process similar to the one for cursor movement. In this task, participants navigated the cursor to the same four targets in each corner of the screen but were instructed to hover over each target for the designated dwell time in order to click the target. Following the completion of the task, the dwell time was increased or decreased over a one second range based on the observations of the researcher and the participant’s perception of ease. Adjustments were made until an optimal dwell time was agreed upon by both participant and researcher.

Prior to the sEMG-based click task, participants completed a calibration process to determine the optimal voluntary facial muscle contraction used to cause a click. Participants were instructed to perform each of the following facial movements three times in quick succession: close eyes tightly, purse lips, raise eyebrows, smile, stick out lower lip. During these movements, the researcher took notes about the perceived ease of contraction, co-contractions, and the size of movements. The participant was also asked to provide feedback regarding the ease of each movement. Based on the researcher's observations and the participant's feedback, a specific facial muscle contraction was chosen and the sEMG sensor was placed over the muscle corresponding to each contraction: winking corresponded to the orbicularis oculi, eyebrow raise corresponded to the frontalis, smiling corresponded to the risorius and orbicularis oris, and the mentalis corresponded to the chin contraction (Vojtech et al., 2018). After the sensor was placed, participants were instructed to perform the contraction twice in order to calibrate the signal with the system. The RMS of the sEMG was averaged across contractions to determine the threshold that must be exceeded to register a muscle contraction as an intentional click. Participants then completed a task identical to the dwell-based calibration process, except that participants were instructed to click each target using the selected voluntary muscle contraction. If participants were unable to comfortably and accurately click on the targets, the movements were recalibrated. In some cases, the sensor location was moved, and calibration was completed using a different voluntary muscle contraction.

Experimental Task

For each modality, the researcher elicited a language sample by reading the participant a fable that had been adapted from *Aesop's Fables* (1947) and asking the participant to state the moral of the fable in their own words. Fable re-telling was used to collect the language sample because previous research with fables and language sampling in adolescents found that syntactic complexity was greater during tasks of fable-retelling compared with a conversational task (Nippold et al., 2015). The fables were adapted into Standard English for easier comprehension by the participants (Nippold et al., 2015). To encourage the production of a robust language sample, participants were told that the task usually takes a few sentences to complete and that there was no time limit. The fables were reread if requested by the participant. The fables were as follows: (a) *The Lion and the Mouse*, (b) *The Dog and the Shadow*, and (c) *The Crow and the Pitcher*. The fables used in this study can be found in Appendix A. The order of the fables remained the same across participants such that *The Crow and the Pitcher* was always used for the natural speech task, whereas *The Lion and the Mouse* and *The Dog and the Shadow* were used for both dwell-based and sEMG-based click.

In both the dwell-based and sEMG-based click modality trials, participants used an on-screen keyboard to respond to the prompt. The keyboard was created using Click-N-Type (Lake Software) which allowed the users to type out orthographic messages by controlling the cursor on the screen. The software allowed for keyboard customization to include the following keys: backspace, capitalization, enter, comma, period, quotation mark, and each alphabetic letter. The alphabetic letters were presented in a QWERTY layout for ease of use. An image of the keyboard can be found in Appendix B. Participants were instructed to move the cursor to type out their answer to the prompt and select the enter key when they were finished in order to play their response with the Natural Reader Text-to-Speech software to generate speech output using the alternative access methods (AT&T Co. 2016 NaturalSoft Limited). This software converted the written text into spoken words and played it out as a computer-generated simulation of human speech (i.e., synthesized speech) which enabled the comparison between responses from the natural speech trial and the alternative access trials. Participants were instructed to use the backspace key to correct mistakes and were advised that punctuation was not necessary.

Subjective Measure of Device Usefulness

Following the communication task, participants were asked to evaluate the usefulness of the device with each click modality using a 5-question questionnaire that was designed to evaluate AAC devices (Calculator, 2014). All questions were answered on a 7-point Likert scale (1 = *very useless,* 2 = *useless,* 3 = *somewhat useless,* 4 = *neutral,* 5 = *somewhat useful,* 6 = *useful,* 7 = *very useful)*. Participants rated how useful the device was in achieving the following outcomes: (a) overall success expressing oneself (b) conveying a variety of messages, (c) communicating clearly, (d) communicating quickly, (e) communicating effortlessly. The questionnaire can be found in Appendix C. The researcher read each question and instructed the participant to manually circle their responses, verbally state their responses, or indicate their response as the researcher moved through the answer choices. The user's overall perception of usefulness for each modality was determined by averaging the responses to each of the 5 questions. Following the participant's natural speech, an identical questionnaire was presented to determine each participant's perceived usefulness of their own speech.

Data Collection

Acoustic signals were recorded in a private room at the Madonna Rehabilitation Hospital or in a private room at the STEPP Lab for Sensorimotor Rehabilitation Engineering at Boston University. The recordings were made using a portable digital audio recorder (Zoom H4n Pro Handy Recorder) and a headset microphone (Shure WH20 Cardioid Dynamic Microphone). For the dwell-based and sEMG-based trials, the microphone headset was placed on the table next to the computer and the microphone was adjusted to be 7 cm from the computer's speakers. In the natural speech trial, the microphone headset was placed on the participant's head and the microphone was adjusted to approximately 7 cm from the corner of the mouth and approximately 45° from the midline (Patel et al., 2018). The audio recordings were used for language analysis.

sEMG was recorded at 2000 Hz and band-pass filtered and accelerometer signals were recorded at 148 Hz. Accelerometer signals and sEMG were time-aligned using the Trigno™ Wireless Biofeedback System and were recorded using PyGesture and custom Python scripts.

Language Analysis

The language samples were transcribed from the audio recordings using the standard conventions of the Systematic Analysis of Language Transcripts Software (SALT; Miller & Iglesias, 2012). The utterances were segmented into communication units (C-units), which are comprised of one main clause and all corresponding subordinate clauses (Loban, 1976). The C-units were coded for Subordination Index: [SI-0] for C-units that lack a subject or verb in the main clause, [SI-X] for incomplete utterances, and [SI-1], [SI-2], and [SI-3] for C-units that contain one, two, or three clauses (Miller, Andriacchi, & Nockerts, 2011). Each clause was then coded for clausal type: [IC] for independent clauses, [ADV] for adverbial clauses, [NOM] for nominal clauses, [REL] for relative clauses, and [infC] for infinitive clauses. Using standard SALT transcription coding, C-units were also coded for errors: [EU] for utterance-level errors, [EW] for extraneous words, and [EW:__] for other word-level errors. Omissions of obligatory words were coded with an asterisk and the omitted word (i.e., *I), and false starts, repetitions, reformulations, and filled pauses (e.g., um) at both the word and part-word levels were coded with parentheses (Miller, Andriacchi, & Nockerts, 2011).

All transcripts were reviewed and coded by a second investigator (FF). A third investigator (RS) reviewed any coding discrepancies and resolved disagreements. Agreement levels were calculated for transcription (93%), SI-Index (97%), and clausal coding (94%). Dr. Michelle Mentis, PhD, CCC-SLP provided the correct SI coding for any remaining discrepancies.

The final coded transcriptions were analyzed in terms of syntactic complexity, semantic complexity, ideational complexity, and the presence of errors. Comparisons within these domains were made across the language samples gathered from the three modalities.

Syntactic Complexity

To analyze syntactic complexity, a variety of syntactical parameters were examined for each language sample. Subordination Indexes were used to calculate the average clausal density of each sample (i.e., the mean number of clauses per utterance). Clausal complexity was further analyzed in terms of the percentage of incomplete, simple, and complex clauses in each utterance.

Language samples with complex and/or compound sentences were further analyzed for a variety of other syntactical parameters. Instances of conjunctions were determined to be either coordinating (e.g., for, and, nor, but, or, yet, so) or subordinating (e.g., because, what). This was reported as a percentage of the total number of each type of conjunction used by speakers across modality.

To analyze subordination type, each instance of subordination was determined to be either adverbial, nominal, relative, or infinitive. This was reported as a percentage of the total number of each type of subordination used by speakers across modality.

To further analyze the syntactic structure of the sentences, noun-phrase and verb-phrase, elaborations were analyzed using the Sampling Utterances Grammatical Analysis Revisited (SUGAR) sub-analyses (Owens & Pavelko, 2020). As SUGAR does not include a sub-analysis of prepositional phrases, phrase elaboration was analyzed using the same principles as those for noun phrase and verb phrase elaborations. The number and type of phrase elements for noun phrases, verb phrases, and prepositional phrases within each C-unit were analyzed and the percentage of the total number of each level of phrase elaboration used by speakers across modality was calculated.

Lastly, mean length of utterance (MLU) in morphemes was calculated for each participant across modality using SALT (Miller & Iglesias, 2012). MLUs were averaged across participants within each modality.

Semantic Complexity

To analyze semantic complexity, a variety of lexical parameters were examined. The use of abstract nouns and metacognitive verbs were each calculated as a percentage of the total number of words in each utterance. Semantic complexity was also analyzed in terms of morphologically complex words. For each utterance, the words containing two or more morphemes were identified and broken into their morphological components (e.g. comes → 2:come + s; Paul, Norbury & Gosse, 2017). The use of morphologically complex words was calculated as a percentage of the total number of words in each utterance. Analysis of these three lexical parameters was initially accomplished by the author. In order to confirm accurate analysis, a second investigator (FF) completed the analysis for these three measures. Out of the 36 language samples, there was perfect agreement for 35 samples for abstract nouns, 33 samples for metacognitive verbs, and 34 samples for morphologically complex words. When agreement could not be reached, the analysis of the initial investigator was included.

To examine the lexical diversity of the samples, Moving-Average Type Token Ratio (TTR) was calculated using SALT Standard Measures Report (Miller & Iglesias, 2012). Moving-Average TTR is a measure of the number of different words compared to the total number of words in an utterance.

Ideational Complexity

Ideational complexity was measured to analyze the extent to which the responses conveyed the participant's ideas (Evans, 2016). Using a 5-point scale, language samples were rated on how well the response accurately conveyed the moral of the fable (*0=no* *accurate information was included, 1=concrete information about fable was presented, but moral was not captured, 2=partially captured moral, 3=completely captured moral with no elaboration, 4=completely captured moral with some elaboration, 5=completely captured moral with elaboration and a real-world example*). A second investigator rated the language samples and out of 36 language samples there was perfect agreement for 33 samples. When agreement could not be reached, the analysis of the initial investigator was included

Results

Syntactic Complexity

Figure 1 shows the mean subordination indexes (SI) averaged across all participants, for all three communication modalities. Error bars correspond to one standard deviation. On average, SI was highest for the speech modality, with an average SI of 1.93 and lowest for the dwell-based click modality, with an average SI of 1.23. In the sEMG-based click modality, the average SI was 1.75. Figure 2 shows the average clausal density of incomplete (SI-0, SI-X), simple (SI-1), and complex clauses (SI-2-4) across communication modality. On average, 37.5% of C-units in the sEMG-based click modality were simple clauses (SI-1) and 62.5% were complex (SI-2-4). In the dwell-based click modality, 80.55% of C-units were simple clauses (SI-1) and 19.44% were complex clauses (SI-2-4). In the natural speech modality, 45.83% of C-units were simple clauses (SI-1), and 54.17% were complex clauses (SI-2-4).

Responses from each communication modality were also analyzed for the presence of conjunctions. In the sEMG-based click modality, N = 5 participants used a total of six conjunctions and all conjunctions were subordinating in nature. In the dwell-based click modality, N = 4 participants used a total of seven conjunctions, with 86% subordinating conjunctions and 14% coordinating. Conjunctions were used in the natural speech modality by N=7 participants. A total of 17 conjunctions were used, with 53% subordinating in nature and 47% coordinating.

When subordination was present, the responses were also analyzed for the type of subordination across communication modality. In the sEMG-based click modality, the most common type of subordination was adverbial, which was used by N=6 participants, making up 46% of the total subordination. Nominal subordination was the second most common type of subordination, used 38% of the time by N=4 participants. Relative and infinitive subordination were both used by N=1 participant, each making up 8% of the total subordination. In the dwell-based click modality, the most common type of subordination was nominal, used by N=3 participants, making up 57% of the total subordination. Relative, adverbial, and infinitive subordination were used by N=1 participant, each making up 14% of the total subordination. In the natural speech modality, the most common type of subordination was adverbial, used by N=5 participants, 42% of the time. Nominal subordination was used by N=3 participants, making up 25% of the total subordination. Relative and infinitive subordination were both used by N=2 participants, each making up 17% of the total subordination.

Responses from each communication modality were also analyzed for the extent of noun phrase elaboration. In the sEMG-based click modality, the majority of noun phrases were not elaborated and contained a single noun element. Single-element noun phrases, used by N=8 participants, comprised 56% of total noun phrases. Noun phrases containing two elements were used 28% of the time by N=7 participants. N=4 participants used three-element noun phrases, making up 11% of total noun phrases. A four-element noun phrase was used by N=1 participant, making up 3% of total noun phrases. A no-element noun phrase, corresponding to when the noun was omitted, was used by N=1 participant, making up 3% of total noun phrases. In the dwell-based click modality, the most common type of noun phrases were single-element phrases without elaboration. Single-element noun phrases, used by N=8 participants, made up 46% of total noun phrases. Noun phrases containing two elements were used 25% of the time by N=5 participants. Three-element noun phrases made up 21% of total noun phrases and were used by N=3 participants. A four-element noun phrase was used by N=1 participant, making up 4% of total noun phrases. A no-element noun phrase was used by N=1 participant, making up 4% of total noun phrases. In the natural speech modality, single-element noun phrases were used 53.5% of the time by N=9 participants. Noun phrases containing two elements were used by N=7, 35% of the time. Three-element noun phrases made up 13.5% of total noun phrases and were used by N=5 participants.

Verb phrase elaboration was also analyzed across communication modality. In the sEMG-based click modality, there were no single-element verb phrases. The majority of verb phrases were three-element, making up 52% of total verb phrases, used by N=6 participants. Two-element verb phrases were used 43% of the time, by N=7 participants. Four-element verb phrases were used by N=2 participants, making up 5% of total verb phrases. In the dwell-based click modality, two- and three-element verb phrases were used most frequently, each making up 36% of total verb phrases and each used by N=7 Participants. N=4 participants used single-element verb phrases, making up 23% of total verb phrases. N=1 participant used a four-element verb phrase, making up 5% of total verb phrases. The majority of verb phrases in the natural speech modality had three-elements. Three-element verb phrases were used 36.4% of the time by N=7 participants. Two-element verb phrases were used 30.3% of the time by N=5 participants. Single-element verb phrases were used by N=7 participants, making up 27.3% of total verb phrases. N=2 participants each used a four-element verb phrase, making up 6% of total verb phrases.

Responses from each communication modality were also analyzed for prepositional phrase elaboration. In the sEMG-based click modality, N=2 participants used two-element prepositional phrases 40% of the time. Three-element prepositional phrases were used by N=2 participants, making up 40% of total prepositional phrases. N=1 participant used a five-element prepositional phrase, making up 20% of total prepositional phrases. In the dwell-based click modality three-element prepositional phrases were used by N=5 participants, making up 45.5% of total prepositional phrases. Two-element prepositional phrases were used 36.4% of the time by N=4 participants. Four-element prepositional phrases were used by N=2 participants, making up 18.2% of total prepositional phrases. In the natural speech modality, N=2 participants each used a two-element prepositional phrase, making up 66.7% of total prepositional phrases and N=1 participant used a three-element prepositional phrase, making up 33.3.% of total prepositional phrases.

Figure 3 shows average MLU in morphemes, averaged across all participants, for all three communication modalities. Error bars correspond to one standard deviation. On average, utterances were longest in the natural speech modality with an average MLU of 10.6 and shortest in the dwell-based click modality with an average MLU of 6.9. In the sEMG-based click modality, average MLU was 10.1.

Figure 1. Average subordination index across communication modalities: sEMG-based click, dwell-based click, and natural speech. Error bars represent one standard deviation.

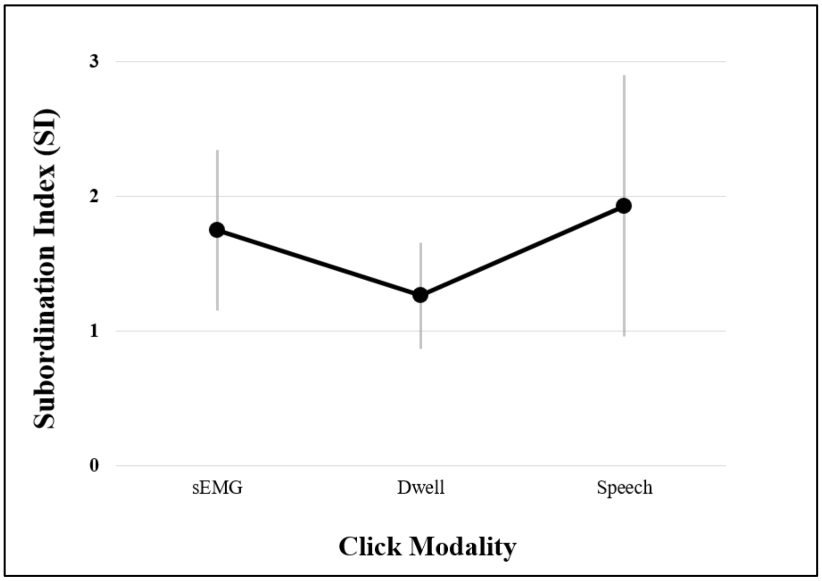


Figure 2. Average distribution of clausal density across communication modalities: sEMG-based click, dwell-based click, and natural speech. C-units were coded by subordination index: SI-X for incomplete clauses, SI-0 for clauses that lack a subject or verb in the main clause, SI-1, SI-2, SI-3, and SI-4 for c-units that contain one, two, three, or four clauses.

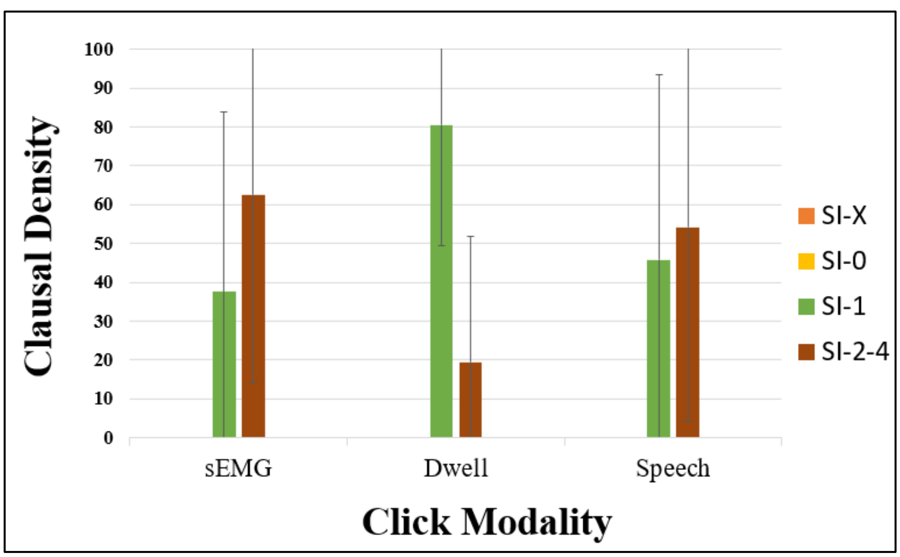
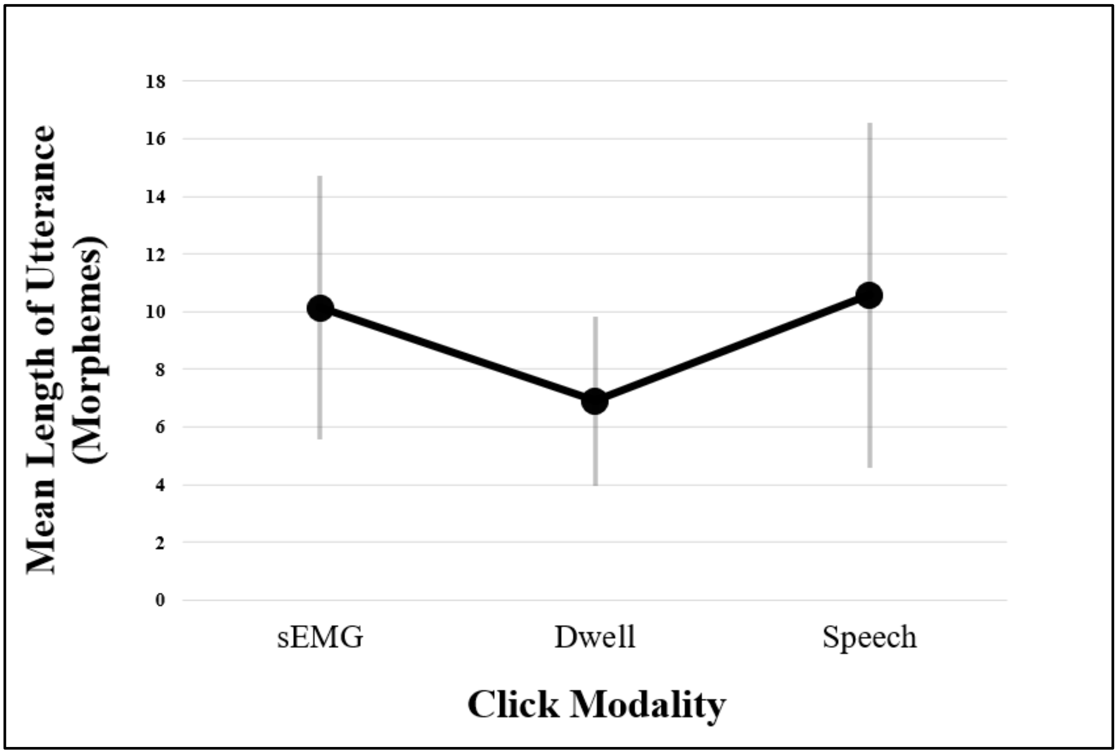


Figure 3. Mean length of utterance in morphemes averaged across communication modalities: sEMG-based click, dwell-based click, and natural speech. Error bars represent one standard deviation.



Semantic Complexity

Semantic complexity was analyzed across modalities using measures of metacognitive verb use, abstract noun use, morphologically complex word use, and the Moving Average Type-Token Ratio (Moving Average TTR). Metacognitive verbs, abstract nouns, and morphologically complex words were calculated as a percentage of total words in each utterance and averaged across participants within each modality.

Figure 4 shows the average percentage of metacognitive verbs used by all participants for each communication modality. Error bars correspond to one standard deviation. On average, the highest use of metacognitive verbs was 6.3% for the sEMG-based click modality. The lowest use of metacognitive verbs was 1.3% for the dwell-based click modality. With natural speech, average metacognitive verb use was 2.5%.

Figure 5 shows the average percentage of abstract nouns used by all participants for each communication modality. Error bars correspond to one standard deviation. On average, abstract noun use was relatively similar across modality. The highest average use of abstract nouns was 10.1% for natural speech. The lowest average use of abstract nouns was 7.1% for the sEMG-based click modality. With the dwell-based click modality, average abstract noun use was 8.4%.

Figure 6 shows the average percentage of morphologically complex words used by all participants for each communication modality. Error bars correspond to one standard deviation. On average, the highest use of morphologically complex words was 14.8% for the dwell-based click modality. The lowest use of morphologically complex words was 5.8% for the sEMG-based click modality. With natural speech, average morphologically complex word use was 10.8%.

Figure 7 shows Moving Average TTR, averaged across all participants, for all three communication modalities. Error bars correspond to one standard deviation. On average, Moving Average TTR was relatively similar across modality. Moving Average TTR was 0.92 for the sEMG-based click modality, 0.94 for the dwell-based click modality, and 0.89 for natural speech.

Figure 4. Average use of metacognitive verbs, as measured by percent of total words, across communication modalities: sEMG-based click, dwell-based click, and natural speech. Error bars represent one standard deviation.

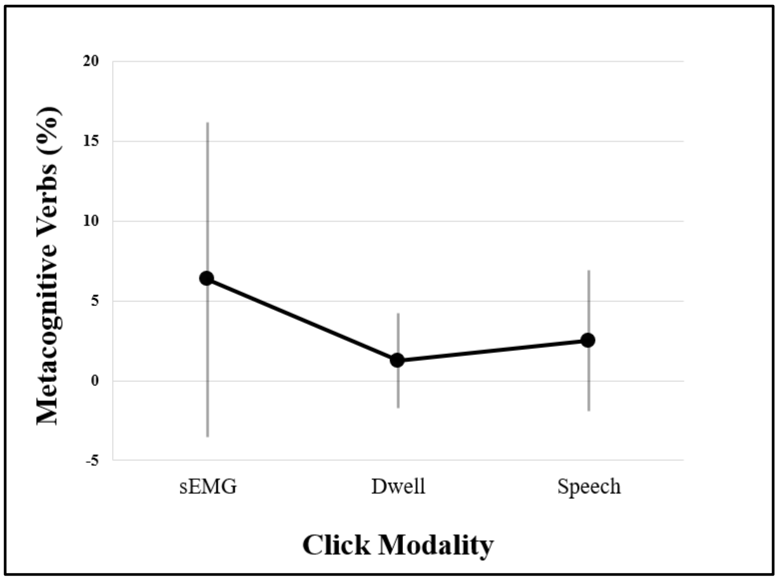


Figure 5. Average use of abstract verbs, as measured by percent of total words, across communication modalities: sEMG-based click, dwell-based click, and natural speech. Error bars represent one standard deviation.

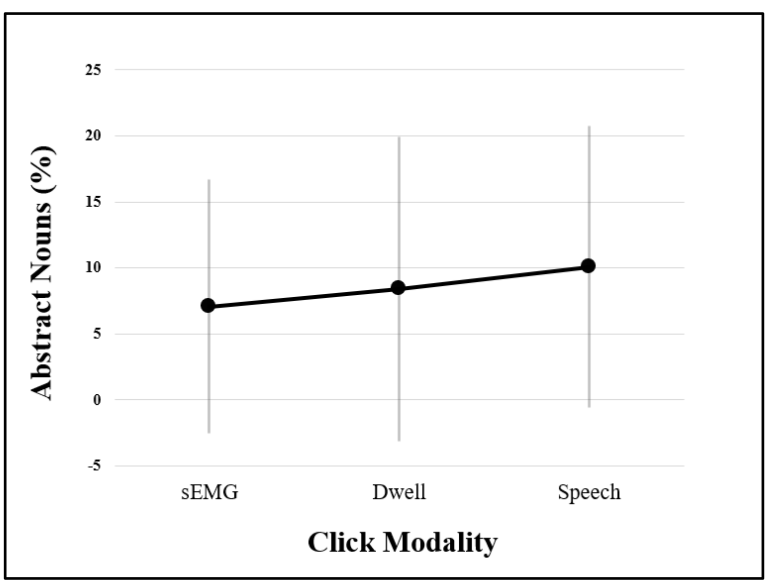


Figure 6. Average use of morphologically complex words, as measured by percent of total words, across communication modalities: sEMG-based click, dwell-based click, and natural speech. Error bars represent one standard deviation.

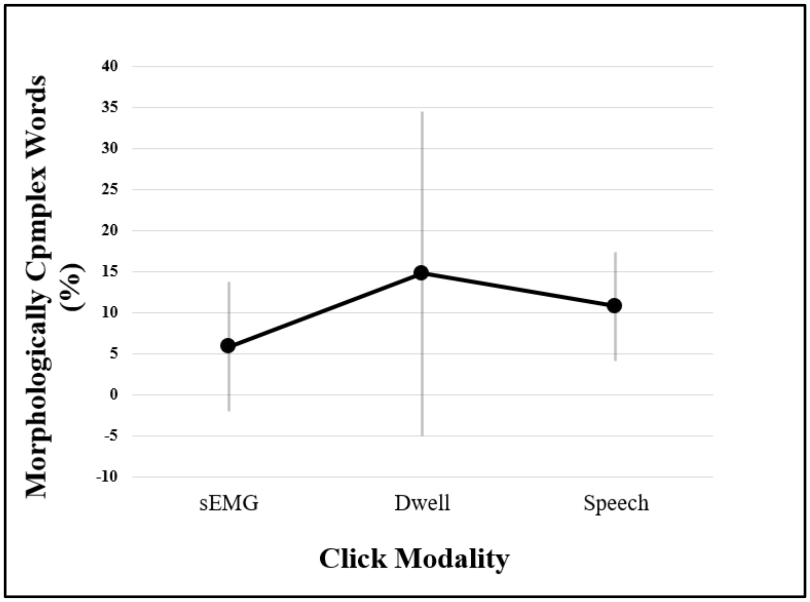
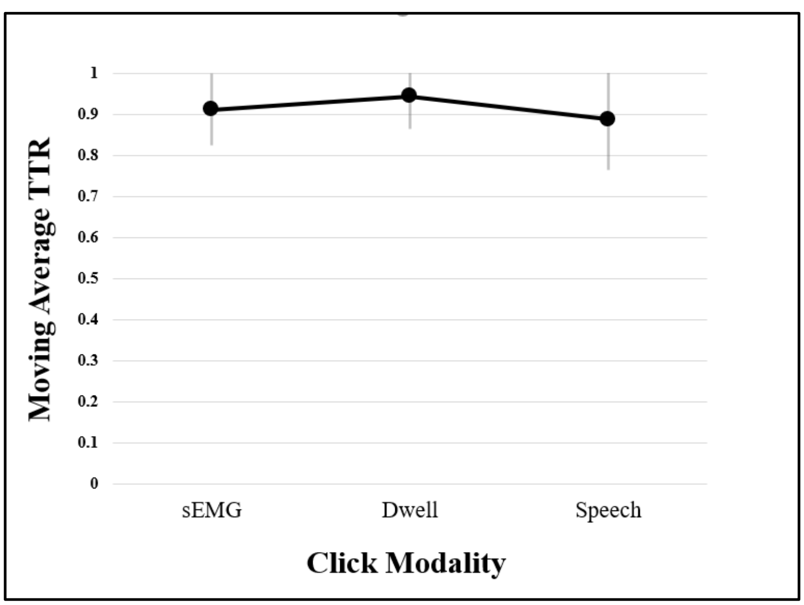


Figure 7. Average Moving Average TTR across communication modalities: sEMG-based click, dwell-based click, and natural speech. Error bars represent one standard deviation. Moving Average TTR is measured between 0 and 1.



Ideational Complexity,

Figure 8 shows average ideational complexity scores averaged across participants for each communication modality. Error bars correspond to one standard deviation. Average scores across all three modalities ranged between a score of *2 (moral partially captured)* and *3 (completely captured moral with no elaboration).* The average ideational complexity score was 2.08 for the sEMG-based click modality, 2.5 for the dwell-based click modality, and 2.5 for natural speech.

Subjective Measure of Usefulness

Figure 9 shows the average perception of usefulness averaged across all participants for each communication modality. Error bars correspond to one standard deviation. On average, participants ranked speech as more useful than either the dwell or sEMG-based click modalities. The average perception of usefulness across all participants was 6.6 for natural speech, corresponding to a score between *useful* (6) and *very useful* (7). The average perception of usefulness across all participants was 5.7 for the sEMG-based click modality and 5.4 for the dwell-based click modality, corresponding to a score between *somewhat useful* (5) and *useful* (6).

Figure 8. Average ideational complexity score across communication modalities: sEMG-based click, dwell-based click, and natural speech. Error bars represent one standard deviation. Ideational Complexity was scored on a 5-point scale: *0=no accurate information was included, 1=concrete information about fable was presented, but moral was not captured, 2=partially captured moral, 3=completely captured moral with no elaboration, 4=completely captured moral with some elaboration, 5=completely captured moral with elaboration and a real-world example.*

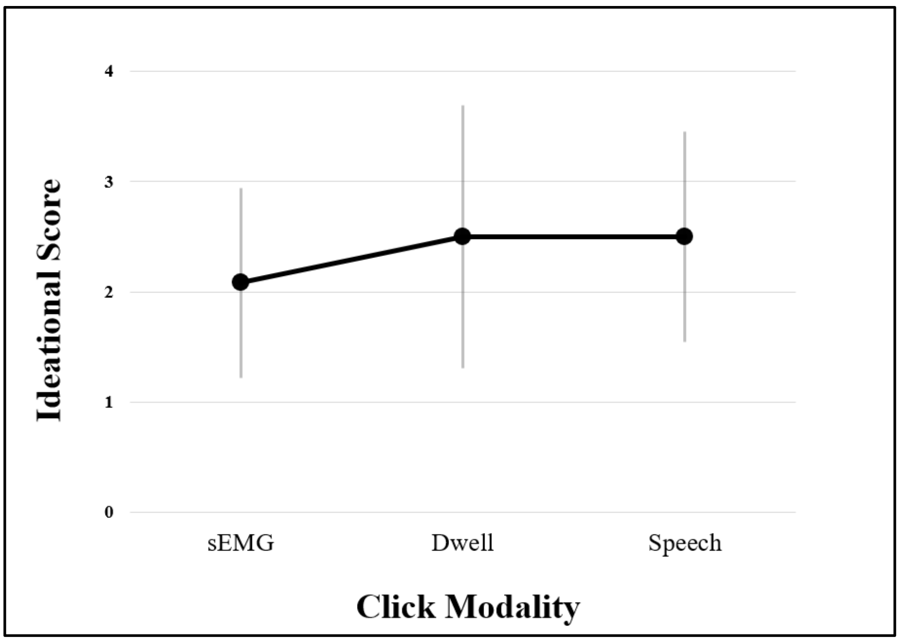
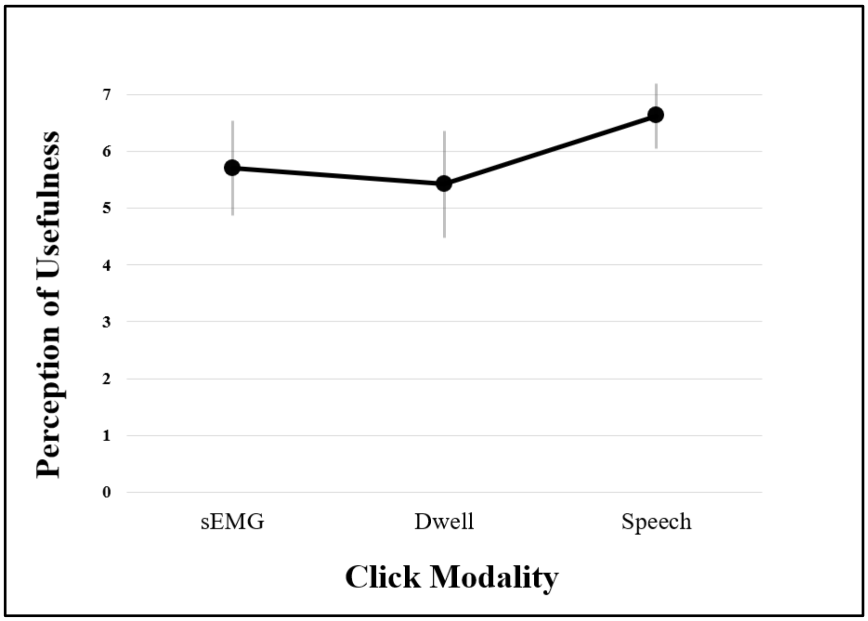


Figure 9. Average perception of usefulness score across communication modalities: sEMG-based click, dwell-based click, and natural speech. Error bars represent one standard deviation. Participants evaluated the usefulness of each modality using a 7-point Likert scale: 1 = *very useless,* 2 = *useless,* 3 = *somewhat useless,* 4 = *neutral,* 5 = *somewhat useful,* 6 = *useful,* 7 = *very useful*



Discussion

The purpose of this study was to explore two different cursor-click modalities (dwell-based and sEMG-based) as access methods in a sEMG/ACC system by comparing the communicative abilities of individuals with neuromuscular disorders when using these access methods. Additionally, these findings were compared to the communicative abilities of individuals while using natural speech. The goal was to utilize these comparisons to understand the practicality of these access methods for future AAC devices to effectively meet communication demands. This was an exploratory study due to the small sample size, but many important observations were made that may have implications for clinicians, AAC users and manufacturers, and researchers.

It was demonstrated that individuals with neuromuscular disorders could successfully utilize both dwell-based and sEMG-based cursor click modalities to access AAC technology following a brief orientation, though two of the fourteen participants were unable to use the device and their data was excluded. This builds on the findings from Groll et al. (2020), which showed that individuals who were neurotypical successfully used both cursor-click modalities as a computer access method. This experiment aimed to assess if these cursor-click modalities could effectively be used by individuals with neuromuscular disorders to interact with an on-screen keyboard and meet complex communication demands at the discourse level, using qualitative and quantitative information regarding language complexity and subjective perceptions of usefulness.

Language Complexity Differs Across Modality on Some Measures

Language sampling analysis of the participants' responses demonstrated that participants were able to use all three modalities to produce a variety of linguistic content, and findings suggest some differences in language complexity. It was hypothesized that the language complexity while using natural speech would surpass the language complexity of users while using either of the AAC cursor-click modalities. It was further hypothesized that language complexity would be less complex when using the dwell-based cursor click compared to the sEMG-based cursor click. Language analysis revealed differences in some measures of syntactic and semantic complexity, providing support for this hypothesis. All individual data were inspected for diagnostic-specific trends, but none were observed.

Syntactic Complexity

Language analysis revealed differences in some measures of syntactic complexity across modality, which may partially be explained by the tendency of AAC users to employ time-saving strategies when conveying messages (Smith et al., 1989).

Measures of MLU revealed that utterances were generally the same length in the natural speech modality (10.9 morphemes) compared to the sEMG-based click modality (10.1 morphemes) and were shorter in the dwell-based click modality (6.9 morphemes). Existing literature suggests that AAC users sometimes produce shorter utterances than what is expected based on the users age and developmental level (Binger & Light, 2008; Yorkston, Beukelman, Smith, & Trice, 1990). This was observed in this study for the dwell-based click modality. On average, the participants produced shorter utterances in morphemes when using the dwell-based click modality compared to when using the sEMG-based click modality and natural speech. Producing utterances using AAC is often time-consuming so using brief utterances is likely an effective time-saving strategy (Smith et al., 1989). Given that using dwell time to make a cursor click requires slightly more time than using sEMG, it is possible that users felt more inclined to produce shortened utterances using the dwell-based click modality. This finding supports the hypothesis that the sEMG-based click modality would produce more complex language than dwell-based click modality, but it does not support the hypothesis that the language complexity of natural speech would surpass both click modalities.

An analysis of clausal density showed that, on average, participants used a majority of simple sentences in the dwell-based click modality (80.55%), whereas in the sEMG-based click modality and the speech modality, the majority of utterances were complex and contained two or more clauses, which further supports the hypothesis of language being more complex in the speech and sEMG-based click modalities than in the dwell-based click modality. An analysis of subordination indexes also supported this finding, illustrating that on average, participants had the lowest subordination indexes in the dwell-based click modality (1.26). Furthermore, participants in the speech modality had a higher subordination index on average (1.93) than participants in the dwell-based click modality (1.75), despite participants in the sEMG-based click modality producing a higher percentage of complex sentences. This suggests that when participants in the speech modality used complex sentences, they typically produced utterances with multiple embedded subordinate clauses. This finding could also be related to the increased selection time required of the cursor click modalities. By nature, complex utterances tend to be longer than simple sentences because they contain multiple clauses. Sentence length further increases with multiple embedded clauses. These findings support both the hypothesis that language would be more complex in the sEMG based-click modality than the dwell-based click modality, as well as the hypothesis that language would be most complex in the speech modality.

Conjunction usage was analyzed to further explore the use of compound and complex sentences, both of which are syntactically more complex than simple sentences (Paul et al., 2017). Overall, conjunctions were used most frequently in the speech modality, demonstrating that more complex and compound sentences were used with natural speech compared to the other modalities. This finding further suggests that natural speech may provide individuals with more linguistic flexibility when conveying messages. This finding supports the hypothesis that language complexity would be greater for natural speech than either of the two cursor-click modalities.

Further analysis of coordinating conjunctions revealed that they were used most frequently in the natural speech condition, with only one total instance across the two cursor-click modalities. This demonstrates that participants rarely used compound sentences in either of the two cursor-click modalities.

Subordinating conjunctions were used by participants in all three communication modalities but were used most frequently in the natural speech modality. Given that subordinating conjunctions can often be omitted, this could be related to time-saving strategies utilized by participants in the cursor-click modalities. A further analysis of the types of subordination that were used by participants did not reveal any modality-specific trends. However, analysis revealed that all four types of subordination (e.g., adverbial, nominal, relative, and infinitive) were used in each modality. This finding provides further evidence that users are able to use both cursor-click modalities to produce language with a variety of syntactical structures.

An analysis of verb phrase, noun phrase, and prepositional phrase elaboration revealed that participants used a variety of phrase structures in each modality. This further supports the finding that users are able to use both cursor-click modalities to produce a variety of language structures, including noun, verb, and prepositional phrases of varying levels of elaboration. There were no modality-specific trends for any of the phrase elaboration measures and the majority of phrases in all three modalities were not elaborated. In both cursor-click modalities one participant omitted an obligatory noun and produced noun phrases in which the noun was absent. Existing literature suggests that omitting information is another effective strategy to reduce the time needed to create a message (Smith et al., 1989). Prepositional phrases were used sparingly across each modality, with varying levels of elaboration, which supports findings that users produced relatively short utterances across modality. Additionally, the lack of prepositional phrase elaboration in either of the cursor-click modalities could provide further support for the idea that time-saving strategies may have impacted the complexity of the participants' language. Although these findings do not support the hypothesis regarding differences in language complexity, this finding may further support the interpretation that participants may have been using time-saving strategies in the cursor-click modalities. However, the lack of prepositional phrases could alternatively suggest that the task did not necessitate the use of prepositional phrases.

Semantic Complexity

An analysis of semantic complexity revealed modality-specific differences only in morphologically complex word usage. There were no modality-specific trends on the other semantic measures, suggesting that using the cursor-click modalities does not negatively impact the lexical diversity that users are capable of producing.

Relatively similar measures of Moving Average TTR across modalities support the claim that using either of the cursor-click modalities does not reduce the lexical diversity of a user's language. Furthermore, an analysis of abstract nouns and metacognitive words showed that they were used by participants in all three modalities. Abstract nouns are nouns that represent an idea, quality, or state, as opposed to a concrete object, and metacognitive verbs are verbs that are used to describe the thoughts, feelings, or perspectives of one's self or others (Paul, Norbury & Gosse, 2017). This indicates that users are able to use both cursor-click modalities to produce language with a variety of lexical categories.

An analysis of morphologically complex word use revealed that participants used morphologically complex words in all three modalities, further demonstrating that AAC use does not negatively impact a user's ability to produce lexically diverse language containing a variety of grammatical and derivational morphemes. On average, participants used morphologically complex words more frequently in the natural speech modality (10.75%) than the sEMG-based click modality (5.83%). These findings support the hypothesis that the complexity of language while using natural speech surpasses that of the cursor-click modalities. Given that words increase in length as the number of morphemes increase, this further aligns with existing literature that suggests that AAC users tend to produce shorter utterances as a time-saving mechanism (Smith et al., 1989).

Overall, the measures of semantic complexity demonstrate the lexical richness and diversity were not compromised, despite the greater cognitive demand that use of the cursor click modalities may have potentially placed on the users. Although the measure of morphologically complex word usage found modality-specific differences, it is the most syntactically based measure of semantic complexity because it analyzes the morphological structure of words and is related to increasing word-length.

Ideational Complexity

Ideational Complexity scores were found to be relatively similar across modality. This provides evidence that although participants used a variety of syntactical, morphological, and lexical structures to respond to the prompts regardless of modality, they were all relatively similar in their ability to accurately use language to respond to the prompt. The average ideational complexity score for each modality fell between 2 (*moral partially captured*) and 3 (c*ompletely captured moral with no elaboration*). This indicates that, regardless of modality, participants generally understood the fable and were able to use language to produce a response that captured some aspects of the moral. In general, participants did not provide extra elaboration, which aligns with the finding that responses were typically short across modalities. Overall, these findings suggest that the ideational complexity of participants' responses was not impacted by their communication modality.

Subjective User Perceptions Differ Between Natural Speech and Cursor Click Modalities

The users' perceptions of usefulness of natural speech and two cursor-click modalities for accessing AAC technology were explored. It was hypothesized at the beginning of this study that participants would rate natural speech as more useful than either of the click modalities and would rate the sEMG-based cursor click as more useful than the dwell-based cursor click. On average, participants did rank their natural speech as being more useful than either of the cursor click modalities, with the average falling between *useful* and *very useful,* which supports the hypothesis. Although the participants in this study all presented with a variety of neuromuscular disorders with varying levels of motoric challenges, all reported that natural speech was their primary modality of communication at the time of the study. The majority of participants reported some level of AAC experience, but given that they were all using natural speech as their primary communication modality, it can be presumed that they generally found natural speech useful enough to meet their current communication demands. Thus, it is not surprising that natural speech received the highest average rating of usefulness. There was little difference in usefulness between the two cursor-click modalities, which does not support the hypothesis. Both averages fell between *somewhat useful* and *useful,* suggesting that participants still had a generally positive perception of both AAC access methods. Although language samples produced using the AAC access methods were less complex on some measures and required longer to complete, these results demonstrate that users still felt both modalities were relatively useful for communication. These findings suggest that linguistic competence may only be one component of determining the communicative success of an individual when using an AAC device.

Limitations and Future Directions

The results of this exploratory study indicate that sEMG and dwell time both serve as potential access methods for controlling a computer cursor using an sEMG/ACC system for individuals with neuromuscular disorders. However, additional research is needed to further explore the potential use of these access methods.

Although the present study used language sample analysis to provide an evaluation of language complexity, the size of the language samples, which ranged from one-six utterances, were small, and therefore provide only limited information about the participants' language abilities and cannot be considered representative of their capabilities. It is possible that larger language samples may have produced different results. However, collecting a larger language sample requires more time, which would have extended the length of the session and caused additional participant fatigue. Increased fatigue could have impacted the participants' ability to produce representative language samples while using the cursor-click modalities and as a result it may have caused them to produce shorter less complex language samples than they normally would have produced. This experiment was part of a larger session in which the participants first completed other tasks not included in this study using each of the cursor-click modalities. While completion of the other tasks provided the participants with familiarity with the device, increased levels of fatigue were a concern. Future studies should aim to further assess differences in language complexity in longer language samples using a range of language measures.

Participants had limited experience with the AAC system which may have also impacted their ability to produce representative language samples. Although the participants gained some familiarity with the system and individual cursor-click access methods during the calibration task and other session tasks, the participants still lacked adequate system experience going into the language task. In a clinical setting, an individual trials a device for a period of time as part of the assessment period, before a decision is made regarding their communication competency with that AAC system (Dietz, Quach, Lund, McKelvey, 2012). This exploratory study provides some important early information about the potential clinical applications of these cursor-click modalities as communication access methods, but if participants had been exposed to the device for a longer period of time during this study, their operational competence with the device may have improved and they may have consequently provided longer and more complex language samples.

This study focused on linguistic competency, but future research should expand the scope to include additional competency areas in determining overall communicative competency. Light (1989) defined communication competence as holding knowledge, judgement, and skill in four individual areas: linguistic competence, operational competence, strategic competence, and social competence. This study aimed to understand the linguistic competencies of participants while using each of the two cursor-click modalities, but to fully understand the potential of these access methods for clinical use, the other three areas must also be investigated. Operational competence refers to the technical skills required to operate the system including the skills required to use the access method (Light, 1989). Although the calibration period was provided as a time for participants to familiarize themselves with the system and gain basic operational competence, future research should investigate this area further. Operational competence is directly impacted by an individual's exposure to a device, so future studies should allow for a longer experimentation period. Additionally, future research should investigate the social competencies of users, as this is another crucial part of successful communication. The present study was limited and assessed only the communicative function of answering a question, so further work should expand the scope to consider the pragmatics of communication when assessing the effectiveness of these access methods. Likewise, strategic competence should also be investigated in future work.

It is also worth noting that all of the individuals who participated in this study used speech as their primary modality of communication, despite the variable communicative profiles represented within a population of people with NMDs. That suggests that the nature and/or severity of the participants' neuromuscular disorder did not have a large functional impact on their communication. Comparing the language samples from the two cursor-click modalities to functional natural speech was useful in providing a baseline language measure, but for individuals who place a higher reliance on AAC for everyday communication, they may have more complex language samples and/or higher perceptions of usefulness for the cursor-click modalities compared with their natural speech. To better understand the impact of the investigated access methods on functional communication, it is recommended that future studies include some participants who currently use an AAC system as their primary communication modality and comparisons should be made between the two cursor-click modalities investigated in the present study with each other as well and with the participants' current AAC system. Furthermore, the present study did not reveal trends within specific NMD diagnoses groups, but differences may emerge with a larger sample size. Given the variety of communicative profiles represented within a population of people with NMDs, further research should compare the two cursor-click modalities in the present study within a larger sample size.

Finally, it is suggested that future studies adapt the on-screen keyboard to include a variety of features that support user efficiency, including predictive text at the single-letter or word level and whole-word keys for high-frequency lexical items (e.g., the, and). In the present study, individuals were required to type their responses letter-by-letter on an onscreen keyboard, which proved to be extremely time-consuming. Despite the participants producing short simple responses to the prompt, they still utilized between 7 and 12 minutes to complete each prompt when using either of the cursor-click modalities. By adapting the keyboard to include features that increase user efficiency, the overall time required to respond to a prompt will decrease and participants may be more motivated to produce a more complex and thoughtful response to the prompt. Using predictive text dynamically changes the options offered to a user based on the portion of the word or sentence that the user has already typed and has been shown to improve communication rates (Buekelman & Mirenda, 2005). Therefore, adapting the on-screen keyboard may lead to the collection of a more robust language sample.

Conclusion

The aim of the present study was to compare the communicative abilities of individuals with neuromuscular disorders when using dwell-based and sEMG-based cursor click modalities in an augmentative and alternative communication device, and to investigate how these differences compared when using natural speech. The present study shows that both dwell-based and sEMG-based cursor clicking can be successfully used by individuals with neuromuscular disorders as an access method in a sEMG/ACC device to convey ideationally relevant messages containing lexically diverse language with a variety of syntactical language structures; however, the dwell-based click modality resulted in reduced syntactic complexity on multiple outcome measures. Furthermore, this study shows that participants found both cursor-click modalities to be at least somewhat useful to them as communication modalities. Finally, this study demonstrates that users of AAC may value additional features beyond the level of their language complexity (e.g., speed of message construction) when using AAC to communicate.

Table 1. Participant demographics. CP= Cerebral Palsy, SCI= spinal cord injury, MD= muscular dystrophy, GBS= Guillain-Barré Syndrome, MS= Multiple Sclerosis. Y= yes. N= no. R=Right. L= Left. S/L= Speech/Language.

Participant	**Age**	**Sex**	**Diagnosis**	**AAC experience**	**History of S/L impairment**	**Dwell Time**	**Sensor Location**
P1	39	M	CP	Y	N	1.5 s	R-Eye
P2	23	F	CP	Y	N	1.5 s	L-Cheek/R-Eye
P3	54	M	C6 SCI	Y	N	1.5 s	L-Eye
P4	24	M	MD	N	N	1.5 s	R-Eye
P5	49	M	C6 SCI	N	N	1.0 s	R-Forehead
P6	45	M	GBS	Y	N	1.0 s	R-Eye
P7	45	M	C3 SCI	Y	Y; S/L therapy post-injury	1.5 s	R-Eye
P8	49	M	C4/C7 SCI	Y	N	2.0 s	R-Eye
P9	51	F	MS	Y	Y; slurring due to respiratory issues	1.0 s	R-Eye
P10	54	F	C6-C7 SCI	Y	N	1.5 s	R-Eye
P11	27	F	CP	Y	N	0.8 s	L-Cheek
P12	73	F	MS	N	N	1.0 s	R-Eye

Appendix

Appendix A.

Fables used in the communication task.

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1. The Lion and the Mouse
(Adapted from *Aesop's Fables*, 1947

Once upon a time, a Lion was sleeping. A little Mouse began running up and down the lion until he woke up. The lion placed his huge paw on the mouse and opening his big jaws to swallow him. The little Mouse cried out "forgive me this time and I'll never forget it. And who knows, maybe I'll be able to help you some day?"
The Lion was so amused at the idea of the Mouse being able to help him that he let him go. Later, the Lion was caught in a trap by hunters. While the hunters went to find a wagon to carry him away, they tied him to a tree.
Just then the little Mouse passed by, and saw the unfortunate situation that the Lion was in. The mouse went up to him and gnawed away the ropes that help the lion.
"Was I not right?" said the little mouse.

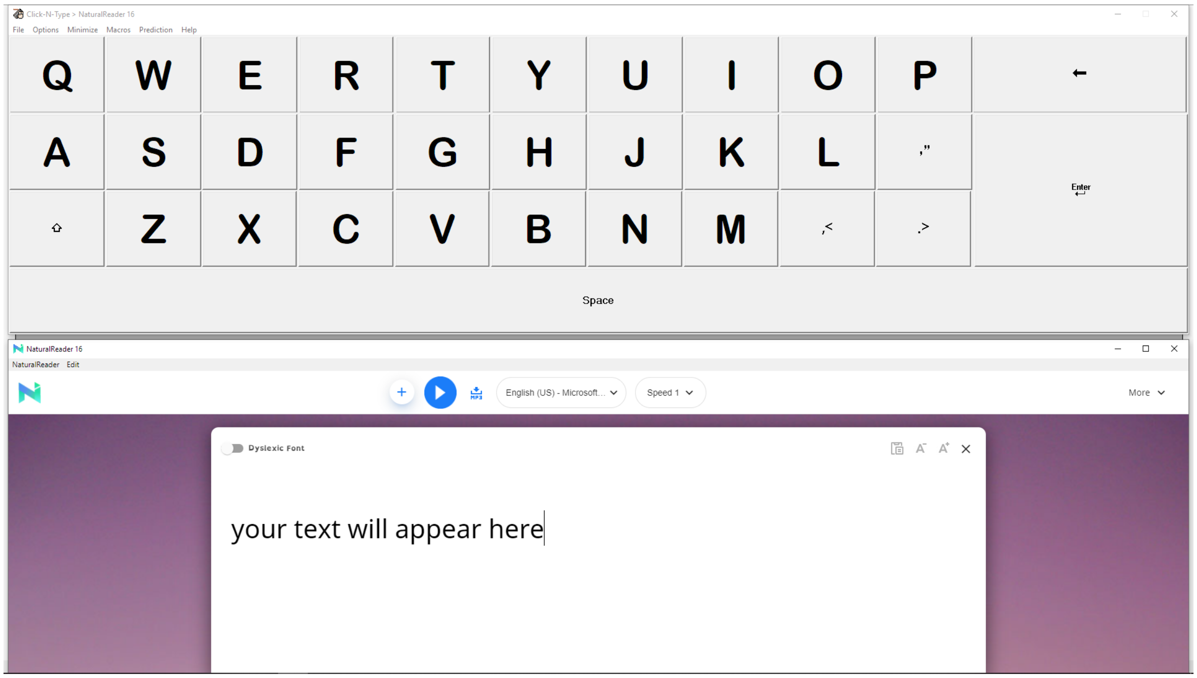
2. The Dog and the Shadow
(Adapted from *Aesop's Fables,* 1947).

Once upon a time a Dog had a piece of meat in his mouth. He decided to carry the meat home to eat it in peace.
On his way home he had to cross a plank laying across a river.
As he crossed, he looked down and saw his own shadow reflected in the water below.
Thinking it was another dog with another piece of meat, he decided that he wanted to have that meat too.
So he snapped at the shadow in the water, but as he opened his mouth the piece of meat fell out, dropped into the water and was never seen again.

3. The Crow and the Pitcher
(Adapted from *Aesop's Fables*, 1947).
Once upon a time, a thirsty half-dead Crow found a pitcher that was once completely full of water; but when the Crow put its beak into the pitcher he found that very little water was left, and that he could not reach far enough down to get a drink.
He tried, and he tried, but at last had to give up.
Then a thought came to him. He took a pebble and dropped it into the pitcher.
Then he took another pebble and dropped it into the pitcher.
Then he took another pebble and dropped it into the pitcher.
Then he took another and dropped that into the pitcher.
At last, he saw the water level rise up, and after casting in a few more pebbles he was able to drink the water and save his life.

Appendix B.

Image of On-Screen Keyboard created with Click-N-Type [Lake Software].



Appendix C.

Participant questionnaire of device usefulness for communication

How useful was this device in the following areas:							
	Very Useless	Useless	Somewhat Useless	Neutral	Somewhat Useful	Useful	Very Useful
1. Overall success expressing yourself	1	2	3	4	5	6	7
2. Conveying a variety of messages	1	2	3	4	5	6	7
3. Communicating clearly	1	2	3	4	5	6	7
4. Communicating quickly	1	2	3	4	5	6	7
5. Communicating effortlessly	1	2	3	4	5	6	7

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