Abstract

KEYBOARD LAYOUT IN EYE GAZE COMMUNICATION ACCESS: TYPICAL VS. ALS

by

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July, 2013

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The purpose of the current investigation was to determine which of three keyboard layouts is the most efficient for typical as well as neurologically-compromised first-time users of eye gaze access. All participants (16 neurotypical, 16 amyotrophic lateral sclerosis; ALS) demonstrated hearing and reading abilities sufficient to interact with all stimuli. Participants from each group answered questions about technology use and vision status. Participants with ALS also noted date of first disease-related symptoms, initial symptoms, and date of diagnosis. Once a speech generating device (SGD) with eye gaze access capabilities was calibrated to an individual participant's eyes, s/he practiced utilizing the access method. Then all participants spelled word, phrases, and a longer phrase on each of three keyboard layouts (i.e., standard QWERTY, alphabetic with highlighted vowels, frequency of occurrence). Accuracy of response, error rate, and eye typing time were determined for each participant for all layouts.

Results indicated that both groups shared equivalent experience with technology. Additionally, neurotypical adults typed more accurately than the ALS group on all keyboards. The ALS group made more errors in eye typing than the neurotypical

participants, but accuracy and disease status were independent of one another. Although the neurotypical group had a higher efficiency ratio (i.e. accurate keystrokes to total active task time) for the frequency layout, there were no such differences noted for the QWERTY or alphabetic keyboards. No differences were observed between the groups for either typing rate or preference ratings on any keyboard, though most participants preferred the standard QWERTY layout. No relationships were identified between preference order of the three keyboards and efficiency scores or the quantitative variables (i.e., rate, accuracy, error scores). There was no relationship between time since ALS diagnosis and preference ratings for each of the three keyboard layouts.

It appears that individuals with spinal-onset ALS perform similarly to their neurotypical peers with respect to first-time use of eye gaze access for typing words and phrases on three different keyboard layouts. Ramifications of the results as well as future directions for research are discussed.

KEYBOARD LAYOUT IN EYE GAZE COMMUNICATION ACCESS: TYPICAL VS. ALS

A Dissertation

Presented to

The Faculty of the Department of Communication Sciences and Disorders

East Carolina University

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy in Communication Sciences and Disorders

by

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For my mother, Lydia Lewis, all my love

ACKNOWLEDGEMENTS

I would like to thank a few individuals who have contributed to the completion of this project. First, I would like to thank my family – Robert and Spencer – for supporting me through both setbacks and triumphs in our lives. Thanks to Dr. Joseph Kalinowski for helming this project and for his unique perspective on the topics discussed within. Heartfelt thanks to Dr. Laura Ball for serving as my mentor through my doctoral program; her support and guidance almost single-handedly molded me into the teacher and researcher that I am today. I would like to thank my committee for their constructive feedback and expertise. Finally, I would like to thank speech-language pathologist Amy Wright for her invaluable assistance in providing willing participants with amyotrophic lateral sclerosis to complete this study.

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CHAPTER I: REVIEW OF THE LITERATU`RE

Individuals develop verbal communication throughout the lifespan; it is constantly changing with new experiences and with formal training or incidental learning. At some time between the fourth and eighth decades of life, however, a small portion of the United States population is diagnosed with a form of amyotrophic lateral sclerosis (ALS) (Eisen, 2002; Logroscino et al., 2008). As many as 95% of individuals with ALS will eventually lose the ability to communicate using natural speech and require the use of augmentative and alternative communication (AAC) to either supplement or completely replace lost speech (Ball, Beukelman, & Pattee, 2004; Beukelman, Fager, & Nordness, 2011). For some individuals, it may be enough to use a finger to activate a touch screen on a speech generating device (SGD). Eventually, however, as the disease causes increasing paralysis people with ALS may rely on the use of preserved eye muscles and tracking by eye gaze systems for communication (Higginbotham, Shane, Russell, & Caves, 2007). The current body of research offers limited insights into the efficiency of eye gaze access of SGDs for communication. After a brief introduction to ocular anatomy and physiology, eye gaze technology, keyboard layout, methods of increasing the efficiency of alternative access methods, ALS, and gaps in the existing corpus of knowledge relative to eye gaze communication are framed in the context of the current research.

A Primer on Ocular Anatomy and Physiology

The human eye is the sole organ of photoreception, which is the process by which light is detected, absorbed, and utilized for vision and depth perception. An illustration of the major anatomical structures of the human eye can be found in Figure 1

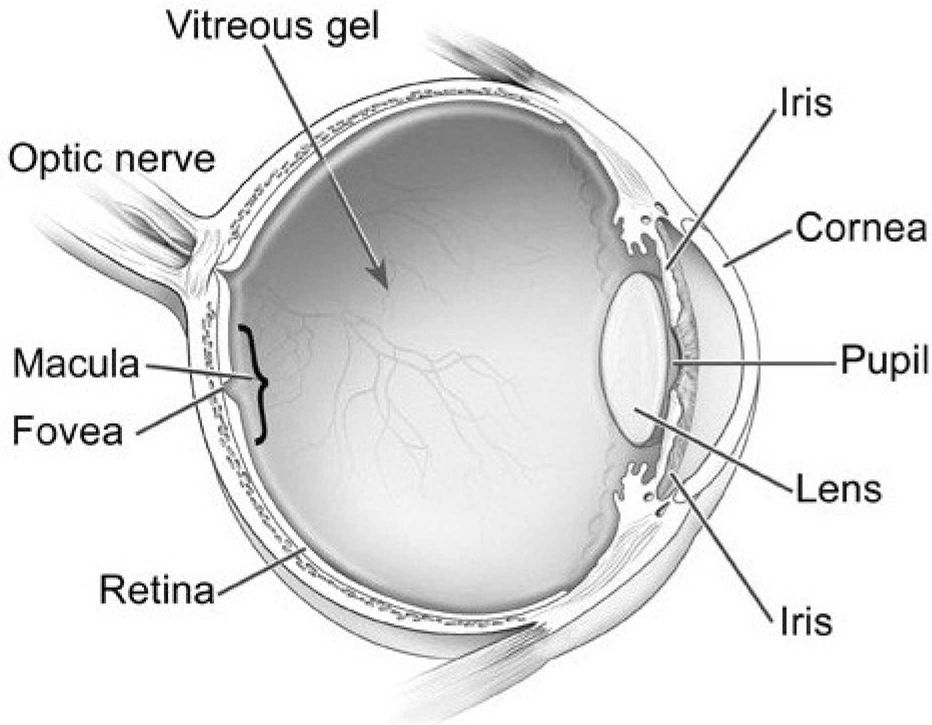

Figure 1. Major anatomical structures of the eye.

(Statewide Vision Resource Centre, 2012). Ocular anatomy and physiology will be discussed with respect to the path light takes when moving through this system.

Ocular Anatomy. The globe, or bulbus oculi, is an almost-spherical organ comprised of multiple layers. The bulbus oculi is the overall eye structure excepting the ocular appendages (i.e., extraocular muscles, eyelids, lacrimal glands). The sclera is the outermost tissue layer of the globe. Joining the opaque sclera at the limbus (border) is the multi-layered cornea. The domed cornea is transparent, allowing light to enter the eye. The radius of corneal curvature is ideal and adds 43 diopters or 2/3 of the refractive power of the eye. Refraction is the deflection from a straight path undergone by light rays passing from one medium into another (i.e., air to cornea plus minor additional refractive effects by the aqueous and vitreous humors as noted below). (Forrester, Dick, McMenamin, & Roberts, 2008; Purves et al., 2009; Smith, 2008; Yanoff, 2009)

The iris is the colored portion of the eye that lies posterior to the cornea; the pupil is an opening located in the center of the iris. The pupil contracts/expands to allow varying amounts of light to enter the eye. Within the iris, the dilator muscle (dilatator papillae) makes the iris smaller and the pupil, consequently, larger (i.e., mydriasis). This allows more light to enter the eye. The sphincter muscle (sphincter pupillae), on the other hand, makes the iris larger and the pupil smaller (i.e., miosis). This lets less light enter the eye. These two muscles encircle the pupil but are found within the iris. Both the dilator and sphincter muscles are innervated by the ciliary ganglion, which is controlled by the autonomic nervous system. (Purves et al., 2009; Smith, 2008; Yanoff, 2009)

Continuing with ocular anatomy, aqueous humor lies behind the cornea but in front of the lens. In addition to inflating the globe of the eye, this fluid provides nutrients to both the cornea and lens; it also provides minimal refractive properties with a refractive index of 1.336. The crystalline lens is encircled by the ciliary processes and held in place by the zonule of Zinn (i.e., zonular fibers) laterally, the anterior vitreous face posteriorly, and the iris anteriorly. The refractive index of the lens varies from 1.386 peripherally to 1.406 centrally; this gradient index lens focuses light on the back of the eye (i.e., retina). In total, the crystalline lens adds about 18 diopters or 1/3 of the refractive power of the eye. The vitreous humor fills the space between the back of the lens and the surface of the retina. The thick, viscous water-collagen gel helps maintain the eye's globular shape and has an index of refraction of about 1.337. (Smith, 2008; Yanoff, 2009)

The aforementioned optical components of the eye work together to achieve a focused image on the surface of the retina. The retina is the innermost layer of the eye. At the back of the retina, there are light-sensitive neurons known as photoreceptors (i.e., rods and cones). Rods contain rhodopsin, a biological pigment, and are used for vision in dark or dim conditions. The three types of cone cells, which function better in relatively bright light conditions, allow for the perception of detail, color, and color gradation. Rods are more numerous and sensitive than cones; cones are concentrated in the macula, which is described below. The photoreceptors modulate the activity of bipolar cells, which connect with different types of ganglion cells (i.e., Magnocellular, Parvocellular, Koniocellular) located at the front of the retina. The retinal ganglion cells receive vision information from the rods and cones and transmit the information from the retina to several regions in the brain via long axons that form the optic nerve, optic chiasm, and optic tract. (Forrester et al., 2008; Møllenbach, Hansen, & Lillholm, 2013; Purves et al., 2009; Smith, 2008)

The macula is a yellow spot near the center of the retina that provides the clearest, most distinct vision. In the center of the macula of the retina, there is a small depression called the fovea. This is the site of greatest visual acuity, as it contains a high neural density of cones and a few rods. Because the fovea is so small, humans spend a great deal of time moving their heads and eyes around. (Purves et al., 2009; Smith, 2008; Yanoff, 2009)

The axons of the ganglion cells exit the retina at the optic disk (i.e., blind spot) to form the optic nerve (i.e., cranial nerve II), which carries the slightly different information from each eye's visual field to the brain. Optic nerves from the left and right eyes extend from the eye to the optic chiasm, where the two optic nerves partially cross at the base of the hypothalamus. Information coming from both eyes is split into visual fields for contralateral processing; that is, the left field is processed by the right side, and the right side is processed by the left. There is a small amount of overlap-processing by both sides of the visual cortex for a small, central area of both fields of view. Visual (sensory) information moves through the lateral geniculate nucleus of the thalamus to the optic radiation then on to the occipital lobe of the brain, where the primary visual cortex is located. The occipital lobe is organized retinotopically; that is, the cells in the structures of this part of the brain form a map of the visual field. (Møllenbach et al., 2013; Purves et al., 2009; Smith, 2008)

Accommodation. Accommodation is the dynamic process by which the eye changes optical power to maintain focus (i.e., clear image) on an object as its distance varies. When viewing distant objects, the shape of the lens is relatively thin and flat; this shape provides the least amount of refractive power. The ciliary muscles relax, which causes the zonular fibers to become taut, pulling the lens into a more flattened shape. When viewing objects up close, the lens relaxes into a more domed shape due to contraction of the ciliary muscles. This causes the zonular fibers to become less tense, thus allowing the lens to become more thick and round. (Forrester et al., 2008; Purves et al., 2009; Satoh et al., 2013; Yanoff, 2009)

Ocular Movement. The eye is capable of different types of movements that help us see the world around us; these include saccades, vergence, and fixation. Saccades are a type of conjugate movement, meaning both eyes move together in an attempt to redirect the focus of the foveas toward objects of interest. These rapid, orienting movements of the eyes are called saccades. Initiation of these ballistic movements or rotations is preceded by a silent period (i.e., 200-250 ms) and they are only 30-120 ms in duration. An important feature of the saccade is that once it begins, it can neither be stopped nor changed online. This means that during the period immediately before the saccade, the saccadic latency, the eye remains in its pre-movement position. (Leigh & Zee, 2006; Møllenbach et al., 2013; Morimoto & Mimica, 2005; Otero-Millan, Macknik, Serra, Leigh, & Martinez-Conde, 2011)

Vergence movements, on the other hand, send the eyes in opposite directions in order to keep images of a single object on the fovea of each eye simultaneously. (Leigh

& Zee, 2006; Møllenbach et al., 2013; Morimoto & Mimica, 2005; Otero-Millan et al., 2011)

Visual fixation is achieved by maintaining the gaze on a single location; the intent is to keep a stationary object centered on the fovea with minimal ocular drift. It is never perfectly steady, as microsaccades interrupt fixations at a rate of about one to two times each second. Drifts, or slow and smooth eye movements that do not correspond to a target movement, as well as tremor and microsaccades are normal fixational eye movements. (Leigh & Zee, 2006; Møllenbach et al., 2013; Morimoto & Mimica, 2005; Otero-Millan et al., 2011)

Extraocular Muscles. Each eye contains three pairs of muscles that work together to control eye movements. These muscle pairs are: the lateral and medial rectus, the superior and inferior rectus, and the superior and inferior oblique.

In order to look to the left or right (i.e., horizontal movements), the lateral and medial rectus muscles are engaged. The medial rectus is responsible for movements toward midline (i.e., the nose), while the lateral rectus is responsible for movements away from midline. For example, if an individual wished to look directly to their left, in the right eye (Figure 2), the medial rectus would engage, but in the left eye, the lateral rectus would be responsible for the movement. (Purves et al., 2009; Smith, 2008)

In order to look up or down (i.e., vertical movement), the superior and inferior rectus muscles must be engaged. The superior and inferior oblique muscles also contribute to vertical movements. If an individual were to look up, the superior rectus and inferior oblique would contract. In order to look down, the inferior rectus and superior oblique muscles must contract. The extent to which the muscles contract

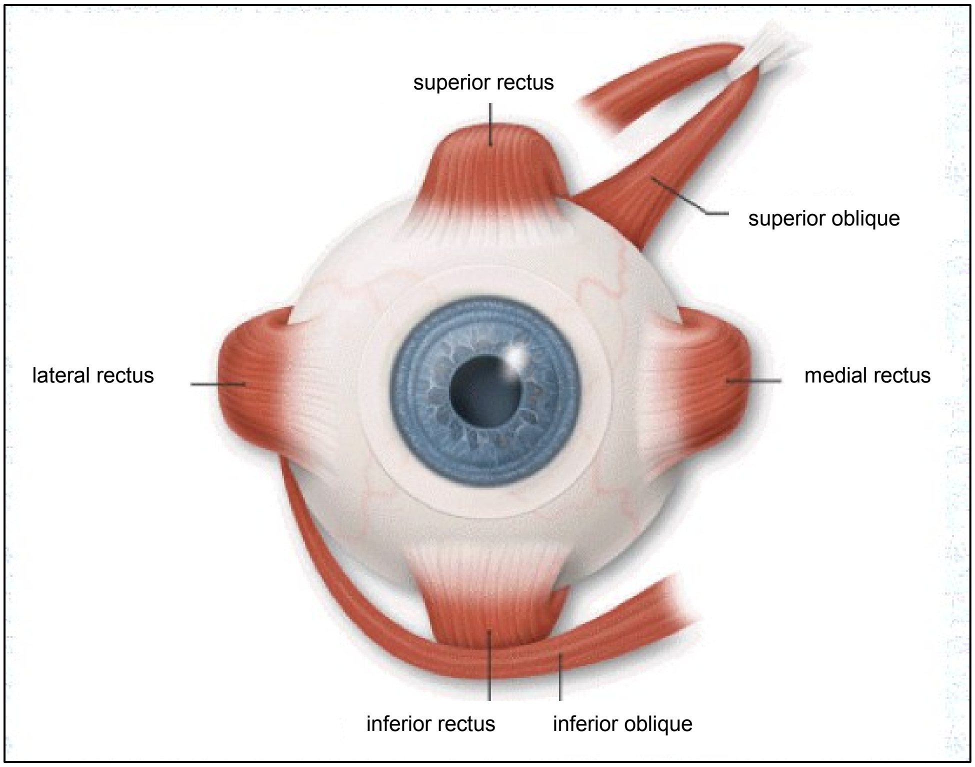

Figure 2. Extraocular muscles of the right eye.

depends on how far up (or down) an individual wishes to look. (Purves et al., 2009; Smith, 2008)

The eyes can look up, down, left, and right to varying degrees based on movement of the superior and inferior rectus, lateral and medial rectus, and superior and inferior oblique muscles. Finally, the eyes are also capable of twisting, or torsional, movements. Although the superior and inferior oblique muscles are primarily responsible for these movements, the other muscles may contribute depending on the nature of the movement. If, for example, the right eye was to move clockwise relative to a person facing them, the superior oblique would contract to create the majority of the movement toward the nose. (Purves et al., 2009; Smith, 2008)

Surgical intervention has been the tradition method for correcting extraocular weakness or tightness (Leigh & Zee, 2006). It is interesting to note that, at this time, research is beginning to emerge to support injection treatment as another means of strengthening extraocular muscles (Bilgin et al., 2013; Li, Wiggins, & von Bartheld, 2010). Currently, the literature does not mention using stretching or exercise as a means of accomplishing the same goal.

Eye Tracking/Eye Gaze Technology

Eye tracking measures eye positions and eye movements. Eye tracking technology provides AAC access through eye movements. Researchers monitor and record eye movements and fixations to investigate oculomotor function, attention, visual search, learning, reading, and auditory processing using many techniques. Eye gaze research informs diverse fields of study including neurology (e.g., correlation with cognitive and emotional influences), psychology (e.g., attention, scene perception), ophthalmology (e.g., oculomotor behavior), education (e.g., reading, auditory language processing), software development (e.g., usability), marketing (e.g., visual attention in advertising), and industrial engineering (e.g., driving, visual inspection). Researchers are even using eye tracking technologies to investigate vision, cognition, and social interaction in dogs, cats, mice, and monkeys. (Duchowski, 2002; Leigh & Zee, 2006; Morimoto & Mimica, 2005; Z, Mills, & Guo, 2011)

Eye movement tracking can be obtained either passively or actively, and either as a noninvasive or invasive procedure. Passive tracking applications are typically used for diagnostic purposes, using data as a means of gathering objective evidence of attentional or visual processes. Active eye tracking is typically used for interactive purposes, using data to respond to or interact with the user based on eye movements. (Duchowski, 2002; Morimoto & Mimica, 2005)

Magnetic Search Coil Technique. In the magnetic search coil technique, wire is embedded in a silastic annulus (i.e., contact lens) that is placed firmly upon the sclera after application of topical anesthetic; in some animal research, coils are surgically implanted beneath the conjunctiva (i.e., transparent covering of the sclera). There is a risk of corneal abrasion with use of this somewhat invasive contact lens. Coils can be placed to detect either horizontal or vertical movement relative to the head; if two coils are placed orthogonally, torsional (i.e., twisting) movements can also be recorded. A participant sits within a magnetic field in which multiple alternating magnetic fields are generated. Through electromagnetic induction, electric currents are generated in the coils. Polarity and amplitude of the current varies with the direction and angular displacement of the eye. Spatial resolution, which is the smallest change in eye position that can be measured, may be as accurate as 0.01 degree or <1 minute of arc; this is extremely sensitive. (Hain, 2011; Houben, Goumans, & van der Steen, 2006; Lee, Cho, Shin, Lee, & Park, 2012; Morimoto & Mimica, 2005)

Electrooculography. Electrooculography (EOG) is a non-invasive technique in which electrodes are placed above and below or to each side of the eye. The electrodes measure the voltage between the front and back of the eye (i.e., corneoretinal action potential) to determine eye position as accurately as 2 degrees. Reliability issues exist for tracking vertical movements of the eye as well as larger saccades. With respect to AAC, only the EagleEyes system currently utilizes this methodology. (Boston College & The Opportunity Foundation of America, 2011; Hain, 2011; Lee et al., 2012; Leigh & Zee, 2006; Morimoto & Mimica, 2005)

Pupil-Corneal Reflection. Pupil-corneal reflection, also termed the remote camera method, is currently the methodology of choice for human-computer interaction in AAC. SGDs utilize interactive eye tracking with the eye in the role of mouse analog or selector. It is noninvasive and nonintrusive. One or several infrared light emitting diodes create reflection patterns on the cornea of one or both eyes. As infrared light is not in the visible spectrum, it does not distract the user. The reflection of the light source on the cornea is the first Purkinje image (i.e., reflection of objects/images from the structure of the eye) or the 'glint'; three additional Purkinje images (i.e., inner surface of the cornea, anterior lens surface, [inverted image] posterior surface of the lens) are not used in most commercially-available pupil-corneal reflection tracking systems. Sensors detect the Purkinje image (i.e., glint) and a mathematical model is used to determine the position of the eye(s) in space and so the point in space.

Manufacturers of eye gaze SGDs offer bright pupil, dark pupil, or combination/hybrid technology. In bright pupil technology, the illuminating source is directed close to the optical axis of the imaging sensor. Consequently, the pupil appears lit up. In contrast, dark pupil technology includes illuminators placed away from the optical axis. This causes the pupil to appear darker than the surrounding iris. In hybrid technologies, near-infrared illumination is directed both along the optical axis as well as away from it. It is important to note that each of these gaze trackers require the user to remain relatively motionless within a 'head box' or 'eye box' in order to calculate eye position. The size of this box varies among distributors of eye gaze systems; some devices accommodate nystagmus (i.e., fast, involuntary eye movements), while others accommodate some rocking movements of the head or body. Another important factor is the accuracy of this tracking methodology. Tracking accuracy is variable; that is, central screen accuracy is currently higher than screen-perimeter accuracy in both commercial and research technologies (Hansen & Hansen, 2006; Hansen & Itoh, 2004; Jacob, 1991; Komogortsev, Holland, & Camou, 2011; Lee et al., 2012; Morimoto & Amir, 2010; Ohno, 1998).

The Midas Touch. One obstacle to gaze tracking and eye-typing has been termed the *Midas Touch* (Bartels & Marshall, 2011; Hansen & Itoh, 2004; Itoh, Aoki, & Hansen, 2006; Jacob, 1991; Jacob & Karn, 2003; Kotani, Yamaguchi, Asao, & Horii, 2010; Morimoto & Amir, 2010). Although it is novel, at first, to simply look at a monitor with an onscreen keyboard and select or speak a letter, this novelty soon wears off as the person discovers that everywhere s/he looks, letters are selected. Humans are not used to using our eyes to meet two disparate needs: gathering information about the contents of the screen (as is typical) and operating the system (atypical) (Ohno, 1998). Eye gaze selection of letters and words from an onscreen keyboard can be likened to manipulation of the same keyboard via computer mouse; that is, directing a cursor to a point, pointing and clicking. This often creates frustration due to the simple physiological facts of the visual system, which is designed more for processing of sensory information than for motor tasks (Jacob & Karn, 2003; Leigh & Zee, 2006). In processing visual sensory information, our eyes are never truly at rest – if they are open, they cannot be 'off' like a computer mouse. Anatomically, the saccades designed elegantly to focus images on the fovea make gazing at a specific point for some time difficult (Aoki, Hansen, & Itoh, 2009; Jacob, 1991; Jacob & Karn, 2003; Ohno, 1998). This is partly due to the limited size of the fovea and optimal visual field as well as the natural continuous movements of the eye (e.g., blinks, tremor) (Aoki, Hansen, & Itoh, 2009; Jacob, 1991; Jacob & Karn, 2003). We use fast movements, saccades, to move our gaze and then fixate on an object; but even in fixation, our eyes are constantly moving. Eye movement is also jerky or ballistic in nature; smooth eye movements are typically only made to track an object of interest in motion and are therefore not used to "point" to a static letter on an onscreen keyboard (Bartels & Marshall, 2011). In order to counteract the *Midas Touch* and work with the inherent physiology of the visual system, it is important to allow the eyes to work as intended: to naturally look around the visual field without selecting every item that is briefly tracked along the way (Aoki, Hansen, & Itoh, 2009; Jacob, 1991; Jacob & Karn, 2003).

Counteracting the Midas Touch. Counteracting the *Midas Touch* problem, perhaps, has resulted in the popularity of "dwell" time as the mode of selection in eye gaze SGDs. When using dwell for eye gaze access, a software command is triggered when an onscreen cell/item has been continuously activated (i.e., looked at) for a certain pre-set time (Aoki, Hansen, & Itoh, 2009; Hansen, Johansen, Hansen, Itoh, & Mashino, 2003; Kotani, Yamaguchi, Asao, & Horii, 2010; Majaranta, Ahola, & Špakov, 2009). If the activation continues for the pre-set time, the item is selected (e.g., the letter is activated); however, if the activation is terminated before the pre-set time elapses, the time counter is reset by the system. Individually fine-tuning dwell time to its optimal length, which range from 100-3000 ms, is an attempt to decrease the effect of the *Midas Touch* (Hansen et al., 2003). This function may be changed based on the individual's proficient use of the system, decline in motor function, cognitive status, or as other needs arise.

Although dwell is probably the most common, other activation modes use blink (i.e., command is activated when user gazes at an item and then blinks within a specific length of time), blink/dwell (i.e., either blink or dwell rules apply for command activation), or an external switch (e.g., Self-Calibrating Auditory Tone Infrared, SCATIR switch). While external switches may be attached to eyewear/head and hamper the person's movement minimally, blinking with purpose and thought is not a natural activity that may also result in adversely applying the technology (Jacob & Karn, 2003).

Keyboard Layout

Research currently distinguishes among three distinctive types of writing: (1) typing, (2) gesturing, and (3) continuous writing (Bee & André, 2008; Urbina & Huckauf, 2010). Gesturing involves utilizing codes to indicate certain letters or functions. The code may fall along a continuum of transparent to opaque. *EyeWrite*, uses the fivequadrant EdgeWrite unistroke alphabet that was developed for use with PDAs and other devices. *Eye-S* uses a system of nine ‘hotspots’ arranged in a grid on a computer monitor. The user’s gaze traces two to three strokes or sequences from one ‘hotspot’ to the next in order to complete specific gestures to form ‘graffiti’ representative of letters of the alphabet, numbers, punctuation, or function keys. While many of the gestures bear a striking resemblance to their orthographic counterparts, some do not. (Morimoto & Amir, 2010; Porta & Turina, 2008; Wobbrock, Rubenstein, Sawyer, & Duchowski, 2007)

Another group of gesture systems requires the user’s gaze to cross one of many groups of letters and commands on the screen. The selected group is then distributed so the user must glance through the intended target. Selection is completed using a single saccade. Examples of this type of gesturing are *pEYEwrite* and *Quickwriting* (Bee & André, 2008; Urbina & Huckauf, 2010).

The closest orthographic analogy to continuous writing (although we must pick up our pens for spacing) is cursive. At the most extreme end of continuous writing is *Dasher*, which contains no static elements in its design. Letters move from right to left across the screen and are gaze-selected. An algorithm determines which combinations are allowable for the particular language the user is working in and offers possible following letters that adhere to the rules of the particular language. *Dasher* is available in character-combining languages (e.g., Korean) as well as the symbol-combining linguistic system, Blissymbols. *StarGazer* is similar to *Dasher* as these writing systems both work with the visual system, using pursuit eye movements more naturally (Urbina & Huckauf, 2010). *Humsher* is an adaptation of *Dasher* (i.e., continuous writing) that utilizes tonal codes (i.e., humming) to select letters; this may be useful for individuals with impaired motor control but residual vocal function. (Hansen & Itoh, 2004; Itoh, Aoki, & Hansen, 2006; MacKay, Wills, & Waller, 2007; Morimoto & Amir, 2010; Poláček, Míkovec, Sporka, & Slavík, 2011; Ward & MacKay, 2002)

The current paper, however, focuses on the other method of writing: typing.

Unambiguous Keyboards. In 1878, Christopher Latham Sholes famously patented the Sholes (i.e., QWERTY-in reference to the upper six letters on the left side) keyboard with the intention of decreasing the likelihood of typewriter-key entanglements (Norman & Fisher, 1982). The QWERTY arrangement prevented commonly-used letters from being too close together, as this caused the type bars in early typewriters to clash (Norman & Fisher, 1982; Noyes, 1998). Type bars coming from different directions did not clash as much, which increased typewriting speed on manual machines (Norman & Fisher, 1982; Noyes, 1998). Because it has remained in common use on mainstream computer and onscreen keyboards, QWERTY, as well as language-specific versions of the Sholes keyboard (i.e., French AZERTY, German QWERTZ), are often used in comparative studies as the reference layout (Noyes, 1998; Yin & Su, 2010). Clavicom NG is another related virtual layout that includes word prediction (i.e., an embedded computer program that provides a set of likely words in response to a person's keystrokes) (Guerrier, Baas, Kolski, & Poirier, 2011a).

Other letter arrangements have been created over the years. Some were created to increase typing speed, usually by decreasing physical distance among the most frequently-used letters or keys. Others simply allowed for the use of non-Latin character sets, diacritical marks (e.g., accents, umlaut, tilde, cedilla), or letters in addition to the

English twenty-six. More recently, researchers have begun considering reduced and scrolling keyboards that do not utilize an entire computer screen space; these layouts are not considered in this review (Li, Guy, Yatani, & Truong, 2011; Špakov & Majaranta, 2008). It should be noted that keyboards designed specifically for alternative access often include a word prediction feature that is intended to improve communication rate and, possibly, effectiveness (Guerrier et al., 2011a). The use of word prediction will be revisited later in this document.

Unambiguous or single-character keyboards, such as QWERTY, have a one-to-one relationship between the key and the letter it will produce (Yin & Su, 2010). The Dvorak (1936) keyboard layout places all vowels as well as the most commonly-used consonants on the middle/home row and was the first keyboard designed that considered ergonomic criteria (e.g., less complex finger-movement demands) (Guerrier et al., 2011a; Noyes, 1998; Yin & Su, 2010). Physical as well as onscreen versions of the Dvorak Simplified Keyboard have been and are currently in use.

XPeRT (2003) is similar to QWERTY in structure, but utilizes digrams (i.e., letters that are used together appear side-by-side) and includes an additional 'E' (Guerrier et al., 2011a). The XPeRT layout can be used onscreen or as a physical keyboard.

FITALI/FITALY, an exclusively onscreen layout, places more frequently-used letters in the middle rows and includes two double-width space keys that somewhat reduce the distance a single typing finger must travel between a letter and subsequent space (Guerrier et al., 2011a; Zhai et al., 2000).

OPTI and OPTI II onscreen keyboards position the most frequently used letters in the middle rows followed by trial-and-error placement of the remaining keys; these layouts have a more squared appearance than (rectangular) QWERTY-types and include four space keys (Zhai, Hunter, & Smith, 2000). These layouts are designed to optimize of the keying sequence by offering four space keys; this reduces finger-movement demands by decreasing the physical distance required to travel from a letter to a space. According to Zhai et al. (2000), users attain manual typing speeds faster than both QWERTY and FITALI/FITALY configurations.

Chubon (1988) was created for the single-digit typist and placed the most frequently-used letters in the center of the keyboard. Research has determined the onscreen Chubon keyboard requires approximately 37% less finger travel than the standard QWERTY arrangement. (Anson, 1997; Anson, George, Galup, Shea, & Vetter, 2001)

Hooke’s alphabetic-only onscreen keyboard features small, circular keys together with the most frequently-occurring clustered in the center around the space key. This design was intended to minimize necessary finger movement. In manual typing research, Hooke’s keyboard proved faster than QWERTY as well as OPTI/OPTI II. (Zhai et al., 2000)

Metropolis resembles Hooke’s clustered alphabetic-only layout, but the onscreen keys are hexagonal, eliminating space between keys (i.e., further minimizing required finger travel) and out-performing the Hooke’s keyboard by almost 2 wpm (Guerrier et al., 2011a; Zhai et al., 2000).

Chewing Word is a dynamic French onscreen layout that rearranges itself as text is entered and can be accessed directly or indirectly (Chewing Word, 2011; Guerrier et al., 2011a).

Ambiguous Keyboards. Ambiguous or multi-character keyboards are those which may require multiple selection of the same key in order to disambiguate or differentiate among possible choices (Harbusch & Kühn, 2003; Judge & Friday, 2011; Yin & Su, 2010). A popular example of this type of layout is the predictive T9 keypad that predominated cell phone technology until the advent of full onscreen keyboards or keypads (Judge & Friday, 2011). One of the motivations for the development of T9 was use in AAC (Judge & Friday, 2011). The T9 keyboard reduces keystrokes by allowing the user to enter a single keypress for each letter instead of multiple taps (e.g., “aaa” for “c”). For ambiguous keyboards that must predict a word list of possible choices from which the user must choose, it is critical that the algorithm that handle the disambiguation process (i.e., word prediction) be optimally effective (Yin & Su, 2010).

UKO-II was originally designed for individuals with cerebral palsy with limited range of movement (CP; Guerrier et al., 2011a; Harbusch & Kühn, 2003; Judge & Friday, 2011). It includes three letter-selection keys, which display alphabetic groupings. It also includes a single function key that is used to access operational directives such as delete or word disambiguation once the letter keys are selected (e.g., user selects whether key selection 1-2-3 was meant to be ‘bag’, ‘ode’, ‘Sam’) (Harbusch & Kühn, 2003).

Other ambiguous layouts include BlinkWrite, K-Thôt, K-Hermes, and GazeTalk. BlinkWrite uses eye blinks on a scanning ambiguous keyboard with four letter groupings (MacKenzie & Ashtiani, 2011). The user then selects the desired word from a list of choices derived from a prediction algorithm. K-Thôt is currently a manual drag and drop keyboard that contains ten keys with four characters each that has a dynamic aspect –

once keys are selected, more frequently-occurring following letters appears as the key's closest neighbors (Baas, Guerrier, Kolski, & Poirer, 2010; Guerrier et al., 2011a). K-Hermes, named for the Greek messenger god, is a T9-type keyboard with nine keys that require multiple 'taps' to enter a single letter via specialized joystick access (Guerrier et al., 2011a; Guerrier, Baas, Kolski, & Poirier, 2011b). GazeTalk, which has versions that support Danish, English, Italian, German, and Japanese uses approximately 10 keys for optimization with low resolution eye trackers; it can also be used with the continuous writing program *Dasher* as well as web browsing (Hansen, Tørning, Johansen, Itoh, & Aoki, 2004). GazeTalk users reportedly type an average of 10 words per minute (ITU GazeGroup, n.d.).

Chorded Keyboards. Chorded keyboards generally use a combination of a few keys to create keystrokes for each letter (Lin, Chen, Yeh, Tzeng, & Yeh, 2006). Stenotype is the chorded keyboard layout used by court clerks and stenocaptioners that requires pressing 22 unlabeled keys in various combinations to spell out syllables, words, and phrases at speeds 8-10 times faster than handwriting (Shackel, 2009). Lin et al. (2006) created an onscreen scanning chorded keyboard. When compared to other physical keyboards, the chorded layout has been found to be the most cognitively and physically demanding (Anderson, Mirka, Joines, & Kaber, 2009).

Interestingly, investigations have also begun to evaluate chorded onscreen keyboards with tactile feedback for Braille reading and text entry (i.e., V-Braille, TypeInBraille, BrailleTouch) (Al-Qudah, Doush, Alkhateeb, Al Maghayreh, & Al-Khaleel, 2013).

Scanning Keyboards. Scanning, especially when layout is optimized, should not be discounted as a means for text entry for users of onscreen keyboards (Bhattacharya, Samanta, & Basu, 2007; Francis & Johnson, 2011). SIBYLLE, which is available in French, German, and English, is intended for switch access and has a dynamic component (Wandmacher, Antoine, & Poirer, 2007). It improves input by altering selection choices via letter- and word-prediction based on what the user has already entered (Guerrier et al., 2011a; Wandmacher, Antoine, & Poirer, 2007). Venkatagiri (1999) compared user efficiency with eight keyboard layouts: linear scanning (i.e., having the choice of the 1st key, then the 2nd and so forth until the entire keyboard has been offered for selection) with QWERTY, alphabetical, or frequency of occurrence; row column scanning (i.e., rows are highlighted until the user selects the row of the desired character, then the column contents are selected one-by-one until a choice is made) with QWERTY, alphabetical, or frequency of occurrence; 12-key multi-character alphabetical or frequency of occurrence. He demonstrated that for scanning access, single-character keyboards in order of letter frequency of occurrence used with row column scanning patterns are significantly more efficient than other unambiguous (i.e., QWERTY, alphabetical) or multi-character layouts (Venkatagiri, 1999). It important to note despite reported visual concerns in the population with motor neuron disease, eye control has been shown to be faster than scanning (Gibbons & Beneteau, 2010).

Investigation of Eye Gaze Keyboards. Several studies have measured speed and accuracy of eye-typing Chinese using *pinyin* (i.e., phonetic transcription) systems created by researchers (Liang, Fu, & Chi, 2012; Wang, Zhai, & Su, 2001).

A study of 12 neurotypical graduate and postgraduate students aged 22-26 years explored the facileness, learnability, efficiency, preference, and task intensity of three onscreen keyboard layouts (i.e., QWERTY, alphabetic, author-created layout based on features of Chinese character input) accessed with either eye typing or mouse control through Likert scale ratings and quantitative measures. Interestingly, eye typing on the author-created layout was determined to outperform both the QWERTY and alphabetic ones, though this new keyboard was not favored by the participants to the point of statistical significance. (Feng & Shen, 2012)

Increasing Efficiency of Access

Humans will communicate using whatever means is the easiest and most effective; this remains true when considering alternative methods of access such as eye gaze. Some research has considered variations on easing the load (e.g., cognitive, physical) of communication.

Cues. Enabling both an auditory cue in the form of click feedback upon key selection and also a visual cue (i.e., key is highlighted when the user dwells on it) has been shown to increase visual typing speed (Jacob & Karn, 2003; Majaranta, MacKenzie, Aula, & Räihä, 2006). Simply put, communication efficiency improves when individuals are sure that what they wish to say will be said.

Eye Strain and Fatigue. Fatigue may have a great impact on the augmented communicator. Eye gaze systems can usually be set to accept input via blink, dwell, combination blink/dwell, or external switch (e.g., infrared sensor). Dwell time, though often set between 500-1000 ms, is often extended upwards before a selection is accepted for novice users, but decreasing this as a user’s comfort and operational competence improve has been shown to decrease eye strain and fatigue (Bee & André, 2008; Hansen, Hansen, & Johansen, 2001; Morimoto & Amir, 2010; Špakov & Miniotas, 2004). Additionally, investigations with neurologically-compromised participants have revealed dwell times near 2000 ms (Istance, Vickers, Hyrskykari, 2012). Recent work with rhesus monkeys has shown that extraocular muscles do not fatigue like skeletal muscles do; perceived eye fatigue may, in fact, be due to cognitive processes (e.g., reduced alertness, motivation, attention) that provide faulty commands which produce saccades of reduced amplitude and lower velocity (Kaminski & Richmonds, 2002; Prsa, Dicke, & Thier, 2010).

Other Considerations. Considering physical positioning and comfort during evaluation for an eye gaze system and ensuring these needs continue to be met whenever the person communicates can decrease fatigue and increase ease of use (Higginbotham, Shane, Russell, & Caves, 2007). In the same vein, considering the status of the individual's visual system is an important step in improving efficiency (Pannasch, Helmert, Malischke, Storch, & Velickkovsky, 2008).

Gaps in the Current Corpus of Knowledge

At this time, the most popular eye gaze SGDs (i.e., DynaVox EyeMax, Prentke Romich ECOpoint, Tobii PCEye/CEye) feature variations of the QWERTY and alphabetic keyboards. Unfortunately, there has been little research to validate this choice by the manufacturers, other than familiarity to literate consumers. There are myriad directions for research including:

1. Are familiar keyboard layouts the easiest for novice users to learn?

2. How long does it take individuals to master (i.e., become skilled in using) them?
3. How long does it take those unfamiliar with these layouts (or even those with emerging literacy skills) to conquer them?
4. Are there other layouts, novel or previously developed, which might be easier to learn?
5. Which keyboard layout is optimal for efficient use via eye gaze access?
6. Is this optimal design different than for those using another form of access (e.g., manual, switch, head-controlled mouse)?
7. Are there ways to improve upon natural eye movements with respect to keyboard layout?
8. Might certain disability populations (e.g., ALS, CP) benefit from different keyboard entry options?

Amyotrophic Lateral Sclerosis (ALS)

ALS is a progressive neurodegenerative disease that attacks motor neurons in the brain (i.e., upper motor neurons) and spinal cord (i.e., lower motor neurons) and affects muscle function. ALS can have familial origins or be sporadic in nature. For sporadic cases, which account for at least 90% of instances of ALS, there is no certain causative agent, but many have been proposed and/or are currently under investigation (e.g., neurotoxicants, protein accumulation, military service, environmental exposure). Generally, sensory functions (e.g., auditory, tactile, visual), bladder, sexual drive, and sexual function are spared. Although cognition will also be spared in the majority of individuals with ALS, some people may show symptoms of various cognitive syndromes: frontotemporal dementia, semantic dementia, or primary progressive aphasia. At present, treatment addresses symptoms (e.g., depression, drooling, cramping) only; there is no cure. One pharmaceutical approach, Riluzole, appears to add three months of life when administered as prescribed to patients with ALS. While this drug does not trigger improvement in patients, it may delay the onset of tracheostomy or ventilator-dependence. (Ball, Beukelman, & Pattee, 2004; Beukelman, Fager, Nordness, 2011; Cannon & Greenamyre, 2011; Hardiman, van der Berg, & Kiernan, 2011; Kano et al., 2013; Kiernan et al., 2011; Logroscino et al., 2008; Lomen-Hoerth, Anderson, & Miller, 2002; Lomen-Hoerth et al., 2003; Murphy et al., 2007; Murphy, Henry, & Lomen-Hoerth, 2007; Olney et al., 2005; Ringholz et al., 2005; Sharma et al., 2011; Zalonis et al., 2012)

There are two subsets of ALS: bulbar and spinal, which refer to the clinical symptoms that manifest at diagnosis. Bulbar-onset ALS is distinguished by cranial nerve involvement and early problems with speaking and swallowing movements, while spinal-onset ALS is characterized by spinal nerve involvement and initial difficulties with upper and lower limb movements. Those with spinal-onset generally survive longer (i.e., 3-5 years) than those with bulbar-onset (i.e., ~18 months). (Ball et al., 2004; Beukelman et al., 2011; Higginbotham et al., 2007)

Unfortunately, diagnosis takes an average of 9-15 months; ALS is, very generally, a diagnosis of exclusion. In reality, however, neurologists establish an ALS diagnosis using the revised El Escorial criteria, which require both the presence and absence of particular signs, symptoms, and evidence. The diagnosis of Clinically Definite or Clinically Probable ALS is assigned when there is clinical, electrophysiological, or neuropathologic evidence of lower motor neuron degeneration (i.e., weakness, atrophy, fasciculations), upper motor neuron degeneration (e.g., pathologic spread of reflexes, clonus), and a progressive spread of symptoms within or to other regions of the body (i.e., brainstem, cervical, thoracic, lumbosacral regions). Additionally, there must be an absence of evidence that might explain the motor neuron degeneration as well as neuroimaging that might explain the clinical and electrophysiological signs. (Brooks, Miller, Swash, & Munsat, 2000)

Research has suggested that the incidence of ALS is higher among younger men than younger women (i.e., 2:1), but as the population ages, the chance of manifesting the degenerative disease equalizes. (Eisen, 2002; McCombe & Henderson, 2010; Ringholz et al., 2005; Talan, 2008)

Nature of the Problem

The purpose of this investigation was to determine which of three onscreen keyboard layouts is the most efficient for typical as well as neurologically-compromised first-time users of eye gaze access. The specific aim of this research was to answer the following experimental questions:

(1) Does keyboard layout (i.e., QWERTY, alphabetic with highlighted vowels, spiraled frequency of occurrence) influence efficiency (i.e., rate, accuracy) in use of an eye gaze SGD for adults with ALS? For adults without a neurological condition?

(2) Do qualitative and quantitative measures of participant preference of keyboard layout correlate with measures of rate, error, or accuracy for adults with ALS? For adults without a neurological condition?

(3) Does previous technology use impact efficiency in use of an eye gaze SGD for both groups? Does it impact preference ratings of eye gaze SGDs for both groups?

(4) Do date of ALS diagnosis or first ALS symptoms impact efficiency in use of an eye gaze SGD? Does it impact preference ratings of eye gaze SGDs for users with ALS?

CHAPTER II: METHODS

This research was reviewed and approved by East Carolina University's University and Medical Center Institutional Review Board (UMCIRB). Initial and continuing approvals are shown in Appendix A. Consent forms are presented in Appendix B.

Participants

Participants consisted of two groups of 16 English-speaking literate individuals: neurotypical adults and those diagnosed with amyotrophic lateral sclerosis. The age of participants ranged from 35-81 years in both groups (M = 54.72, SD = 11.011), which falls within the typical age span of persons with ALS (Logroscino et al., 2008). Neurotypical participants ranged from 35 to 76 years of age (M = 53.75, SD = 12.337), while those with ALS ranged from 46 to 81 years old (M = 55.69, SD = 9.816). The Levene's Test for Equality of Variances (F = 3.273, p = .08) suggested the assumption of equal variance was indeed met. This t test failed to reveal a statistically significant difference between the mean ages of the two groups ($t(30)$ = .492, p = .627); that is, the mean group age may be considered to be equal. Appendix C lists ages for all members of both groups.

Neurotypical adults as well as adults diagnosed with ALS were recruited through word of mouth and a flyer sent to speech-language pathologists and other appropriate professionals (i.e., neurologists). The recruitment flyer is presented in Appendix D.

Among the neurotypical participants, there were 4 males and 12 females. Among the participants with ALS, there were 10 males and 6 females. As the neurotypical individuals were truly a sample of convenience, gender differences will not be taken into account in analysis. Although men on the lower end of the expected age range are slightly more susceptible to ALS (i.e., higher incidence), over time, prevalence becomes equal between the genders (Eisen, 2002; McCombe & Henderson, 2010).

Interestingly, all participants with ALS had the spinal-onset form of the disease, as determined by initial symptoms. The participants described these symptoms as: “fasciculations in my arms/legs”, “weakness in my arms/legs”, “decreased physical abilities with respect to sports”, “drop foot”, “difficulty walking”, “balance problems”, “frequent falls”, “arm muscle wasting with a ‘dent’ in my arm”, and “cramping in my legs/stomach”.

As noted earlier, the average length of time that elapses from the notice of first (ALS) symptoms to official diagnosis by a neurologist is between 9 and 15 months. Participants in the ALS group averaged 15.25 months to diagnosis (*SD* = 13.533 months), which places them at the top end of this reported range. They had all been diagnosed by the same neurologist and diagnosis was established based on the El Escorial criteria.

All participants in both groups had (corrected) visual acuity and literacy skills sufficient to interact with all stimuli. Several participants noted additional visual deficits/conditions not corrected by lenses. In the neurotypical group, participants reported bilateral midposition fixed pupils, cataracts, and astigmatism. In the ALS group, a single participant reported bilateral glaucoma. Since all participants met calibration requirements and reported no difficulty seeing or selecting onscreen keys, these deficits were simply noted and not deemed problematic to this investigation. And although several of the participants with ALS currently use other forms of augmentative and alternative communication, accepted study participants had no previous experience with eye gaze access.

Instrumentation

SGD with eye gaze access. Currently, SGDs function using bright pupil, dark pupil, or combination/hybrid technology. The DynaVox Vmax with EyeMax attachment (DynaVox Mayer-Johnson), which was used in this investigation, operates using dark pupil technology.

As noted previously in this document, in dark pupil technology, an illuminating source (i.e., infrared light) is placed away from the optical axis. This causes the pupil to appear darker than the surrounding iris, but also creates a corneal reflection (i.e., the ‘glint’ or first Purkinje image). The glint does not move, as the infrared light source is fixed. This means that the corneal reflection can be used as a reference point to help determine where the gaze is directed.

Dwell (time to select) time was set at 1500 ms for all participants, which is within the range supported by previous research literature.

Practice screen. A tic-tac-toe screen (DynaVox Mayer Johnson, November, 2011) was revised for initial eye control practice. Each of the four corners of the screen contained a cell to ensure each participant had range of motion across the entire layout. One corner restarted the tic-tac-toe game. The other three corners simply spoke aloud, naming the color of the cell when activated. Appendix E shows the practice layout.

Keyboard layouts. The DynaVox Vmax features keyboards with the following layouts: QWERTY, alphabetic with (or without) highlighted vowels, and frequency of occurrence (Solso & King, 1976). The frequency layout utilized in this study spiraled the letters and function keys outward from the center, which was designed to optimize the higher central accuracy of the SGD screen. It was also intended to decrease the physical distance between the most-used characters on the screen. The commercial frequency layout simply orders letters from left to right and top to bottom.

Each keyboard layout included a message box on the top portion of the screen, which is the traditional position of this feature. When letters were typed, they appeared in this area of the SGD screen. The three study layouts included all 26 letters, as well as two function keys: space and backspace. With respect to frequency of occurrence in English, there is information to support inclusion of the space key in its current position; the space is utilized in the experimental task. The backspace key was positioned where the comma falls in the frequency of occurrence of English. The backspace is important for participant self-correction during the experimental task. The principal investigator also utilized the backspace to clear the message box between tokens. All keyboard layouts were created by the investigator using Series 5 software (DynaVox Mayer Johnson, November, 2011) and appear in Appendix F.

Word and phrase tokens. A list of 12 words, six 13-keystroke phrases, and a longer 23- keystroke phrase was compiled by the author to serve as stimuli for all participants. Half of the tokens included a series of keystrokes based mainly in the central portion of the SGD screen, while the other half used a series of keystrokes based mainly in the peripheral portions of the screen. Tokens were keyboard specific. Appendix G lists the stimuli used for each keyboard layout as well as the percentage of central keystrokes.

Video camera. A digital camera was used to record the SGD screen during the investigation. The participant's face was not recorded. Files were encrypted and placed on an encrypted hard drive with access limited to the researchers via password. Video files were used to evaluate accuracy and efficiency measures of the experimental task and establish reliability.

Pre-Experimental Tasks

All participants completed a questionnaire surveying current/past technology use to determine whether experience with technology had an effect on either performance or preference of keyboard layout. All participants noted whether visual deficits other than those corrected by glasses or contact lenses were present. Participants with ALS also indicated: approximate date of initial symptoms, initial ALS symptoms, and approximate date of diagnosis. Participant questionnaires may be found in Appendices H (typical) and I (ALS), respectively.

Calibration of Eye Gaze Access

Per the user manual, the participant was seated comfortably in front of the DynaVox Vmax with the EyeMax attachment on a repositionable mount accessible to participants seated in wheelchairs or standard chairs (DynaVox, 2008). The upper portion of the Vmax screen was moved to a range of 17-28 inches from the participant's face, parallel to and tilted to parallel the angle of the head. The Vmax with the EyeMax attachment was individually calibrated to each particular participant's eyes to prepare to track eye movement in the following manner:

(1) The investigator instructed the participant to keep his/her head still as the eyes were positioned within a blue box that appears in the middle of the screen (DynaVox, 2008; Figure 3).

(2) Once the camera view of the eyes was within the blue box and green crosshairs appeared over each eye image, five targets appeared in sequence to cue the person to direct their gaze at the target.

(3) As necessary, the Vmax was repositioned and the target gaze sequence re-launched in order to obtain viable calibration.

(4) Calibration scores were displayed after this process was completed (DynaVox, 2008; Figure 4). Scores ≤19 at each eye were deemed sufficiently acceptable to begin the first task. Calibration scores higher than 20 were not accepted; the calibration process was repeated on deficient targets until appropriate scores were achieved for all targets with both eyes.

Practice

Once an acceptable calibration was achieved, each participant played an onscreen game of tic-tac-toe (DynaVox, 2011) to establish experience with the eye gaze task and increase comfort with using eye movements to emulate a computer mouse. Participants were allowed and encouraged to play the game multiple times to ensure facility with the eye gaze technology. As the game was located in the center of the SGD screen, four additional cells were added by the author to the corners of the of the practice screen. As noted earlier, one cell cleared the tic-tac-toe board and started a new game, while the other three simply spoke the names of the colors that

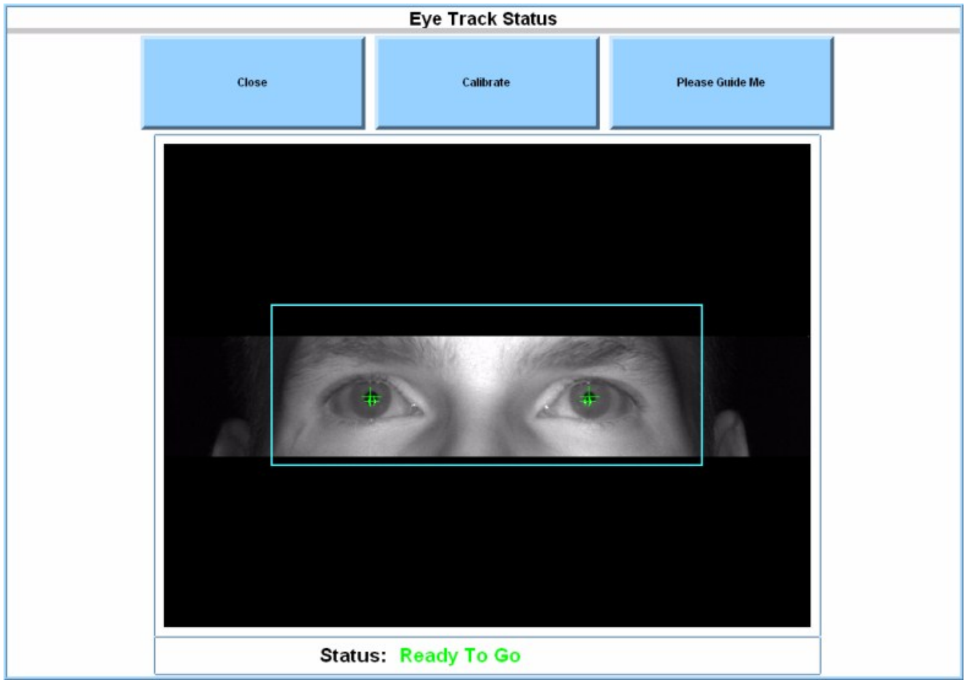

Figure 3. Position of the eyes in the calibration box.

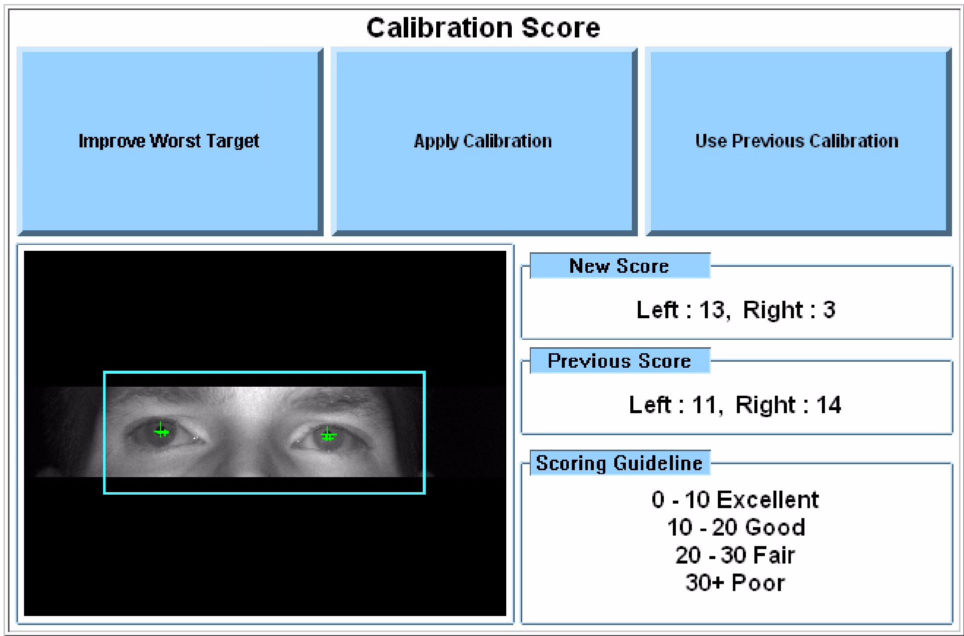

Figure 4. Sample calibration scores for both eyes.

corresponded to cell appearance (i.e., yellow, blue, purple). Appendix H contains an illustration of the practice screen.

Each time the participant used a new keyboard, 4-letter practice words were spelled aloud by the investigator before the experimental task was started. This provided practice directly related to the layout at hand and served to familiarize participants with each keyboard in turn.

Experimental Task

Each participant completed letter-selection tasks involving each of the three experimental keyboard layouts. The investigator spelled out single words and posted the correct spelling and spacing for each token on a card in an easily-viewable location on the upper central border of the Vmax, as this was not considered to be a spelling task.

For each keyboard layout, the participant was required to complete the following:

1. Spell four individual four-letter words. Half of the words used letters primarily appearing in the central portion of the screen, while the other half used mostly letters appearing on the outer edges of the screen.
2. Spell two phrases. One phrase used mostly central-positioned letters, while the other used mostly peripherally-positioned letters. Including spaces, each phrase totaled 13 keystrokes.
3. Spell a longer phrase. This 23-keystroke phrase, including spaces, used both central and peripheral characters and was the same across all three layouts.

Appendix G contains lists of words and phrases for use with each of the layouts. In addition, after each layout was completed, the participant completed a preference form that rated it on a 5-point Likert scale. When all three layouts were completed, the participant was asked to indicate their overall preference via ranking 1-3 (i.e., 1=most preferred,…, 3=least preferred). Appendix J shows preference rating forms as well as the form for overall preference ranking.

CHAPTER III: RESULTS

Pre-Experimental Tasks

Each participant completed a brief survey that included questions about technology use and visual health. In addition to the seven questions answered by the neurotypical adults, the group with ALS noted approximate date of initial disease symptoms, initial ALS symptoms, and date of official diagnosis. The following section details analyses conducted on each survey question; as noted, questionnaires for both groups can be found in Appendices H and I, respectively.

Computer access. The percentage of participants with access to a computer in the home, work, or another location did not differ for the neurotypical and ALS group ($p = 1.000$, two-tailed Fisher's exact test).

Weekly computer use. Participants reported average weekly computer use. Of note, nearly half (43.8%) of neurotypical respondents and three-quarters (75%) of participants with ALS reported relatively high use (i.e., more than 20 hours). Tables 1 and 2 contain frequency information across seven possible response categories for the neurotypical and ALS group, respectively.

Computer activities. Participants from both groups reported that their activities completed using a computer included: sending/receiving electronic mail (e-mail), word processing, social media (e.g., Facebook, Twitter), playing games, or other. Neurotypical stated that they a computer for these activities: e-mail (93.8%), word processing (75%), social media (62.5%), playing games (43.8%), and other (e.g., research, code development, shopping, spreadsheets, sewing software; 56.3%). Respondents with ALS reported computer use as follows: e-mail (100%), word

Table 1

Frequency Distribution of Weekly Computer Use (Neurotypical)

Hours Per Week	Frequency	Percent	Cumulative Percent
1-5	3	18.8	18.8
6-10	2	12.5	31.3
11-15	2	12.5	43.8
16-20	2	12.5	56.3
More than 20	7	43.8	100.0
Total	16	100.0	

Table 2

Frequency Distribution of Weekly Computer Use (ALS)

Hours Per Week	Frequency	Percent	Cumulative Percent
None	1	6.3	6.3
1-5	1	6.3	12.5
11-15	1	6.3	18.8
16-20	1	6.3	25.0
More than 20	12	75.0	100.0
Total	16	100.0	

processing (87.5%), social media (81.3%), playing games (43.8%), and other (e.g., spreadsheets, environmental control, speech generation, paying bills, creating presentations; 37.5%). Tables 3 and 4 present frequency information for both groups across the five response categories.

Cellular phone use. The percentage of cell phone users did not differ significantly between the neurotypical and ALS groups (p = .226, two-tailed Fisher's exact test).

"Smart" phone use. A chi-square test of independence was performed to examine the relationship between neurological status and "smart" phone use. The relation between these variables was not significant, X^2 (1, N = 32) = 0.719, p > .05. "Smart" phones were defined as cell phones with advanced features (e.g., applications, high-resolution screen) and operating systems (e.g., iOS, Android).

Other regularly used technology. Participants responded to the question "do you use any other technology on a regular basis". Neurotypical respondents recounted using the following regularly: no other technology (6.3%), video game system (6.3%), computer notepad (e.g., iPad; 31.3%), and DVD/Blu-Ray player (81.3%). ALS participants reported the following patterns of use: video game system (6.3%), computer notepad (81.3%), and DVD/Blu-Ray player (68.8%).

Uncorrected visual deficits. The percentage of individuals with visual deficits not corrected by glasses or contact lenses (e.g., cataract, glaucoma) did not differ significantly between the two groups (p = .333, two-tailed Fisher's exact test).

Time to ALS diagnosis. Respondents with ALS were asked to indicate when they became symptomatic as a means of determining the approximate length of time

Table 3

Frequency Distribution of Computer Activities (Neurotypical)

Activities	Frequency	Percent	Cumulative Percent
None	1	6.3	6.3
E	1	6.3	12.5
E, W	1	6.3	18.8
E, W, S	2	12.5	31.3
E, W, O	2	12.5	43.8
E, S, G	1	6.3	50.0
E, S, O	1	6.3	56.3
E, W, S, G	1	6.3	62.5
E, W, S, O	1	6.3	68.8
E, W, G, O	1	6.3	75.0
E, W, S, G, O	4	25.0	100.0
Total	16	100.0	

Note. E = email; W = word processing; S = social media; O = other; G = games

Table 4

Frequency Distribution of Computer Activities (ALS)

Activities	Frequency	Percent	Cumulative Percent
E, W	1	6.3	6.3
E, S	1	6.3	12.5
E, W, S	5	31.3	43.8
E, W, G	1	6.3	50.0
E, W, O	1	6.3	56.3
E, S, G	1	6.3	62.5
E, W, S, G	1	6.3	68.8
E, W, S, O	1	6.3	75.0
E, W, S, G, O	4	25.0	100.0
Total	16	100.0	

Note. E = email; W = word processing; S = social media; G = games; O = other from onset to diagnosis. All dates were verified by the referring speech-language pathologist. The mean time from initial symptoms to official diagnosis was 15.25 months (SD = 13.533 months).

Initial ALS symptoms. Participants with ALS described the first symptoms associated with the disease process in order to determine whether the disease was bulbar- or spinal-onset in nature. As noted, reported initial symptoms were all consistent with spinal-onset ALS.

Date of ALS diagnosis. Participants in the ALS group reported date of official diagnosis by a neurologist in order to evaluate impact on task performance. Table 5 presents this information for each respondent. The Shapiro-Wilk test indicated normality is a reasonable assumption for this data ($S\text{-}W$ = - .917, df = 13, p = .151), which had an average of 21.13 months (SD = 12.36 months) since ALS diagnosis.

Experimental Task

All participants utilized eye gaze to type words and phrases on all three keyboard layouts (i.e., QWERTY, alphabetic with highlighted vowels, spiraled frequency of occurrence) used in this investigation. Presentation order of the layouts was randomized to decrease order effect as well as the effect of fatigue. Within each layout, the four 4-letter words were presented in a random order as determined by a random integer generator (“Random integer generator”, 2002), as were the two phrases. The final token for each layout was the longest phase “GIVE THE HENS MORE REST”.

Rate. Timing for each token was initiated from the auditory cue resulting from selecting the correct beginning letter. Timing ended when the final letter of the token was selected and the corresponding click was activated. This data did not satisfy the

Table 5

Frequency Distribution of Time Since ALS Diagnosis

Months	Frequency	Percent	Cumulative Percent
4	1	6.3	6.3
7	1	6.3	12.5
8	1	6.3	18.8
10	2	12.5	31.3
19	2	12.5	43.8
20	2	12.5	56.3
22	3	18.8	75.0
30	1	6.3	81.3
39	1	6.3	87.5
41	1	6.3	93.8
45	1	6.3	100.0
Total	16	100.0	

assumption of normality and non-parametric analysis was used.

QWERTY layout. For the standard keyboard layout, neurotypical participants typed the tokens within the range of 135600 to 254800 ms (*Mdn* = 154200 ms). ALS participants completed the same layout within 128500 and 716800 ms (*Mdn* = 165300 ms). A Mann-Whitney test indicated there was no difference in performance with respect to speed on the QWERTY layout ($U = 99.0$, $p = .287$, $r = .27$).

Alphabetic layout. Neurotypical participants used the layout arranged in alphabetic order within the range of 135400 and 279400 ms (*Mdn* = 161700 ms). Participants with ALS typed the required tokens on the alphabetic keyboard within 139800 and 375800 ms (*Mdn* = 179550 ms). The Mann-Whitney non-parametric test statistic revealed that both groups completed tasks on this keyboard at the same rate ($U = 90.0$, $p = .16$, $r = .36$).

Frequency layout. On the keyboard that spiraled outward in order of most frequently-occurring letters in English, neurotypical participants typed all word and phrase tokens within 137100 and 279900 ms (*Mdn* = 172750 ms). The ALS group completed the same task within 143700 and 651200 ms (*Mdn* = 212850 ms). A Mann-Whitney test once again indicated there was no difference in performance with respect to speed on this novel layout ($U = 81.0$, $p = .08$, $r = .44$).

Accuracy. Accuracy data was calculated for each layout. As many participants achieved 100% accuracy on one or more layouts, the data was skewed with respect to the distribution, mean, and the variance structure of the sample. A mathematical formula was used to calculate new variables with the goal of revealing a more normal variance structure. The arcsine square root transformation was conducted on the proportion of accurate keystrokes in each layout for both groups, but did not correct the violation of the central limit theorem. As a result, nonparametric analyses were conducted on the original proportions calculated for each layout.

QWERTY layout. On the traditional keyboard layout, neurotypical participants typed all word and phrase tokens within 93.85% and 100% (*Mdn* = 100%) accuracy. The ALS group completed the same task within 56.92% and 100% (*Mdn* = 98.46%) accuracy. A Mann-Whitney test indicated there was a statistically significant difference with respect to layout accuracy between the two groups ($U = 70.0$, $p = .029$, $r = .42$). The mean rank of accuracy for the neurotypical group is higher than that of the ALS group, indicating the neurotypical group had a higher mean accuracy score than did the ALS group.

Alphabetic layout. Neurotypical participants typed tokens on the alphabetic layout within 95.38% and 100% (*Mdn* = 100%) accuracy. The ALS group completed the same task within 76.92% and 100% (*Mdn* = 96.92%) accuracy. A Mann-Whitney test indicated there was a statistically significant difference with respect to accuracy between the two groups ($U = 73.5$, $p = .039$, $r = .38$). The neurotypical group, in general, was more accurate using this layout than the ALS group.

Frequency layout. Neurotypical participants completed all word and phrase tasks on the frequency layout at an accuracy rate between 84.62% and 100% (*Mdn* = 100%). Accuracy for the ALS group fell between 60% and 100% (*Mdn* = 95.38%). A Mann-Whitney test indicated there was a statistically significant difference with respect to layout accuracy between the two groups ($U = 55.5$, $p = .005$, $r = .49$). Mean ranking of the groups suggested the neurotypical participants typed on the frequency layout more accurately than the group with ALS.

Patterns of accuracy. Considering the skewed nature of the data, the Mantel-Haenszel statistic was calculated for both groups and all three keyboards. Each participant was assigned a binary code signifying whether s/he was accurate or not accurate with respect to keyboarding on a particular layout. The threshold for accuracy on all three keyboards was 100% for the neurotypical group and 98% for the ALS group based on performance with the standard QWERTY layout. The results (X^2_{MH} = 1.824, p = .15) reveal that the row and column variables (i.e., disease status, accuracy) are independent from one other. That is, whether an individual has ALS or not is not connected to task accuracy on any of the investigational keyboards. A summary contingency table for the three keyboard layouts is shown in Table 6.

Within group measures. A Friedman test was performed with accuracy data for the neurotypical group and the three keyboards: QWERTY (*Mdn* = 100), alphabetic (*Mdn* = 100), and frequency (*Mdn* = 100). There was no difference in keyboard performance with respect to accuracy among the layouts X^2 (2, N = 16) = 1.879, p = .391,

A Friedman test was also conducted to evaluate differences within the ALS group with respect to percentage accurate for QWERTY (*Mdn* = 98.46), alphabetic (*Mdn* = 96.92), and frequency (*Mdn* = 95.38). The test was not significant X^2 (2, N = 16) = 5.525, p = .063, suggesting no significant differences in accuracy among the three keyboard layouts.

Table 6

Summary Contingency Table for the Three Keyboard Layouts

Keyboard		Accuracy: Accurate	Accuracy: Not Accurate
QWERTY	Neurotypical	11	5
	ALS	9	7
Alphabetic	Neurotypical	9	7
	ALS	8	8
Frequency	Neurotypical	9	7
	ALS	5	11

Errors. Many of the participants made typing errors on one or more of the three layouts. Sometimes, an adjacent key to the desired character or command was activated. At other times, the participant failed to include a space between words. These were all counted as errors. Once again, the data was not normally distributed for any of the keyboards, so nonparametric methods were utilized for comparison of these tallies.

QWERTY layout. The error rate ranged from 0 to 4 (Mdn = 0) for the neurotypical group. The error tally for the ALS group was between 0 and 28 (Mdn = 1) for the popular QWERTY keyboard. A Mann-Whitney test indicated there was a statistically significant difference with respect to number of errors made on this layout by the two groups (U = 70.0, p = .029, r = .42). The group with ALS made more errors on this layout than the neurotypical group did.

Alphabetic layout. Neurotypical participants typed tokens on the alphabetic layout with an error rate between 0 and 3 (Mdn = 0). The ALS group completed the same task with between 0 and 15 (Mdn = 2) errors. A Mann-Whitney test was calculated and revealed a statistically significant difference with respect to error rate between the two groups (U = 73.5, p = .039, r = .38). The neurotypical group, in general, had fewer errors on this layout than the ALS group.

Frequency layout. The neurotypical participants committed between 0 and 10 (Mdn = 0) errors on the spiraled frequency layout. The ALS group had between 0 and 26 (Mdn = 3) errors on the same keyboard. The Mann-Whitney test indicated a statistically significant difference in errors committed by the two groups (U = 55.5, p = .005, r = .49). The participants with ALS had more spacing and selection errors on this layout than the neurotypical participants.

Efficiency. The ratio of accurate keystrokes to total active task time for a layout was calculated for participants for all three keyboards. Efficiency data was normally distributed for neurotypical participants for all layouts: QWERTY ($S\text{-}W$ = .917, df =16, p =.152), alphabetic ($S\text{-}W$ = .911, df =16, p =.121), frequency ($S\text{-}W$ = .906, df =16, p =.102). The assumption of normality was also satisfied by the ALS group: QWERTY ($S\text{-}W$ = .917, df =16, p =.153), alphabetic ($S\text{-}W$ = .971, df =16, p =.860), frequency ($S\text{-}W$ = .895, df =16, p =.066).

The mean efficiency ratio for neurotypical participants on the QWERTY layout was 0.402 (SD = 0.064). For the alphabetic and frequency layouts, the means for the neurotypical group were .375 (SD = .084) and .355 (SD = .077), respectively. The efficiency ratios for the ALS groups were as follows: QWERTY (M = .358, SD = .112), alphabetic (M = .329, SD = .099), frequency (M = .293, SD = .093). This suggests that both groups were most efficient when using the QWERTY keyboard and least efficient with the frequency layout.

A one-way analysis of variance (ANOVA) was conducted on efficiency data. ANOVA revealed a group effect for efficiency ratios with respect to the frequency keyboard layout, $F(1, 30) = 4.259$, $p = .048$, $\alpha = .05$. This outcome suggests the neurotypical group was significantly more efficient than the ALS group; that is, the .355 efficiency ratio of the neurotypical group was significantly different from the .293 efficiency ratio of the ALS group. ANOVA conducted on QWERTY and alphabetic layouts yielded no significant differences between the groups in regard to keyboard efficiency, QWERTY $F(1, 30) = 1.809$, $p = .189$ and alphabetic $F(1, 30) = 1.926$, $p = .175$.

Preference ratings. After each participant typed all word and phrase tokens for a layout, preference ratings were obtained for that particular layout. The participants were asked to rate the keyboard in question on a 5-point Likert scale. The suggested ratings were as follows: 1 = like a lot, 2 = like, 3 = neither like/dislike, 4 = dislike, 5 = dislike a lot. As the intervals between two adjacent numbers may not have necessarily been equal to the participant rating the keyboard, this data was treated as ordinal and analyzed using the nonparametric Mann-Whitney test.

QWERTY layout. Neurotypical participants rated the traditional keyboard layout between 1 and 4 (Mdn = 1.5). Ratings given by the ALS group were also between 1 and 4 (Mdn = 2.0). Statistical testing revealed no differences between groups for the rating of this keyboard (U = 111.0, p = .539, r = .12).

Alphabetic layout. Ratings for the alphabetic keyboard with highlighted vowels ranged from 1 to 4 (Mdn = 2.0) for both the neurotypical and ALS group. The Mann-Whitney test failed to reveal differences in preference ratings between the two groups (U = 105.5, p = .402, r = .17).

Frequency layout. The range of preference ratings for the neurotypical group fell between 2 and 5 (Mdn = 3.0). The ALS range for this keyboard was slightly wider, with ratings between 1 and 5 (Mdn = 3.0). Despite the greater range of ratings provided by the ALS group, Mann-Whitney testing did not find any differences between the two groups (U = 119.5, p = .752, r = .06).

Overall layout ranking. Once participants had completed token-typing on all three layouts, they placed the keyboards in order of overall preference from 1 (i.e., like the best) to 3 (i.e., like the least). The QWERTY layout was selected as the favorite layout of 10 (62.5%) members of the neurotypical group and 9 (56.3%) of the ALS group. The alphabetic layout was chosen as the preferred design by 4 (25%) neurotypical and 4 (25%) of the ALS participants. Finally, 2 (12%) neurotypical adults and 3 (18.8%) of the ALS group opted for the frequency keyboard. Of note, 14 (87.5%) neurotypical and 12 (75%) of ALS participants rated the novel frequency keyboard as the layout least preferred among the three. Layout preference frequency data for all participants combined (i.e., neurotypical and ALS groups) are shown in Tables 7, 8, and 9, respectively.

A chi-square test was performed and no relationship was found between group (i.e., neurotypical, ALS) and preference ranking of keyboard layout, X^2 (4, N = 32) = 2.22, p = .695.

Correlation data. Pearson product-moment correlations were conducted to examine relationships between preference order of the three layouts and computed efficiency scores (i.e., ratio of total accurate keystrokes to total task time per layout) for both groups. Correlations for the neurotypical group were not significant for any layout with respect to efficiency: QWERTY, r(14) = -.025, p = .927; alphabetic, r(14) = .193, p = .473; frequency, r(14) = .130, p = .631. Inspection of the ALS group did not reveal any relationships between the variables: QWERTY, r(14) = -.103, p = .705; alphabetic, r(14) = .016, p = .953; frequency, r(14) = . -.149, p = .582.

Spearman's rank correlation coefficients were calculated to examine relationships between preference order of the keyboard layouts and three non-normal variables (i.e., rate, accuracy, error scores) for both neurotypical and ALS participant

Table 7

Frequency Distribution of Preferred Layout Order for All Participants

Layout Order	Frequency	Percent	Cumulative Percent
QAF	18	56.3	56.3
AQF	8	25.0	81.3
FAQ	4	12.5	93.8
FQA	1	3.1	96.9
QFA	1	3.1	100.0
Total	32	100.0	

Note. Q = QWERTY; A = alphabetic; F = frequency

Table 8

Frequency Distribution of Preferred Layout Order for Neurotypical

Layout Order	Frequency	Percent	Cumulative Percent
QAF	10	62.5	62.5
AQF	4	25.0	87.5
FAQ	2	12.5	100.0
Total	16	100.0	

Note. Q = QWERTY; A = alphabetic; F = frequency

Table 9

Frequency Distribution of Preferred Layout Order for ALS

Layout Order	Frequency	Percent	Cumulative Percent
QAF	8	50.0	50.0
AQF	4	25.0	75.0
FAQ	2	12.5	87.5
FQA	1	6.3	93.8
QFA	1	6.3	100.0
Total	16	100.0	

Note. Q = QWERTY; A = alphabetic; F = frequency

groups. None of the variables were correlated for either group. Table 10 and 11 illustrate correlation data for neurotypical and ALS participants, respectively.

Pearson product-moment correlation coefficients were calculated to identify relationships between the months since ALS diagnosis and the efficiency ratio for each layout. Correlations were not significant for any layout: QWERTY, $r(14) = .148$, $p = .583$; alphabetic, $r(14) = .245$, $p = .360$; frequency, $r(14) = .269$, $p = .313$.

Spearman's rank-order correlation was conducted to examine the relationship between the time since ALS diagnosis and preference ratings for each of the three layouts. Layout ratings were not correlated with time since diagnosis for any layout: QWERTY, $r_S(14) = .009$, $p = .972$; alphabetic, $r_S(14) = .032$, $p = .906$; frequency, $r_S(14) = .022$, $p = .935$.

Pearson product-moment correlation was conducted on rate data to determine inter-rater reliability for four participants. Time in milliseconds was compared for two independent raters; one computed rate online during the investigation, while the other recorded rate based on viewing of the videos at another time. The time each rater determined was required to complete each word and phrase token was strongly correlated, $r(82) = .897$, $p < .001$.

Practice effect. Presentation order of keyboard layouts was randomized for each participant. A Pearson chi-square test was performed to examine the relationship between group (i.e., neurotypical, ALS) and quantitative measures (i.e., accuracy, rate, errors). Fisher's exact test was used in each case as some cell counts were less than or equal to five. There was insufficient evidence to conclude that disease status influences

Table 10

Spearman Rho Correlation Coefficients for Preferred Layout Order for Neurotypical

Spearman's rho	QWERTY	Alphabetic	Frequency
Accuracy	.238	.124	.426
Rate	-.051	-.154	-.239
Errors	-.238	-.124	-.426

Table 11

Spearman Rho Correlation Coefficients for Preferred Layout Order for ALS

Spearman's rho	QWERTY	Alphabetic	Frequency
Accuracy	-.228	.259	-.204
Rate	.140	.019	.055
Errors	.228	-.259	.204

an improvement in task accuracy across the experimental task, Fisher's exact test, p = .685. Whether a participant had ALS also did not affect whether their error rate decreased from the first to the last keyboard layout, Fisher's exact test, p = .433. Participants with ALS, however, were significantly more likely than neurotypical participants to improve layout rate (i.e., decrease time to complete tasks on each keyboard) over the experimental task at α = .05, Fisher's exact test, p = .043. Crosstabulations for practice effect are shown in Tables 12, 13, and 14.

Table 12

Crosstabulation of Group and Improved Accuracy Over Time

	Improve Accuracy	
Group	No	Yes
Neurotypical	13	3
ALS	11	5

Table 13

Crosstabulation of Group and Decreased Errors Over Time

	Decrease Errors	
Group	No	Yes
Neurotypical	13	3
ALS	10	6

Table 14

Crosstabulation of Group and Decreased Rate Over Time

	Decrease Rate	
Group	No	Yes
Neurotypical	16	0
ALS	11	5

CHAPTER IV: DISCUSSION

The purpose of this study was to establish which of three keyboard layouts is the most efficient for naïve users of eye gaze access with respect to neurotypical individuals as well as those with ALS. Experimental questions addressed efficiency differences between the groups, the correlation between qualitative and quantitative measure for both groups, the effect of technology use on efficiency and preference ratings, and the effect of date of ALS diagnosis on efficiency and preference ratings.

Keyboard Layout and Task Efficiency

The first experimental question addressed difference in task efficiency for neurotypical and neurologically-compromised adults. Task efficiency was determined to be the ratio of accurate keystrokes to the total time to complete typing required by a particular layout. Although there was no significant difference in efficiency measures on the QWERTY and alphabetic layouts for the two groups, the neurotypical participants were more efficient than their ALS counterparts when typing on the frequency keyboard. The ALS participants were most effective when typing on the standard QWERTY layout, followed by the alphabetic, then the frequency layout.

Pattern of Preference Ratings and Qualitative and Quantitative Measures

The second experimental question dealt with the correlations in both groups for participant’s preference ratings with regard to qualitative and quantitative measures. The frequency keyboard layout was the only one to have “dislike a lot” (i.e., 5) ratings assigned by members of both groups. Additionally, while some members of the ALS group rated the frequency layout as “like a lot” (i.e., 1), no one in the neurotypical group viewed the novel keyboard layout that favorably.

No relationships were identified between keyboard layout preference ratings and efficiency, rate, accuracy, or error rate.

Impact of Previous Technology Use on Efficiency and Preference Ratings

The third experimental question addressed the difference in the pattern of typing efficiency for individuals with or without previous experience with technology. It should be noted that 100% of participants in both groups had previous familiarity with a variety of technology (e.g., cell phones, computers). With this in mind, the two groups were simply compared. As noted earlier, while the neurotypical group completed the token-typing on the frequency layout more efficiently, individuals with ALS performed comparably to the control group on the QWERTY and alphabetic layouts.

This experimental question also addressed preference ratings for the three layouts. Again, since all participants were technology-savvy to some degree, this comparison was made between the groups. There was no difference found with respect to participant layout-ratings on either the QWERTY, alphabetic, or frequency keyboards.

Impact of ALS Diagnosis Date on Efficiency and Preference Ratings

The final experimental question addressed possible relationships between date of ALS diagnosis and efficiency as well as preference ratings for individuals with a neurological condition. Efficiency and preference measures did not correlate with diagnosis date with respect to any of the keyboard layouts.

General Discussion

Accuracy and error rate. The ALS group was less accurate and more prone to errors on all three of the investigational keyboard layouts. As all participants were easily calibrated to access eye gaze using the EyeMax attachment to the Vmax and oculomotor function is generally spared in ALS, what possible explanation is there for these measurements?

Extraocular muscle dysfunction in the form of slow saccades due to frontotemporal damage might account for the discrepancy (Donaghy et al., 2010; Sharma et al., 2011). A participant with slowed saccades might find the target letter or computer function key a fraction of a second slower than someone with typical oculomotor function; over the course of the typing task, these additional milliseconds could contribute to a significant difference between neuropathological and typically functioning adults.

Another possibility might be undetected cognitive impairment of the frontal lobe. A cognitive screening tool (e.g., Brief Cognitive Assessment Tool, Mini-Mental State Examination, Montreal Cognitive Assessment) was not utilized during this study. Although all neurotypical as well as ALS participants appeared to the author to be functioning conversationalists, it is certainly possible that cognitive deficits existed within one or both groups. Impaired executive function could make it difficult for a participant to integrate sensory information (e.g., auditory instructions, visual information of letter position) or to plan the shortest path from one letter to the next.

A final possibility might be related to the realization for participants with ALS that use of eye gaze access with an SGD is a potential glimpse into their personal future. The referring speech-language pathologist promised prospective participants a look at “some technology with which you might not be familiar” and many were observed commenting on the chance to see this novel access method before actually needing it for communication. Thoughts of future disability may have interfered with performance, decreasing accuracy and increasing error rates for some of the participants with ALS.

Motor memory. Anecdotally, a large number of people touch-type, i.e., position index fingers on central keys (often identified by tactile markings) and then depress certain areas of the keyboard with specific digits. Individuals may also use a modified touch-type method, occasionally glancing at the keyboard to either check accuracy or to depress less frequently used keys (Whitcroft, 2006). Another large group of individuals utilize visual search in a "hunt and peck" or "two-finger typist" methodology (Brown, 1988; Whitcroft, 2006).

Touch-typing and its modifications fall under the purview of so-called motor memory (Shusterman, 2011; Whitcroft, 2006). Muscles in our hands and fingers move to a desired key location without thought, as typing or keyboarding is an acquired skill that has the potential to improve with practice (Whitcroft, 2006). When one focuses on the task of typing, one's words per minute decreases and error rate increases. The same is not necessarily true for the "hunt and peck" typist, though they most likely have different motor memory demands (Brown, 1988). Lifelong two-finger typists will still acquire a certain level of motor memory even if these movements are focused more in the index fingers (Whitcroft, 2006); that is, if fewer muscles are utilized, which might make this sort of manual keyboarding a better analog to eye typing.

Most participants in the investigation preferred the QWERTY keyboard layout over the other choices. In conversation surrounding the experimental task, most of the participants claimed some degree of proficiency with touch-typing. Yet muscle memory does not translate across muscles groups. Just because a series of manual movements lead to the depression of the “t” followed by the “h” and then “e”, the movements may not be translated to the eyes. After all, while each hand has many muscles, joints, and tendons that may be involved in typing on a physical keyboard (plus additional muscles used for stabilization), each eye only has six extraocular muscles that are utilized for the same task (Baker, Cham, Cidboy, Cook, & Redfern, 2007).

Entrenchment of QWERTY. In the 1800’s, the layout created and then later modified by Christopher Sholes was the best available option for the hardware (i.e., manual typewriters) of the time. For many years after, the advantages of the QWERTY layout with respect to decreased incidence of key entanglements were not replicated or improved upon by competing novel keyboards. Even as optimized layouts improve outcome measures such as words per minute and decreased finger (or gaze) travel distance, QWERTY is so deeply ensconced in our culture that it will take a layout multitudes better to displace its supremacy. (Kay, 2013; Margolis, 2013)

Limitations

Limited sample size (i.e., 16 participants per group) as well as an unequal gender distribution among the two groups may have been limitations to the current investigation. This limited sample, however, may aid in power analysis with future related research. The imbalance with respect to gender for participants prohibited the consideration of gender differences in layout comparisons for the two groups.

Implications for Future Research

Additional investigation of efficiency measures for gaze based typing on various keyboard layouts is warranted. Plausible areas of exploration include gender differences for naïve users to this particular method of access (i.e., eye gaze) as well as further comparisons for first-time users with other neurological impairments (e.g., cerebrovascular accident, autism, cerebral palsy, locked-in syndrome). It is within the realm of possibility that the qualitative and quantitative measures used in the present investigation might divide along the lines of age group, gender, ALS onset-type (i.e., spinal, bulbar), or even scores on the revised ALS Functional Rating Scale (ALSFRS-R). The ALSFRS-R is a questionnaire-based scale that is used to asses performance in activities of daily living (i.e., speech, salivation, swallowing, handwriting, cutting food and handling utensils, dressing and hygiene, turning in bed, walking, climbing stairs, dyspnea, orthopnea, respiratory insufficiency) in order to track disease progression (Cedarbaum et al., 1999).

While all participants mentioned familiarity with and frequent usage of the QWERTY keyboard layout, the technological questionnaire did not ask participants to judge where manual typing skills should be categorized. Is there a measureable difference in performance of those who claim to touch-type vs. modified touch-typing vs. two-finger typing? Future research should consider the implications of manual keyboarding style and whether eye typing is affected. While motor memory from the hands and fingers would not be accessible to the extraocular muscles, visual memory for those who utilize search procedures as a part of typing might carry that memory over to gaze-access keyboards with similar layouts to manual setups.

Further questions were raised during the course of this investigation. On several occasions, participants—interestingly, most were in the ALS group—noted they saw the value in the frequency layout, but added that it would take time to adjust to the location of the various keyboard characters before they would feel confident in using it. Future studies might look at the same types of measures recorded in the current investigation, but over time to evaluate learning. Recording data over the course of several sessions (e.g., 3-5) would provide individuals the opportunity to practice the novel use of gaze for this purpose and to become more at ease with less-familiar keyboards.

The current investigation was only concerned with performance and preference of layouts with the 26 letters of the English alphabet plus two function keys (i.e., space, backspace). In reality, most commercially available onscreen keyboards are not limited to this character repertoire. Instead, many SGD keyboards include approximately five additional function keys that serve to predict words or phrases that users are in the process of typing (i.e., word prediction to minimize overall keystrokes) as well as punctuation, numbers, and additional command keys (e.g., enter, shift). When users are properly instructed on the integration of word prediction into word generation, significant gains can be made with respect to words per minute, which translates into higher accuracy and efficiency (Higginbotham et al., 2007; Trnka, McCaw, Yarrington, McCoy, & Pennington, 2009; Trnka, Yarrington, McCaw, McCoy, & Pennington, 2007). Since eye typing typically produces a meager handful of words (i.e., 4.33-6.84 in this investigation, depending on the keyboard utilized) per minute when compared to speech or manual typing, this would seem to be a valid line of questioning with possibly far-reaching conclusions (Hansen et al., 2004; Majaranta & Räihä, 2002).

Summary

The results indicated that technology-savvy neurotypical adults and adults with ALS perform similarly (i.e., rate, preference ratings, overall layout rankings) when eye typing on three different keyboard layouts. Neurotypical adults typed more accurately on all keyboards. ALS participants had a higher error rate across the layouts when compared to the neurotypical group. While the neurotypical group was more efficient with respect to the frequency layout, there was no statistical difference between the groups on the other two keyboards. Participants in both groups preferred the traditional QWERTY layout, followed by the alphabetical layout with highlighted vowels, then the spiraled frequency of occurrence keyboard.

REFERENCES

Al-Qudah, Z., Doush, I.A., Alkhateeb, F., Al Maghayreh, E., & Al-Khaleel, O. (2013). Utilizing mobile devices' tactile feedback for presenting Braille characters: An optimized approach for fast reading and long battery life. *Interacting with Computers,* doi:10.1093/iwc/iwt017

Anderson, A.M., Mirka, G.A., Joines, S.M.B., & Kaber, D.B. (2009). Analysis of alternative keyboards using learning curves. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 51*, 35-45.

Anson, D. (1997). Alternative computer access: A guide to selection. Philadelphia: F.A. Davis.

Anson, D., George, S., Galup, R., Shea, B., & Vetter, R. (2001). Efficiency of the Chubon versus the QWERTY keyboard. *Assistive Technology: The Official Journal of RESNA, 13*(1), 40-45.

Aoki, H., Hansen, J.P., & Itoh, K. (2009). Learning gaze typing: What are the obstacles and what progress to expect? *Universal Access in the Information Society, 8*, 297-310.

Baas, M., Guerrier, Y., Kolski, C., & Poirer, F. (2010). Système de saise de texts visant à réduire l'effort des utilisateurs à handicap moteur. In G. Calvary & M. Wolff (Eds.), *Proceedings of the Ergonomic et Informatique Avancée Conference*.

Baker, N.A., Cham, R., Cidboy, E.H., Cook, J., & Redfern, M.S. (2007). Kinematics of the fingers and hands during computer keyboard use. *Clinical Biomechanics, 22*(1), 34-43.

Ball, L., Beukelman, D., & Pattee, G. (2004). Augmentative and alternative communication acceptance by persons with amyotrophic lateral sclerosis. *Augmentative and Alternative Communication, 20*, 113-123.

Bartels, M. & Marshall, S.P. (2011). Eye tracking and universal access: Three applications and practical examples. In C. Stephanidis (Ed.), *Universal Access in Human-Computer Interaction: Users Diversity* (pp. 525-534). Berlin: Springer.

Bee, N. & André, E. (2008). Writing with your eye: A dwell time free writing system adapted to the nature of human eye gaze. In E. André, L. Dybkjær, W. Minker, H. Neumann, R. Pieraccini, M. Weber (Eds.), *Perception in Multimodal Dialogue Systems* (pp. 111-122). Berlin: Springer.

Beukelman, D., Fager, S., & Nordness, A. (2011). Communication support for people with ALS. *Neurology Research International, 2011, 6 pgs*. doi:10.1155/2011/714693

Bhattacharya, S., Samanta, D., & Basu, A. (2008). Performance models for automatic evaluation of virtual scanning keyboards. *IEEE Transactions on Neural Systems and Rehabilitation Engineering, 16*(5), 510-519.

Bilgin, B., Gursoy, H., Basmak, H., Ozkurt, M., Tuncel, N., Canaz, F., . . . Colak, E. (2013). The effects of bupivacaine injection and oral nitric oxide on extraocular muscle in the rabbit. *Graege's Archive for Clinical and Experimental Ophthalmology.* doi:10.1007/s00417-013-2390-8

Boston College & The Opportunity Foundation of America. (2011). *EagleEyes 2011: User Manual*. Retrieved from http://www.eagleeyes.org

Brooks, B.R., Miller, R.G., Swash, M., & Munsat, T.L. (2000). El Escorial revisited: Revised criteria for the diagnosis of amyotrophic lateral sclerosis. *ALS and Other*

Motor Neuron Disorders, 1, 293-299.

Brown, C.M. (1998). Comparison of typing and handwriting in “two-finger typists”. *Proceedings of the Human Factors and Ergonomics Society Annual Meeting, 32*, 381-385.

Cannon, J.R. & Greenamyre, J.T. (2011). The role of environmental exposures in neurodegeneration and neurodegenerative diseases. *Toxicological Sciences, 124*(2), 225-250.

Cedarbaum, J.M., Stambler, N., Malta, E., Fuller, C., Hilt, D., Thurmond, B., & Nakanishi, A. (1999). The ALSFRS-R: A revised ALS functional rating scale that incorporates assessments of respiratory function. *Journal of the Neurological Sciences, 169*(1-2), 13-21.

Chewing Word. (2011, November 8). Chewing word. Retrieved from http://chewingword.wikidot.com

Donaghy, C., Pinnock, R., Abrahams, S., Cardwell, C., Hardiman, O., Patterson, V., McGivern, R.C., & Gibson, J.M. (2010). Slow saccades in bulbar-onset motor neurone disease. *Journal of Neurology, 257*, 1134-1140.

Duchowski, A.T. (2002). A breadth-first survey of eye tracking applications. *Behavior Research Methods, Instruments, and Computers, 34*(4), 455-470.

DynaVox. (2008). EyeMax user’s guide. Available from http://www.dynavoxftp.com/KB%20Documents/EyeMax_UsersGuide.pdf

DynaVox. (November, 2011). Series 5 (Version 1.07.2) [Software]. Available from http://www.dynavoxtech.com/support/downloads/

Eisen, A. (2002). Amyotrophic lateral sclerosis: A review. *British Columbia Medical*

Journal, 44(7), 362-366.

Feng, C. & Shen, M. (2012). A study on the layout of on-screen keyboard for eye-typing of Chinese characters. *Advances in Mathematical and Computational Methods, 2*(4), doi.10.5729/amcm.vol2.issue4.60

Forrester, J.V., Dick, A.D., McMenamin, P.G., & Roberts, F. (2008). *The Eye: Basic Sciences in Practice* (3rd ed.). New York, NY: Elsevier.

Francis, G. & Johnson, E. (2011). Speed-accuracy tradeoffs in specialized keyboards. *International Journal of Human-Computer Studies, 69*, 526-538.

Gibbons, C. & Beneteau, E. (2010). Functional performance using eye control and single switch scanning by people with ALS. *Perspectives on Augmentative and Alternative Communication, 19*(3), 64-69.

Guerrier, Y., Baas, M., Kolski, C., & Poirier, F. (2011a). Comparative study between AZERTY-type and K-Hermes virtual keyboards dedicated to users with cerebral palsy. In C. Stephanidis (Ed.), *Universal Access in Human-Computer Interaction: Users Diversity* (pp. 310-319). Berlin: Springer.

Guerrier, Y., Baas, M., Kolski, C., & Poirier, F. (2011b). Étude comparative entre un clavier virtuel AZERTY et un clavier multitap pour des utilisateurs souffrant d'une Infirmité Motrice Cérébrale de type tétraplégique athétosique. In *Proceedings ASSISTH 2011, 2ème Confèrence Internationale Sur l'Accessibilité et les Systèmes de Suppléance aux personnes en situations de Handicap*, Paris, France, 148-155.

Hain, T.C. (2011, December 13). Eye movement recording devices. Retrieved from http://dizziness-and-balance.com

Hansen, D.W. & Hansen, J.P. (2006). Robustifying eye interaction. Paper presented at the Conference on Computer Vision and Pattern Recognition Workshop, 152-152.

Hansen, J.P., Hansen, D.W., & Johansen, A.S. (2001). Bringing gaze-based interaction back to basics. In *Proceedings of Universal Access in Human-Computer Interaction (UAHCI 2001)*, New Orleans, LA, 325-333.

Hansen, J.P., Johansen, A.S., Hansen, D.W., Itoh, K., & Mashino, S. (2003). Command without a click: Dwell time typing by mouse and gaze selections. In *Proceedings of INTERACT 2003*, IOS Press, 121-128.

Hansen, J.P., Tørning, K., Johansen, A.S., Itoh, K., & Aoki, H. (2004). Gaze typing compared with input by head and hand. In *Proceedings of the 2004 Symposium on Eye Tracking Research & Applications,* 131-138.

Harbusch, K. & Kühn, M. (2003). Towards an adaptive communication with text input from ambiguous keyboards. In *EACL 2003 Proceedings*, Budapest, Hungary.

Hardiman, O., van der Berg, L.H., & Kiernan, M.C. (2011). Clinical diagnosis and management of amyotrophic lateral sclerosis. *Nature Reviews Neurology, 7*(11), 639-640.

Higginbotham, D.J., Shane, H., Russell, S., & Caves, K. (2007). Access to AAC: Present, past, and future. *Augmentative and Alternative Communication, 23*(3), 243-257.

Houben, M.M.J., Goumans, J., & Van Der Steen, J. (2006). Recording three-dimensional eye movements: Scleral search coils versus video oculography. *Investigative Ophthalmology & Visual Science, 47*(1), 179-187.

Istance, H., Vickers, S., & Hyrskykari, A. (2012). The validity of using non-representative users in gaze communication research. In *Proceedings of the 2012 Symposium on Eye Tracking Research & Applications,* 233-236.

Itoh, K., Aoki, H., & Hansen, J.P. (2006). A comparative usability study of two Japanese gaze typing systems. In *Proceedings of the 2006 Symposium on Eye Tracking Research & Applications,* 59-66.

ITU GazeGroup (n.d.). Research: Gaze based interaction. Retrieved from http: www.gazegroup.org/research

Jacob, R.J.K. (1991). The use of eye movements in human-computer interaction techniques: What you look at is what you get. *ACM Transactions on Information Systems, 9*(3), 152-169.

Jacob, R.J.K. & Karn, K.S. (2003). Eye tracking in human-computer interaction and usability research: Ready to deliver the promises. In R. Radach, J. Hyona, & H. Deubel (Eds.), *The Mind's Eye: Cognitive and Applied Aspects of Eye Movement Research* (pp. 573-605). Oxford: Elsevier.

Judge, S. & Friday, M. (2011). Ambiguous keyboards for AAC. *Journal of Assistive Technology, 5*(4), 249-256.

Kaminski, H.J. & Richmonds, C.R. (2002). Extraocular muscle fatigue. *Annals of the New York Academy of Sciences, 956*(1), 397-398.

Kano, O., Iwamoto, K., Ito, H., Kawase, Y., Cridebring, D., Ikeda, K., & Iwasaki, Y. (2013). Limb-onset amyotrophic lateral sclerosis patients visiting orthopedist show a longer time-to-diagnosis since symptom onset. *BMC Neurology, 13*(19), doi:10.1186/1471-2377-13-19

Kay, N.M. (2013). Rerun the tape of history and QWERTY always wins. *Research Policy, 42*(6-7), 1175-1185.

Kiernan, M.C., Vucic, S., Cheah, B.C., Turner, M.R., Eisen, A., Hardiman, O., . . ., Zoing, M.C. (2011). Amyotrophic lateral sclerosis. *The Lancet, 377*(9769), 942-955.

Komogortsev, O., Holland, C., & Camou, J. (2011). Adaptive eye-gaze-guided interfaces: Design & performance evaluation. In *Proceedings of the 2011 Annual Conference Extended Abstracts on Human Factors in Computing Systems*, New York, NY.

Kotani, K., Yamaguchi, Y., Asao, T., & Horii, K. (2010). Design of eye-typing interface using saccadic latency of eye movement. *International Journal of Human-Computer Interaction, 26*(4), 361-376.

Lee, J.W., Cho, C.W., Shin, K.Y., Lee, E.C., & Park, K.R. (2012). 3D gaze tracking using Purkinje images on eye optical model and pupil. *Optics and Lasers in Engineering, 50*(5), 736-751.

Leigh, R.J. & Zee, D.S. (2006). *The neurology of eye movements* (4th ed.).New York, NY: Oxford University Press.

Li, F.C.Y., Guy, R.T., Yatani, K., & Truong, K.N. (2011). *The 1line keyboard: A QWERTY layout in a single line.* Paper presented at the ACM Symposium on User Interface Software and Technology, Santa Barbara, CA.

Li, T., Wiggins, L.M., & von Bartheld, C.S. (2010). Insulin-like growth factor 1 and cardiotrophin 1 increase strength and mass of extraocular muscle in juvenile chicken. *Investigative Ophthalmology & Visual Science, 51*(5), 2479-2486.

Liang, Z., Fu, Q., & Chi, Z. (2012). Eye typing of Chinese characters. In *Proceedings of the 2012 Symposium on Eye Tracking Research & Applications*, 237-240.

Lin, Y.-L., Chen, M.-C., Yeh, Y.-M., Tzeng, W.-J., & Yeh, C.-C. (2006). Design and implementation of a chorded on-screen keyboard for people with physical impairments. In K. Miesenberger, J. Klaus, W. Zagler, A.I. Zagler (Eds.). International Conference on Computers Helping People with Special Needs 2006, LNCS 4061, pp. 981-988.

Logroscino, G., Traynor, B.J., Hardiman, D., Chiò, A., Couratier, P., Mitchell, J.D., . . ., Beghi, E. (2008). Descriptive epidemiology of amyotrophic lateral sclerosis: New evidence and unsolved issues. *Journal of Neurology, Neurosurgery & Psychiatry, 79*, 6-11.

Lomen-Hoerth, C., Murphy, J., Langmore, S., Kramer, J.H., Olney, R.K., & Miller, B. (2003). Are amyotrophic lateral sclerosis patients cognitively normal? *Neurology, 60*, 1094-1097.

Lomen-Hoerth, C., Anderson, T., & Miller, B. (2002). The overlap of amyotrophic lateral sclerosis and frontotemportal dementia. *Neurology, 59*, 1077-1079.

MacKay, D., Wills, S., & Waller, A. (2007). Bliss-Dasher – Efficient semantic writing with any muscle. Cambridge, UK.

MacKenzie, I.S. & Ashtiani, B. (2011). BlinkWrite: Efficient text entry using eye blinks. *Universal Access in the Information Society, 10*, 69-80.

Majaranta, P., Ahola, U.-K., & Špakov, O. (2009). Fast gaze typing with an adjustable dwell time. In *Proceedings of the 27th International Conference on Human Factors in Computing Systems,* 357-360. New York: ACM.

Majaranta, P., MacKenzie, I.S., Aula, A., & Räihä, K.-J. (2006). Effects of feedback and dwell time on eye typing speed and accuracy, *Universal Access in the Information Society, 5*, 199-208.

Majaranta, P. & Räihä, K.-J. (2002). Twenty years of eye typing: Systems and design issues. In *Proceedings of the 2002 Symposium on Eye Tracking Research & Applications,* 15-22, New York: ACM.

Margolis, S.E. (2013). A tip of the hat to Kay and QWERTY. *Research Policy, 42*(6-7), 1188-1190.

McCombe, P.A. & Henderson, R.D. (2010). Effects of gender in amyotrophic lateral sclerosis. *Gender Medicine: The Journal for the Study of Sex & Gender Differences, 7*(6), 557-570.

Møllenbach, E., Hansen, J.P., & Lillholm, M. (2013). Eye movements in gaze interaction. *Journal of Eye Movement Research, 6*(2), 1-15.

Morimoto, C.H. & Amir, A. (2010). Context switching for fast key selection in text entry applications. In *Proceedings of the 2010 Symposium on Eye Tracking Research & Applications*, 271-274.

Morimoto, C.H. & Mimica, M.R.M. (2005). Eye gaze tracking techniques for interactive applications. *Computer Vision and Image Understanding, 98*(1), 4-24.

Murphy, J., Henry, R., Langmore, S., Kramer, J.H., Miller, B.L., & Lomen-Hoerth, C. (2007). Continuum of frontal lobe impairment in amyotrophic lateral sclerosis. *Archives of Neurology, 64*, 530-534.

Murphy, J., Henry, R., & Lomen-Hoerth, C. (2007). Establishing subtypes of the continuum of frontal lobe impairment in amyotrophic lateral sclerosis. *Archives of*

Neurology, 64, 330-334.

Norman, D.A. & Fisher, D. (1982). Why alphabetic keyboards are not easy to use: Keyboard layout doesn't much matter. *Human Factors, 24*(5), 509-519.

Noyes, J. (1998). QWERTY — The immortal keyboard. *Computing & Control Engineering Journal, 9,* 117-122.

Ohno, T. (1998). Features of eye gaze interface for selection tasks. In *Proceedings of the 3rd Asia Pacific Conference on Computer Human Interaction*, Shonan Village Center, Japan, 176-181.

Olney, R.K., Murphy, L., Forshew, D., Garwood, E., Miller, B.L., Langmore, S., . . . Lomen-Hoerth, C. (2005). The effects of executive and behavioral dysfunction on the course of ALS. *Neurology, 65*(11), 1774-1777.

Otero-Millan, J., Macknik, S.L., Serra, A., Leigh, R.J., & Martinez-Conde, S. (2011). Triggering mechanisms in microsaccade and saccade generation: A novel proposal. *Annals of the New York Academy of Sciences, 1233*, 107-116.

Pfoff Laser & Eye. (n.d.) *Extraocular muscles (front view)* [illustration]. Retrieved from: http://pfofflaserandeye.com/anatomy.htm

Poláček, O., Míkovec, Z., Sporka, A., & Slavík, P. (2011). Humsher: A predictive keyboard operated by humming. In *Proceedings of the 13th International ACM SIGACCESS Conference on Computers and Accessibility,* 75-82.

Porta, M. & Turina, M. Eye-S: A full-screen input modality for pure eye-based communication. In *Proceedings of the 2008 Symposium on Eye Tracking Research & Applications,* 27-34.

Prsa, M., Dicke, P.W., & Thier, P. (2010). The absence of eye muscle fatigue indicates that the nervous system compensates for non-motor disturbances in oculomotor function. *The Journal of Neuroscience, 30*(47), 15834-15842.

Purves, D., Augustine, G.J., Fitzpatrick, D., Hall, W.C., LaMantia, A.-S., McNamara, J.O., & White, L.E. (Eds.) (2009). *Neuroscience* (4th ed.). Sunderland, MA: Sinauer Associates, Inc.

Random integer generator. (2002). Retrieved December 1, 2012, from http://www.cs.uis.edu/~troy/spring02/sc101/random.html

Ringholz, G.M., Appel, S.H., Bradshaw, M., Cooke, N.A., Mosnik, D.M., & Schutz, P.E. (2005). Prevalence and patterns of cognitive impairment in sporadic ALS. *Neurology, 65*(4), 586-590.

Satoh, N., Shimizu, K., Goto, A., Igarashi, A., Kamiya, K., & Ohbayashi, K. (2013). Accommodative changes in human eye observed by Kitasato anterior segment optical coherence tomography. *Japanese Journal of Ophthalmology, 57*(1), 113-119.

Shackel, B. (2009). Designing for people in the age of information. *Interacting with Computers, 21*, 325-330.

Sharma, R., Hicks, S., Berna, C.M., Kennard, C., Talbot, K., & Turner, M.R. (2011). Oculomotor dysfunction in amyotrophic lateral sclerosis. *Archives of Neurology, 68*(7), 857-861.

Shusterman, R. (2011). Muscle memory and the somaesthetic pathologist of everyday life. *Human Movement, 12*(1), 4-15.

Smith, S. (2008) Basic ocular anatomy. *Insight, 33*(3), 19-25.

Solso, R.L. & King, J.F. (1976). Frequency and versatility of letters in the English language. *Behavior research Methods & Instrumentation, 8*(3), 283-286.

Špakov, O. & Miniotas, D. (2004). On-line adjustment of dwell time for target selection by gaze. In *Proceedings of the Third Nordic Conference on Human-Computer Interaction (NordiCHI 2004)*, New York, NY, 203-206.

Statewide Vision Resource Centre. (2012). *The eye* [illustration]. Retrieved from: http://svrc.vic.edu.au/AVtheeye.shtml

Talan, J. (2008). New law passed to create first national ALS registry. *Neurology Today, 8*(21), 4.

Trnka, K., McCaw, J., Yarrington, D., McCoy, K.F., & Pennington, C. (2009). User interaction with word prediction: The effects of prediction quality. *ACM Transactions on Accessible Computing (TACCESS), 1*(3), doi:10.1145/1497302.1497307

Trnka, K., Yarrington, D., McCaw, J., McCoy, K.F., & Pennington, C. (2007). The effects of word prediction on communication rate for AAC. In *NAACL-Short '07 Human Language Technologies 2007: The Conference of the North American Chapter of the Association for Computational Linguistics; Companion Volume, Short Papers*, 173-176.

Wang, J., Zhai, S., & Su, H. (2001). Chinese input with keyboard and eye-tracking: An anatomical study. In *Proceedings of ACM CHI01,* Seattle, WA, 349-356.

Ward, D.J. & MacKay, D.J.C. (2002). Fast hands-free writing by gaze direction. *Nature, 418*, 838.

Whitcroft, J. (2006). *Color coding the computer keyboard.* Cupertino, C.A.: Psycho-Logic Technologies. Retrieved from http://keyright.com/keyright_whitepaper.pdf

Williams, F.J., Mills, D.S., & Guo, K. (2011). Development of a head-mounted, eye-tracking system for dogs. *Journal of Neuroscience Methods, 194*(2), 259-265.

Urbina, M.H. & Huckauf, A. (2010). Alternatives to single character entry and swell time selection on eye typing. In *Proceedings of the 2010 Symposium on Eye Tracking Research & Applications,* 315-322.

Venkatagiri, H.S. (1999). Efficient keyboard layouts for sequential access in augmentative and alternative communication. *Augmentative and Alternative Communication, 15*, 126-134.

Wandmacher, T., Antoine, J.-Y., & Poirer, F. (2007). SIBYLLE: A system for alternative communication adapting to the context and its user. In *ACM ASSETS 2007*, Tempe, AZ.

Williams, F.J., Mills, D.S., & Guo, K. (2011). Development of a head-mounted, eye-tracking system for dogs. *Journal of Neuroscience Methods, 94*, 259-265.

Wobbrock, J.O., Rubinstein, J., Sawyer, M., & Duchowski, A.T. (2007). Not typing but writing: Eye-based text entry using letter-like gestures. In *Proceedings of the 3rd Conference on Communication by Gaze Interaction (COGAIN 2007),* Leicester, UK, 61-64.

Yanoff, M. (2009). *Ophthalmology*. Available from http://mdconsult.com

Yin, P.-Y. & Su, E.-P. (2011). Cyber Swarm optimization for general keyboard arrangement problem. *International Journal of Industrial Ergonomics, 41*, 43-52.

Zalonis, I., Christidi, F., Paraskevas, G., Zabelis, T., Evdokimidis, I., & Kararizou, E. (2012). Can executive cognitive measures differentiate between patients with spinal- and bulbar-onset amyotrophic lateral sclerosis? *Archives of Clinical*

Neuropsychology, 27(3), 348-354.

Zhai, S., Hunter, M., & Smith, B.A. (2000). The Metropolis keyboard – An exploration of quantitative techniques for virtual keyboard design. In *Proceedings of ACM Symposium on User Interface Software and Technology (UIST 2000)*, San Diego, CA, 119-128.

APPENDIX A: IRB APPROVALS

EAST CAROLINA UNIVERSITY FILE COPY
University & Medical Center Institutional Review Board Office
1L-09 Brody Medical Sciences Building• 600 Moye Boulevard • Greenville, NC 27834
Office **252-744-2914** • Fax **252-744-2284** • **www.ecu.edu/irb**

E-MAILED
6-24-11

TO: Skye Lewis, MA, Department of CSDI, ECU, Mailstop #668

FROM: UMCIRB JTC

DATE: June 24, 2011

RE: Expedited Category Research Study

TITLE: "Keyboard Layout in Eye Gaze Communication Access: Typical vs. ALS"

MAILED
6-24-11

UMCIRB #11-0390

This research study has undergone review and approval using expedited review on 6/22/11. This research study is eligible for review under an expedited category number 4 & 6 where this is a collection of data through noninvasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be cleared/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indications.) Examples: (a) physical sensors that are applied either to the surface of the body or at a distance and do not involve input of significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual. Also, this is a collection of data from voice, video, digital, or image recordings made for research purposes. The Chairperson (or designee) deemed this **unfunded** study **no more than minimal risk** requiring a continuing review in **12 months**. Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The investigator must adhere to all reporting requirements for this study.

The above referenced research study has been given approval for the period of **6/22/11** to **6/21/12**. The approval includes the following items:

- Internal Processing Form (dated 6/13/11)
- Informed consent (dated 6/13/11)
- COI disclosure form (dated 6/13/11)
- Recruitment flyer
- Participant questionnaire

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

The UMCIRB applies 45 CFR 46, Subparts A-D, to all research reviewed by the UMCIRB regardless of the funding source. 21 CFR 50 and 21 CFR 56 are applied to all research studies under the Food and Drug Administration regulation. The UMCIRB follows applicable International Conference on Harmonisation Good Clinical Practice guidelines.

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
4N-70 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · **www.ecu.edu/irb**

Notification of Continuing Review Approval: Expedited

From: Biomedical IRB
To: Skye Lewis
CC:
Laura Ball
Date: 6/21/2012
Re: CR00000450
UMCIRB 11-0390
[IMPORTED] Keyboard Layout in Eye Gaze Communication Access: Typical vs. ALS

The continuing review of your expedited study was approved. Approval of the study and any consent form(s) is for the period of 6/20/2012 to 6/19/2013. This research study is eligible for review under expedited category #4and 6. The Chairperson (or designee) deemed this study no more than minimal risk. Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

The approval includes the following items:

Name	Description	Modified	Version
ALS questionnaire | History	Surveys and Questionnaires	6/1/2012 10:04 AM	0.01
Consent form | History	Consent Forms	6/1/2012 2:07 PM	0.01
Keyboard rating pages | History	Surveys and Questionnaires	6/1/2012 10:04 AM	0.01
Project flyer | History	Recruitment Documents/Scripts	6/1/2012 10:01 AM	0.01
Typical questionnaire | History	Surveys and Questionnaires	6/1/2012 10:03 AM	0.01

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
4N-70 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · **www.ecu.edu/irb**

Notification of Continuing Review Approval: Expedited

From: Biomedical IRB
To: Skye Lewis
CC:
Joseph Kalinowski
Date: 5/17/2013
Re: CR00001070
UMCIRB 11-0390
[IMPORTED] Keyboard Layout in Eye Gaze Communication Access: Typical vs. ALS

The continuing review of your expedited study was approved. Approval of the study and any consent form(s) is for the period of 5/17/2013 to 5/16/2014. This research study is eligible for review under expedited category #4 and 7. The Chairperson (or designee) deemed this study no more than minimal risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

The approval includes the following items:

Name	Description	Modified	Version
ALS questionnaire | History	Surveys and Questionnaires	6/1/2012 10:04 AM	0.01
Consent form | History	Consent Forms	5/17/2013 2:49 PM	0.02
Keyboard rating pages | History	Surveys and Questionnaires	5/17/2013 2:49 PM	0.02
project flyer | History	Recruitment Documents/Scripts	6/1/2012 10:01 AM	0.01
typical questionnaire | History	Surveys and Questionnaires	6/1/2012 10:03 AM	0.01

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418

APPENDIX B: APPROVED CONSENT FORMS

1907-2007 CENTENNIAL

University Health Systems of Eastern Carolina

East Carolina University

Informed Consent to Participate in Research

Information to consider before taking part in research that has no more than minimal risk.

Title of Research Study: Keyboard Layout in Eye Gaze Communication Access: Typical vs. ALS

Principal Investigator: Skye Lewis, M.A./CCC-SLP
Institution/Department or Division: Communication Sciences & Disorders
Address: Mail Stop #668
Telephone #: 744-6119

Researchers at East Carolina University (ECU) study problems in society, health problems, environmental problems, behavior problems and the human condition. Our goal is to try to find ways to improve the lives of you and others. To do this, we need the help of volunteers who are willing to take part in research.

Why is this research being done?

The purpose of this research is to determine which on-screen keyboard is most efficient on first exposure to eye gaze access. The decision to take part in this research is yours to make. By doing this research, we hope to learn whether (1) keyboard layout influences efficiency, (2) participant preference of keyboard layout correlates with use efficiency, (3) previous technology use impacts efficiency or preference of an eye gaze speech generating device (SGD) for neurologically intact adults as well as those with amyotrophic lateral sclerosis (ALS), and (4) if ALS symptoms/date of diagnosis impact either efficiency or preference of keyboard layout.

Why am I being invited to take part in this research?

You are being invited to take part in this research because you have been diagnosed with ALS <u>or</u> you are a healthy volunteer who is the same age and gender of a participant with ALS. If you volunteer to take part in this research, you will be one of about 52 people to do so.

Are there reasons I should not take part in this research?

I understand I should not volunteer for this study if I have any diagnosed neurological condition other than ALS.

What other choices do I have if I do not take part in this research?

You can choose not to participate in this investigation. The investigators are unaware of other studies examining similar questions as an alternative.

Where is the research going to take place and how long will it last?

The research procedures will be conducted in a quiet laboratory space at East Carolina University unless this is impossible. At ECU, You will need to come to the second floor of the Allied Health Sciences Building (2310-M or 2310-U) one time during the study. The total amount of time you will be asked to volunteer for this study is less than one hour.

UMCIRB Number:____________

Consent Version # or Date: 15 August 2012
UMCIRB Version 2010.05.01

____
Participant's Initials

What will I be asked to do?

You are being asked to do the following:

- Complete a questionnaire that asks general questions about your health status and use of technology. This helps us understand whether your performance during the study, as well as your stated preferences, may be affected by your familiarity with technology. It will also allow us to place you in the appropriate study group.
- Sit in front of a computer monitor while a researcher calibrates the equipment to your eyes. This will allow the software to track your eye gaze across a computer screen.
- Spell words and sentences on several different keyboards using your eyes.
- Answer basic questions on several different keyboards using your eyes.
- Rate each keyboard on a scale of 1 to 5 based on how much you liked using it.
- Put several keyboards in order of personal preference.

All of your interactions with the keyboards will be videotaped and this is an integral part of the research, as it will allow the researchers the chance to verify objective measurements. The camera will focus on the computer screen and record your performance; it will not record your face during the study. Only individuals involved in this investigation (Ms. Lewis, Dr. Laura J. Ball, Dr. Joseph Kalinowski) will have access to these recordings, which will be encrypted on a hard drive and stored in a locked laboratory.

What possible harms or discomforts might I experience if I take part in the research?

It has been determined that the risks associated with this research are no more than what you would experience in everyday life. If you become tired during the study, you will be given breaks as needed.

What are the possible benefits I may experience from taking part in this research?

We do not know if you will get any benefits by taking part in this study. There may be no personal benefit from your participation but the information gained by doing this research may help others in the future. This research might help us learn more about which type of keyboard layout is the most efficient for communication system access. Implementing such knowledge in clinical interventions may shorten the duration necessary for individuals to learn how to use certain types of high-tech augmentative and alternative communication (AAC).

Will I be paid for taking part in this research?

You will not be paid for the time you volunteer for this study.

What will it cost me to take part in this research?

It will not cost you any money to be part of the research.

Who will know that I took part in this research and learn personal information about me?

To do this research, ECU and the people and organizations listed below may know that you took part in this research and may see information about you that is typically kept private. With your permission, these people may use your private information to do this research:

- Any agency of the federal, state, or local government that regulates human research. This includes the Department of Health and Human Services (DHHS), the North Carolina Department of Health, and the Office for Human Research Protections.
- The University & Medical Center Institutional Review Board (UMCIRB) and its staff, who have responsibility for overseeing your welfare during this research, and other ECU staff who oversee this research.

How will you keep the information you collect about me secure? How long will you keep it?

All video will be encrypted and stored on a hard drive in a locked laboratory. These videos will focus on the computer screen only, and not your face. The data from the paper questionnaire and preference rating forms will be transferred

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Participant's Initials

to electronic spreadsheet and the paper forms then destroyed. Your name will not appear on any video or document besides this consent form, so any information or preference you state will not be connected to you.

What if I decide I do not want to continue in this research?
If you decide you no longer want to be in this research after it has already started, you may stop at any time. You will not be penalized or criticized for stopping. You will not lose any benefits that you should normally receive.

Who should I contact if I have questions?
The people conducting this study will be available to answer any questions concerning this research, now or in the future. You may contact the Principal Investigator at 744-6119 (days, 8:00 a.m. - 4:00 p.m.).

If you have questions about your rights as someone taking part in research, you may call the Office for Human Research Integrity (OHRI) at phone number 744-2914 (days, 8:00 a.m. - 5:00 p.m.). If you would like to report a complaint or concern about this research study, you may call the Director of the OHRI, at 744-1971.

I have decided I want to take part in this research. What should I do now?
The person obtaining informed consent will ask you to read the following and if you agree, you should sign this form:

- I have read (or had read to me) all of the above information.
- I have had an opportunity to ask questions about things in this research I did not understand and have received satisfactory answers.
- I know that I can stop taking part in this study at any time.
- By signing this informed consent form, I am not giving up any of my rights.
- I have been given a copy of this consent document, and it is mine to keep.

____

Participant's Name (PRINT) **Signature** **Date**

Person Obtaining Informed Consent: I have conducted the initial informed consent process. I have orally reviewed the contents of the consent document with the person who has signed above, and answered all of the person's questions about the research.

____

Person Obtaining Consent (PRINT) **Signature** **Date**

UMCIRB Number:___________

Consent Version # or Date: 15 August 2012
UMCIRB Version 2010.05.01

____
Participant's Initials

APPENDIX C: PARTICIPANT AGES FOR BOTH GROUPS

Neurotypical	ALS
35	46
40	46
42	47
42	47
44	48
44	50
47	52
50	55
55	56
57	57
65	57
65	58
65	58
65	59
68	74
76	81

APPENDIX D: RECRUITMENT FLYER

PARTICIPANTS NEEDED FOR STUDY OF EYE GAZE COMMUNICATION

KEYBOARD LAYOUT IN EYE GAZE COMMUNICATION ACCESS: TYPICAL VS. ALS

The Department of Communication Sciences and Disorders at East Carolina University is conducting a research study to determine the most efficient keyboard layout for first-time users of eye gaze communication devices. The principal investigator is Skye Lewis, M.A., CCC-SLP, Doctoral Student. Dr. Laura J. Ball, Ph.D., CCC-SLP, associate professor is also involved in this investigation.

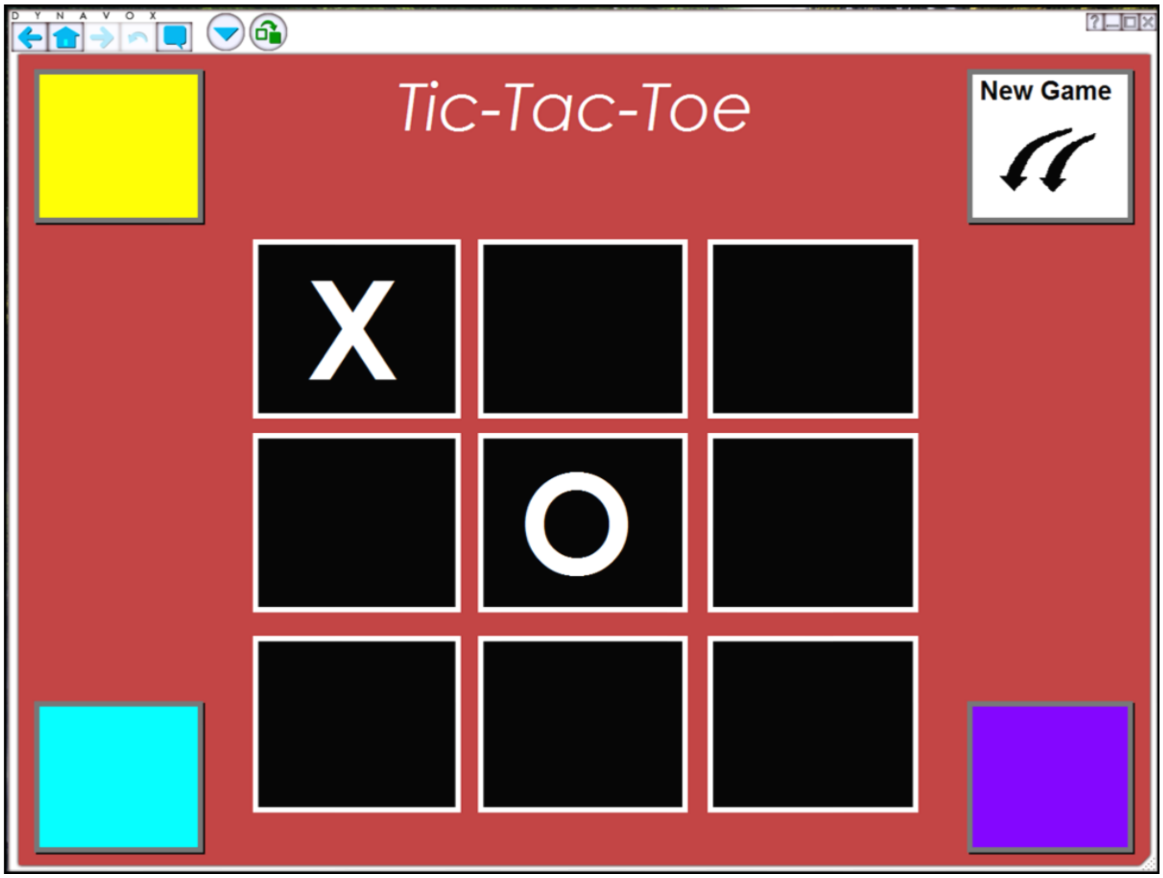
Adults who have been diagnosed with amyotrophic lateral sclerosis (ALS) are needed for this study. Adults without diagnosed neurological impairments are also needed for the investigation. Each participant will complete a brief questionnaire about technology use and personal health. Each adult will use his/her eyes to type words, sentences, and open-ended questions on several on-screen keyboards. This can be completed in a single study session that will last approximately 1 hour. There is no cost to participants.

In order to be included in the study, adults must have ALS or be the same age and gender as a participant with ALS. They must not have any other known neurological or cognitive impairment.

FOR MORE INFORMATION, PLEASE CONTACT *(CALL OR EMAIL)*

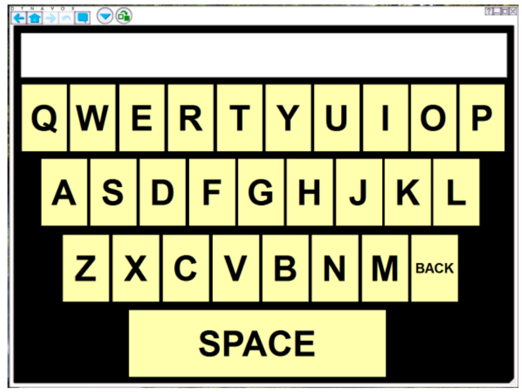
1. **Skye Lewis, M.A., phone 252-744-6119, email: lewiss08@students.ecu.edu**
2. **Laura J Ball, Ph.D., phone 252-744-6147, email: balll@ecu.edu**

APPENDIX E: PRACTICE SCREEN FOR ALL PARTICIPANTS

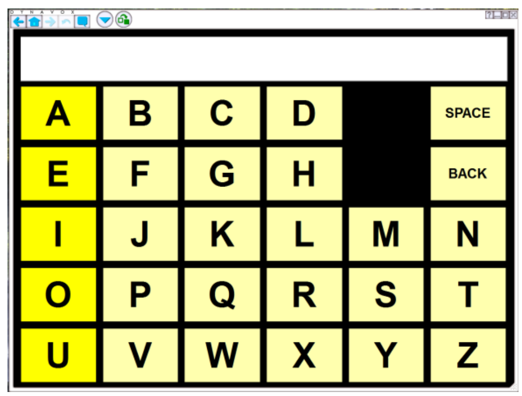


APPENDIX F: KEYBOARD LAYOUTS

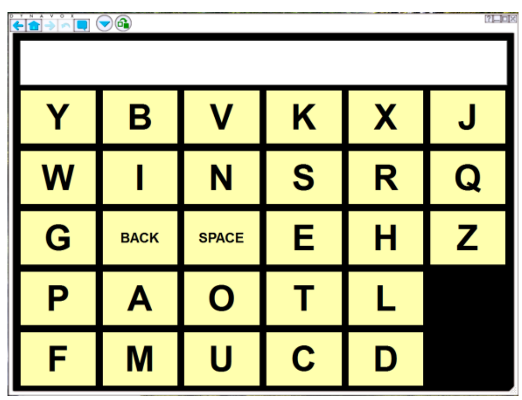
QWERTY



Alphabetic with highlighted vowels



Frequency of occurrence



APPENDIX G: LIST OF TOKENS FOR EACH KEYBOARD LAYOUT

Keyboard Layout	Token	Central Keystrokes (%)
QWERTY		
	HURT	100
	GIFT	75
	PLAY	25
	MEAL	0
	BUY_THE_THING	69.2
	MONKEY_AROUND	38.5
	GIVE_THE_HENS_MORE_REST	34.8
Alphabetic		
	GLOW	50
	LIPS	75
	DEBT	0
	VASE	25
	GIVE_HER_MORE	38.5
	WE_TASTED_TEA	7.7
	GIVE_THE_HENS_MORE_REST	34.8
Frequency		
	HENS	100
	TONE	100
	WALK	50
	JUNK	50
	REST_IN_HOTEL	100
	MY_QUIZ_GRADE	46.2
	GIVE_THE_HENS_MORE_REST	87

APPENDIX H: TYPICAL ADULT QUESTIONNAIRE

Participant Questionnaire
Technology Use & Health Information

1. Do you have access to a computer at your home, office, or at another location?

   ☐ Yes ☐ No

2. About how many hours do you use a computer each week?

   ☐ I do not use a computer. ☐ Less than 1 hour.

   ☐ Between 1 and 5 hours. ☐ Between 6 and 10 hours.

   ☐ Between 11 and 15 hours. ☐ Between 16 and 20 hours.

   ☐ More than 20 hours.

3. For what types of activities do you use a computer? (Select all that apply)

   ☐ Sending/receiving e-mail ☐ Word processing

   ☐ Social media (e.g., Facebook, Twitter) ☐ Playing games

   ☐ Other (please specify): ____

4. Do you use a cell phone?

   ☐ Yes ☐ No

5. Do you use a "smart" phone?

   ☐ Yes ☐ No

6. Do you use any other technology on a regular basis? (Select all that apply)

   ☐ I do not use any other technology. ☐ Video game system

   ☐ Computer notepad (e.g., iPad) ☐ DVD or Blu-Ray player

7. Do you have any visual deficits that are not corrected by glasses/contacts?

   ☐ Yes: _________________________ ☐ No

APPENDIX I: ALS PARTICIPANT QUESTIONNAIRE

Participant Questionnaire
Technology Use & Health Information

1. Do you have access to a computer at your home, office, or at another location?

   ☐ Yes ☐ No

2. About how many hours do you use a computer each week?

   ☐ I do not use a computer. ☐ Less than 1 hour.

   ☐ Between 1 and 5 hours. ☐ Between 6 and 10 hours.

   ☐ Between 11 and 15 hours. ☐ Between 16 and 20 hours.

   ☐ More than 20 hours.

3. For what types of activities do you use a computer? (Select all that apply)

   ☐ Sending/receiving e-mail ☐ Word processing

   ☐ Social media (e.g., Facebook, Twitter) ☐ Playing games

   ☐ Other (please specify): ____

4. Do you use a cell phone?

   ☐ Yes ☐ No

5. Do you use a “smart” phone?

   ☐ Yes ☐ No

6. Do you use any other technology on a regular basis? (Select all that apply)

   ☐ I do not use any other technology. ☐ Video game system

   ☐ Computer notepad (e.g., iPad) ☐ DVD or Blu-Ray player

7. When did your first (ALS) symptoms appear?

   Approximate date: ______________________

8. The onset of ALS was:

   ☐ Spinal ☐ Bulbar

9. What is the approximate date you received your diagnosis of ALS?

   Approximate date: ______________________

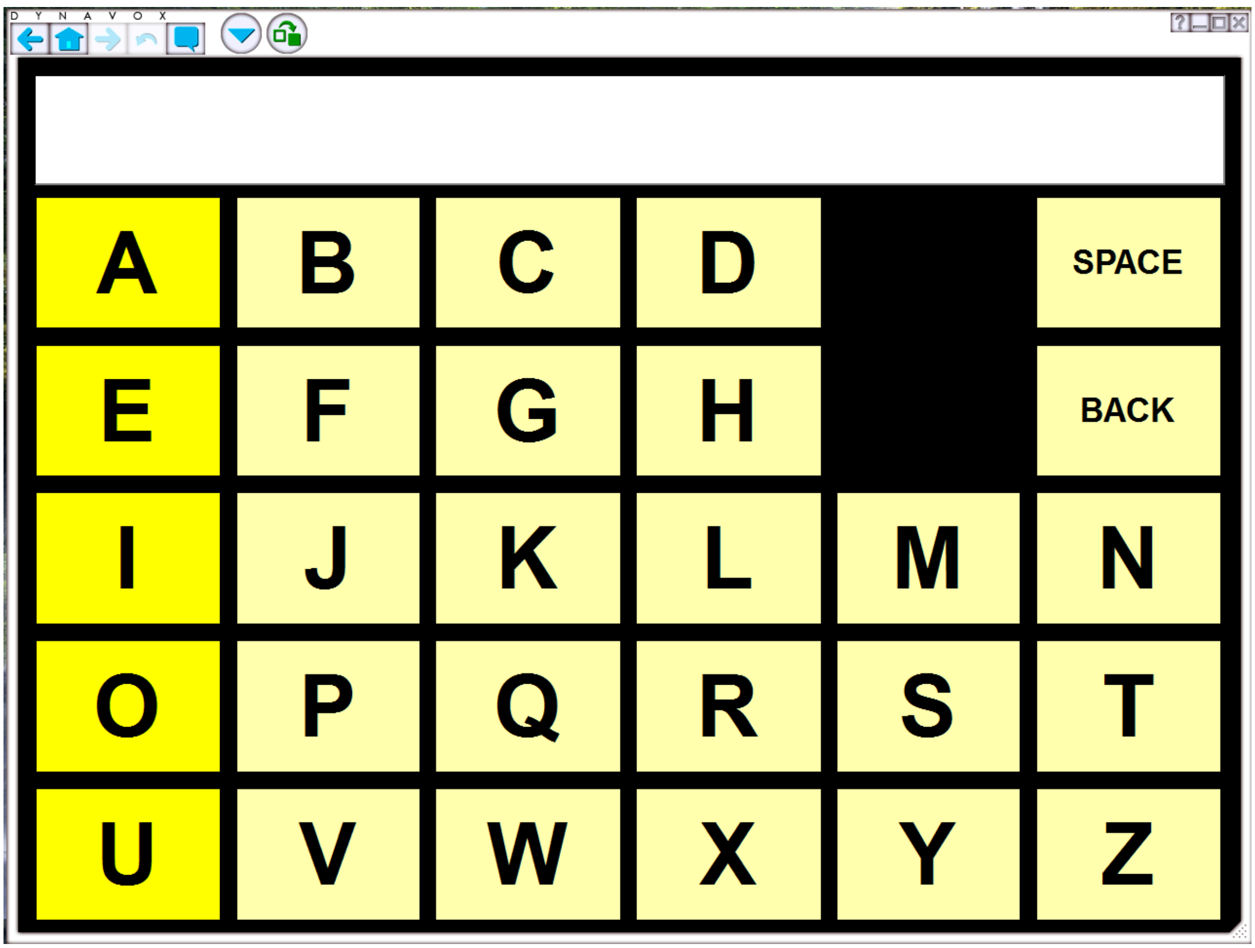
10. Do you have any visual deficits that are not corrected by glasses/contacts?

   ☐ Yes: __________________________ ☐ No

APPENDIX J: KEYBOARD RATING PREFERENCE PAGES

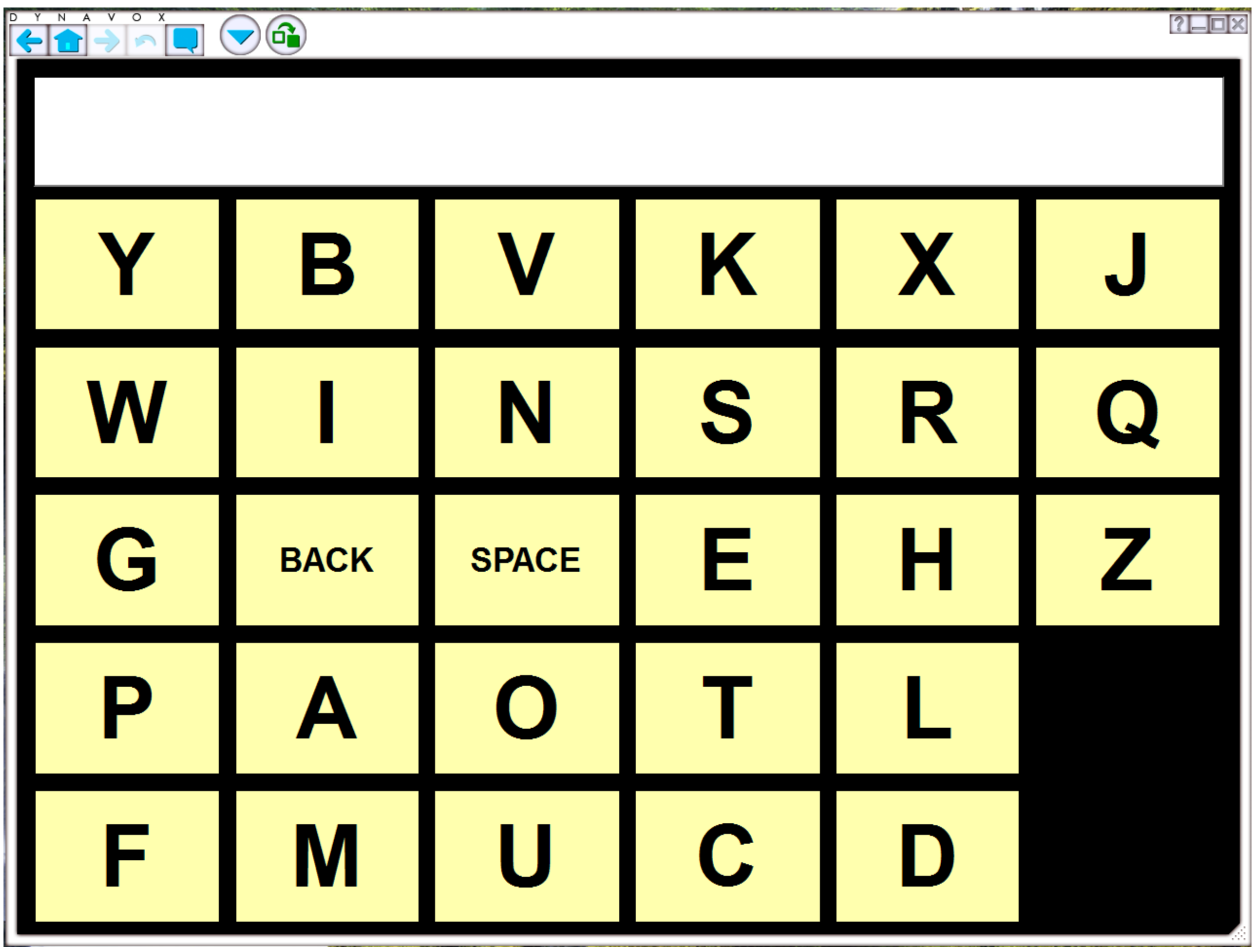
On a 5-point scale, how would you rate this particular keyboard?

1	2	3	4	5
Like a lot	**Like**	**Neither like/dislike**	**Dislike**	**Dislike a lot**



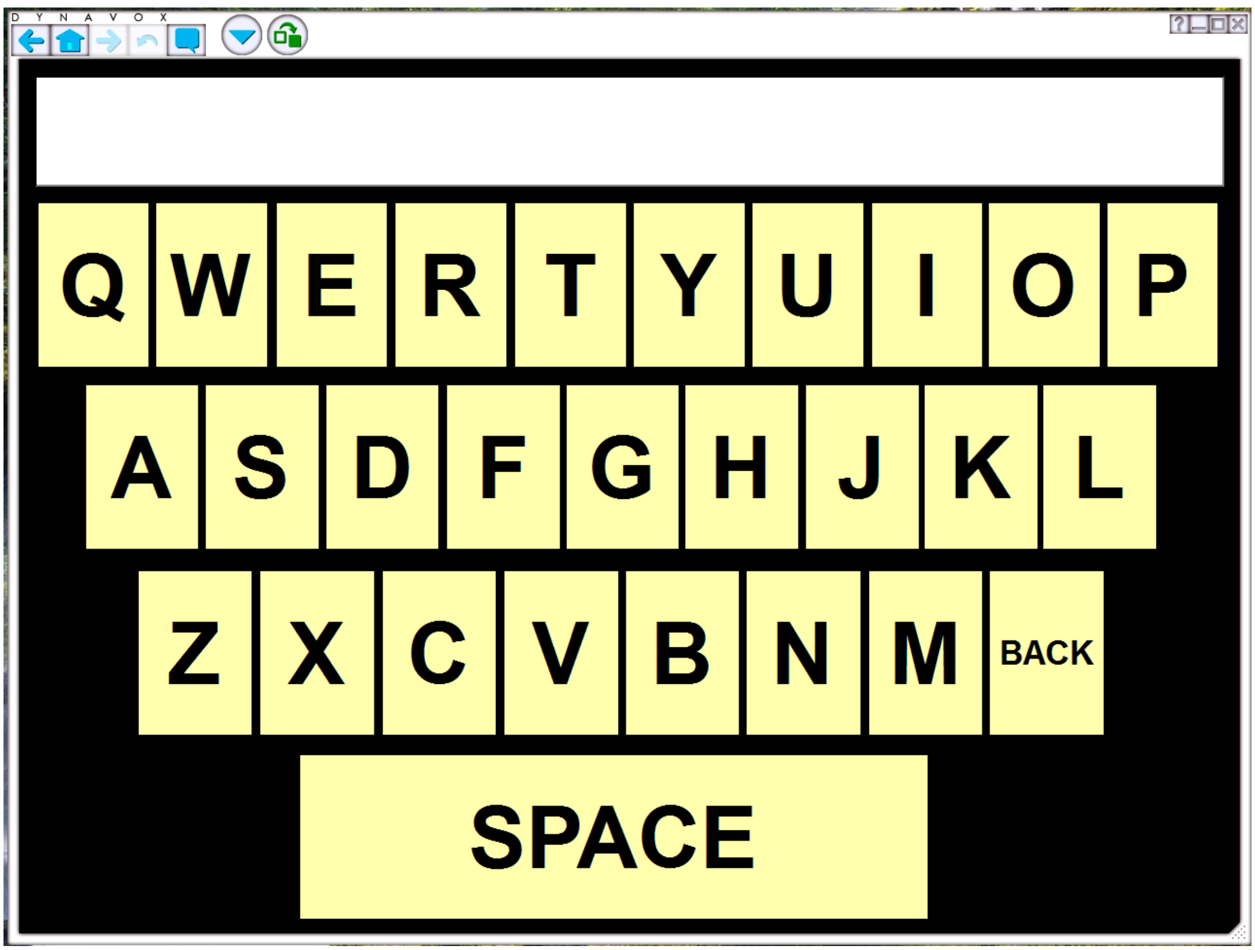
On a 5-point scale, how would you rate this particular keyboard?

1	2	3	4	5
Like a lot	**Like**	**Neither like/dislike**	**Dislike**	**Dislike a lot**



On a 5-point scale, how would you rate this particular keyboard?

1	2	3	4	5
Like a lot	Like	Neither like/dislike	Dislike	Dislike a lot



Please place the keyboards in order of preference, ranking them from 1 (like the best) to 3 (like the least).