Abstract

ANDERSON, ALLISON M. Learning Curve Analysis for Alternative Keyboards. (Under the direction of Dr. Gary A. Mirka).

Although research has shown that alternative keyboards can offer ergonomic benefits over the standard QWERTY keyboard, the simple single-plane QWERTY layout is still the most widely used keyboard design. One of the hypothesized reasons for this resistance to change is the expected time to learn a new layout of the keys or time to become accustomed to a modified keyboard profile/orientation (e.g. split, contoured). To begin to address this concern, the current study was performed to quantify learning rates for four alternative keyboards (a chord keypad, a contoured split keyboard, a Dvorak layout keyboard, and a fixed split keyboard). To gain a deeper understanding of the underlying phenomenon that may lead to differences in learning rate, this study also sought to understand how physical, cognitive, and perceptual demands of the different keyboard design affect this learning rate.

Sixteen proficient typists participated in five, three-sentence typing trials on each alternative keyboard. Time-to-complete and error percentage were collected after every trial, and subsequent learning rates were calculated. Upon completion of each trial, subjects completed a subjective questionnaire that asked them to evaluate the physical, the perceptual, and the cognitive demands posed by each keyboard. Finally, in an effort to assess the quality of the predictions of the learning rate of these five trial sessions, nine different subjects performed the typing trials 20 times on one of the alternate keyboard designs so that a comparison could be made between the learning rate estimate of 5 typing trials and 20 typing trials.

Results demonstrated five trials were sufficient to provide stable estimates of the learning rates for each keyboard. The results also showed that the learning rate for the fixed split keyboard (90.4%) was significantly different (F=23.25, p<0.001) from the learning rates for the other three keyboards (chord: 77.3%, contour split: 76.9%, Dvorak: 79.1%). Previous studies have suggested that cognitive tasks have a learning rate of 70% while physical tasks would have a learning rate of 90%. Our results indicate that the fixed split keyboard was primarily a physical intervention while the other keyboards appear to have both a physical and cognitive learning component. Learning rate was negatively correlated to all types of demand (physical, cognitive, and perceptual), meaning that learning rate was slower with higher demand, regardless of the type of demand.

Productivity is also an important measure when implementing an ergonomic intervention. The average time for the QWERTY trials (control condition) was 40.2 seconds, and the average time for the 5th trial on the split keyboard was 42.4 seconds (5% slower than QWERTY). Also, after 20 trials on the contour split keyboard, subjects were able to type each trial in an average of 44 seconds, within 10% of typing speed on the QWERTY keyboard. These two alternative keyboards utilize the QWERTY key layout but are physically shaped differently to promote more neutral wrist postures. Subjects were able to regain typing speeds on these two keyboards, but trial times were much slower on the other two keyboards given the higher cognitive demands.

This study successfully applied learning curve theory to the implementation of alternative keyboards. The results show that productivity decrements can be quickly regained for the fixed split and contour split keyboard. Many alternative keyboards have

been shown to have ergonomic benefits and the results of this study would indicate that the learning rates associated with some of the keyboard designs are such that they can easily be implemented into the workplace without long-term productivity decrements.

Learning Curve Analysis for Alternative Keyboards

by

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Biography

Allison Anderson was born the youngest of five daughters of Gordon and Judy Marks. Allison grew up in Valrico, FL. In May of 2001, Allison graduated from Brandon High School in Brandon, FL, and decided to pursue a degree in engineering at North Carolina State University. Allison swam distance freestyle for NC State, and was involved in several programs on campus including the Caldwell Fellows Program and Alumni Association Student Ambassador program. Allison also served as a resident advisor on campus for two years. In May 2005, she graduated with a Bachelors of Science in Biomedical Engineering. A few weeks after graduation, Allison married David Anderson, who she was fortunate enough to meet in her first semester at NC State. In the fall of 2005, Allison started working on her M.S. of Industrial Engineering where she had the honor of serving as a research assistant for Dr. Gary A. Mirka. Allison looks forward to graduating in May 2007 and starting her first job as an ergonomics consultant at the Ergonomics Center in Raleigh, NC.

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1. Introduction

One objective of human factors and ergonomics is to design tools and environments to "better match the capabilities, limitations, and needs of people" (p.4 Sanders and McCormick, 1993). Proven benefits of implementing human factors knowledge into design are: increased productivity, decreased error, increased system safety, increased system reliability, and increased user satisfaction and acceptance (Sanders and McCormick, 1993).

There are two sub-disciplines of ergonomics: cognitive ergonomics and physical ergonomics. Cognitive ergonomics deals with mental processes and people's mental interactions with systems. Physical ergonomics deals with how physical and anatomical characteristics affect people's interactions with systems. This paper focuses on the physical and cognitive demands associated with alternative keyboards, and how each of these factors affects learning ability.

1.1 Occupational Musculoskeletal Disorders

Musculoskeletal disorders (MSDs) are conditions that involve the nerves, tendons, muscles, and supporting structures of the body (NIOSH, 1997-1). Work-related musculoskeletal disorders (WMSDs) refer to MSDs that are caused or made worse by the work environment. Physical risk factors for MSDs are: highly repetitive tasks and frequency of movement, force applied/needed, posture (static and awkward), and exposure to vibration (NIOSH, 1997-1; Hargraves et al., 1992). MSDs often occur as a result of the mismatch between the physical abilities of the worker and the work requirements.

Occupational MSDs have a costly impact on society and the individual. It has been estimated that occupational MSDs cost between $13 and $20 billion each year (NIOSH, 1997-1). High-risk industries include nursing, air transportation, mining, food processing, leather tanning, and manufacturing of automobiles, furniture, appliances, electrical products, textiles, and apparel (NIOSH, 1997-1). It is easy to associate MSDs with these highly physical jobs, but many office workers develop MSDs each year as well. According to Hargraves et al., "most people who work in an office know a coworker who has experienced chronic pain or they have experienced it themselves" (p.365 Hargraves et al., 1992). People who sit at a computer each day are exposed to awkward static postures that can affect the upper back, hand, and wrist. MSDs in the office environment more than doubled each year from 1988 to 1992 (BLS, 1994). Between 1988 and 1993 there was a 1000% increase in the number of reported cases of carpal tunnel syndrome (CTS), which is associated with keyboarding tasks (BLS, 1993). In 2003, approximately one quarter of all carpal tunnel cases involving days away from work were caused by repetitive typing or keyentry (BLS, 2003). In order to prevent hand/wrist injuries in the office environment, it is important to understand the causes of these injuries.

There are three main types of hand/wrist region MSDs: carpal tunnel syndrome (CTS), hand/wrist tendinitis, and hand-arm vibration syndrome. Hand-arm vibration syndrome is caused by vibration in the hand/arm from things such as vibrating tools, but it is not a concern with computer work. Hand/wrist tendinitis is inflammation, irritation, and/or swelling of a tendon (NIOSH, 1997-1); it is caused by repetition, force, and posture or a combination of these factors (NIOSH, 1997-1).

Finally, CTS is compression of the median nerve at the wrist, and symptoms of CTS include numbness, tingling, weakness, and/or muscle atrophy in the hand and finger; force, repetition, and vibration can all contribute to cause CTS (Atencio, 1993; NIOSH, 1997-1). CTS is actually the most frequently reported "disorder associated with repeated trauma" (NIOSH, 1997-1). CTS starts with tendinitis (inflamed tendons), and when these inflamed muscles and tendons go through the carpal tunnel, they put pressure on the nerves in the wrist. This added pressure can pinch a nerve (median nerve) and this can cause pain, weakness, tingling, and numbness in the fingers and hand. Treatments for CTS include: wearing wrist splints at night, modifying the work area, job rotation, prescribed anti-inflammatory drugs, and surgery if the case is severe (Atencio, 1993).

There are a number of studies that have explained the relationship between office work and upper extremity MSDs. Gerr et al. followed 632 individuals for three years in jobs requiring 15 hours or more hours each week of computer use. Workers' daily diaries followed work practices and incidence of musculoskeletal pain, and more than 50% of computer users reported musculoskeletal pain within the first year. Computer usage higher than 15 hours per week can contribute to MSDs affecting the upper extremity, shoulder and neck region (Gerr et al., 2002). However, it is difficult to completely estimate computer usage since many people are using a computer at home and at work.

Awkward static and dynamic postures can lead to upper extremity disorders. The complex structure of the wrist allows for a wide range of movement, which also allows for a wide range of problems if misused. When the wrist is in a neutral

position, the tendons are only exposed to tensile load, but when the wrist is bent there are also compressive and frictional forces (Keyserling et al., 2000). The pressure inside the carpal tunnel is elevated when the wrist is extended, ulnarly deviated, or the forearm is pronated past 45° (Marklin and Simoneau, 2001; Serina et al., 1999). A review of 39 epidemiological studies investigating the connection between computer use and MSDs concluded that postures specific to computer workstations such as placing the keyboard below elbow (elbow at 90 degrees or greater), limiting head rotation, and resting the arms can lead to reduced risk of neck/shoulder injuries (Gerr et al., 2006). Minimizing ulnar deviation of the wrist and keyboard thickness appears to result in reduced risk of hand/arm outcomes (Gerr et al., 2006). Since the use of computers is prevalent, it is necessary to learn more about prevention of musculoskeletal problems.

1.2 Office Environment

A properly designed computer workstation is one key to reducing risk of occupation related musculoskeletal problems in the office environment. Risk factors that may negatively affect health are: working positions, workstation components, and work process. OSHA has developed a workstation checklist so anyone can generally evaluate his or her own workspace. Overlooking any of these components in workstation design can be detrimental to employees' health (OSHA, 2004; Sanders and McCormick, 1993).

Proper workstation setup includes correct posture and correct support in order to promote a neutral body position. If the body is neutrally aligned, muscles and tendons are more likely to stay healthy. The body should be in 90 degree

angles (elbow joint, hip joint, knee joint), so forearms and thighs are almost parallel to the floor. The head should be relaxed and in line with the torso. The back and thighs should be supported with proper cushioning. Feet should be flat on the floor or on a foot rest (Figure 1).

Figure 1: Correct posture for seated work environment (OSHA, 2004)

Workstation components such as monitors, keyboards, mice, and chairs should be positioned to support a neutral posture. That means the most used components should be closest to the body in order to reduce awkward postures while reaching. Monitors should be placed so that the top of the monitor lines up with a 0-20° line of sight to reduce neck flexion. As mentioned earlier, chairs and keyboards should be placed at a height in order to produce 90° angles with the body (a neutral posture). Furthermore, high frequency typists should consider keyboard height and placement distance to minimize frequent and awkward reaches.

Finally, computer workstation users should know how to recognize task hazards and warning signs of musculoskeletal problems. Even if computer workstations are set up correctly, typists may still be affected by long periods of typing with high repetition and static postures. Working with computers has become

such a large part of our culture that most people accept possible risk associated with computer work because of the normalcy of the task (OSHA, 2004).

1.3 Overview of Ergonomic Interventions for Office Environment

There are several types of ergonomic intervention strategies for office work, but the main goal of any intervention is to improve the health and safety of employees in the workplace. The recommended order of implementation of ergonomic interventions is engineering controls, administrative controls, and personal protective equipment (Goetsch, 2005). Engineering controls are executed by transforming the problem at the source by changing the workstation, changing the tool, or changing the task to better protect workers. Preventing a problem at the source is the best way to keep people safe in the workplace. However, it is not always feasible or cost-efficient to change the problem at the source, so changing the worker's job through administrative controls or adding personal protective equipment are other possible strategies. Administrative controls are policies that are implemented in the workplace to limit employee exposure to potentially harmful conditions (Goetsch, 2005). No matter what type of ergonomic intervention is implemented, the goal is still the same: to reduce exposure to recognized risk factors for MSDs.

1.3.1 Administrative Controls

Administrative controls are an important type of ergonomic intervention for the workplace since many MSDs can be caused by long time periods of repetitive motions (e.g. typing). Examples of administrative controls are required rest breaks, changing jobs, job rotation, rotating schedules, work shifts, short rest breaks or

micro breaks, and stretch breaks for increased blood flow. Perhaps the most important administrative standard is to educate employees about ergonomic workstations, MSDs, early warning signs, and preventative solutions (Goetsch, 2005; OSHA, 2004). Some companies simply post signage with proper workstation setup, a list of stretches, and warning signs such as pain and weakness in the wrists. Simple practices can be implemented to help keep employees healthy.

1.3.2 Engineering Controls

There are a number of engineering controls that can be applied to computer workstations. It is important for people to carefully setup a workstation since 8 hours or more each day are spent working there. The components within the workstation that can be added, moved and/or changed are: monitor, keyboard, mouse, wrist/palm rest, document holder, desk, chair, new lighting, and telephone (Aaras et al., 1998; NIOSH, 1997-2; OSHA, 2004). Objects used most frequently should be placed in close reach. Improper placement of any of these components can cause awkward postures, repetition, and contact stress. Aside from relocating items in the workstation, objects can also be changed. Among the most common changes are keyboards, chairs, and lighting (Aaras et al., 1998). Alternative keyboard designs are an interesting ergonomic intervention and are the focus of the current study.

1.3.3 Keyboards

Keyboards are the most frequently used computer input device, and most people have at least some contact with a keyboard everyday. Proper placement (height and distance), design and use, and key usage are important characteristics to consider for computer keyboard typing. Common measures used to evaluate

keyboards are posture, discomfort, keying force, and user acceptance (Hargraves et al., 1992; Sanders and McCormick, 1993).

Alternative keyboard designs can differ from the standard QWERTY keyboard by physical shape of the keyboard (including slope, lateral inclination, rotation, splitting keyboard in halves) and physical location of keys (Cakir, 1995). Keys should be placed in rows to best fit human capacity, and the shape of the keyboard should reduce tendon workload and awkward static postures. Ergonomic keyboard designs should efficiently utilize muscles involved in keying, optimize tactile feedback, reduce static postures, and assist with the visual recognition of keys. Design factors affecting static postures are: keyboard size and shape, wrist and arm support, and key layout (Hargraves et al., 1992). Consideration should also be given to key travel, key shape, inter-key distance, keying frequency, keyboard shape, and key assignment when considering efficient use of executive muscle groups (Hargraves et al., 1992). Using the body more efficiently reduces the risk of overused muscles, thus reducing risk for MSDs.

1.3.3.1 Standard QWERTY keyboard

The standard QWERTY keyboard refers to both the Q-W-E-R-T-Y layout of the keys and the standard flat profile of the keyboard. The QWERTY key layout was developed over 100 years ago to deliberately slow typists because the mechanical machinery in a typewriter could not keep up with typists' speed (Dvorak, 1943). Sholes developed the standard QWERTY keyboard expecting typists to "hunt and peck," but most proficient typists do not use that method of typing (Dvorak, 1943).

Therefore, the design parameters for the original typewriter keyboard are obsolete in today's society (Gopher and Raij, 1988).

The main design problems of the standard QWERTY keyboard are poor shape (single plane profile of the keyboard) and poor key allocation. Both problems promote awkward postures that can lead to MSDs. Because the standard QWERTY was designed for one or two finger typists, the keyboard does not efficiently assign keys to fingers and some fingers are overworked (Dvorak, 1943); the weaker (left) hand and weaker fingers typically type the most commonly used letters (Sanders and McCormick, 1993; Dvorak, 1943). Only 32% of typing is done on the home row of the standard QWERTY keyboard (52% on upper row and 16% on lower row). A more efficient keyboard would place the most used letters on the home row (Dvorak, 1943).

The profile of the standard keyboard promotes awkward postures such as abduction of shoulders, pronation of forearms, extension of wrists, and ulnar deviation of wrists shown in Figure 2 (Fagarasu et al., 2005; Hargraves et al., 1992; Simoneau et al., 1999; Simoneau et al., 2003; Swanson et al., 1997). Simoneau et al. 1999 examined 90 office workers to quantify the wrist and forearm postures of conventional keyboard users and found that wrist position was far from neutral. For the left wrist, typing posture resulted in a mean ulnar deviation of 15°, mean wrist extension of 21°, and mean forearm pronation of 62°. For the right wrist, typing posture resulted in a mean ulnar deviation of 10°, mean wrist extension of 17°, and mean forearm pronation of 66° (Simoneau et al., 1999; Simoneau et al., 2003). Muscles can generate a maximum force in a resting posture, so improved posture

will exploit muscle force capability; the flat, non-adjustable shape of the standard

keyboard does not effectively use the length-tension relationship in muscle force

generation (Hargraves et al., 1992). Several alternative designs have been

designed to address these problems, and are outlined in the following sections.
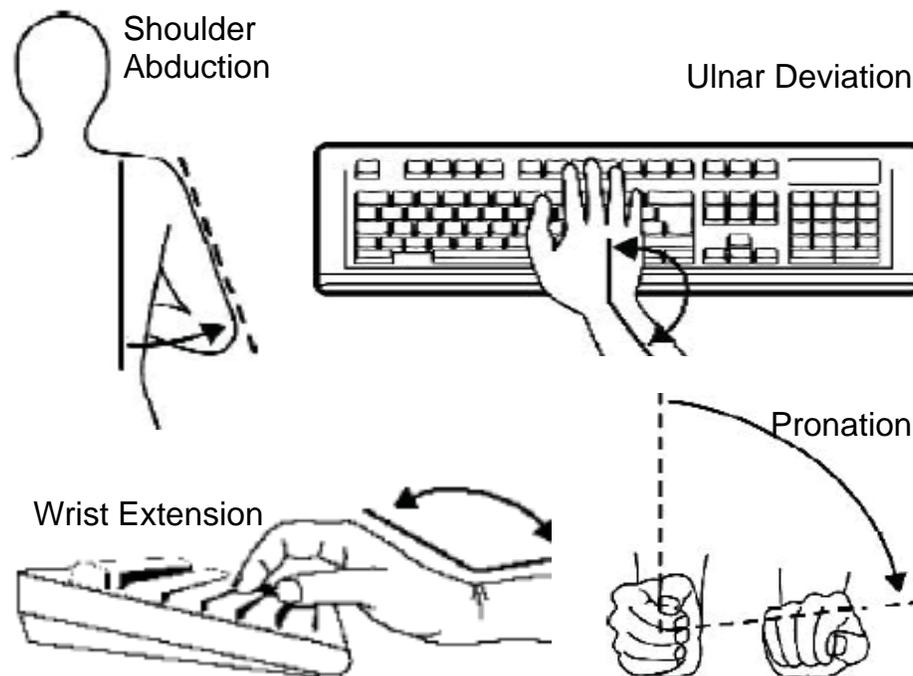
Figure 2: Postures promoted by the standard, flat keyboard (NIOSH, 1997-2)

1.3.3.2 Fixed Split Keyboard

The most basic alternative keyboard is a fixed split QWERTY keyboard

(Figure 3). The keyboard is split into two halves separated at the B-N, G-H, and T-Y

character keys and angled to form a slight v-shape. Split keyboards can differ from

standard keyboards on three planes: lateral inclination, rotation, and slope shown in

Figure 4 (Swanson et al., 1997). The goal of changing lateral inclination is reduction

of forearm pronation, the goal of changing the rotation angle is a reduction of ulnar

deviation, and the goal of changing the slope angle is a reduction in wrist extension

(Marklin et al., 2004). Several combinations of angle adjustments to each of these

planes have been tested (Baker and Cidboy, 2006; Cakir, 1995; Fagarasanu et al., 2005; Honan et al., 1995; Marklin et al., 1999; Nakaseko et al., 1985; Rempel et al., 2007; Simoneau et al., 1999; Simoneau et al., 2003; Smith et al., 1998; Zecevic et al., 2000).
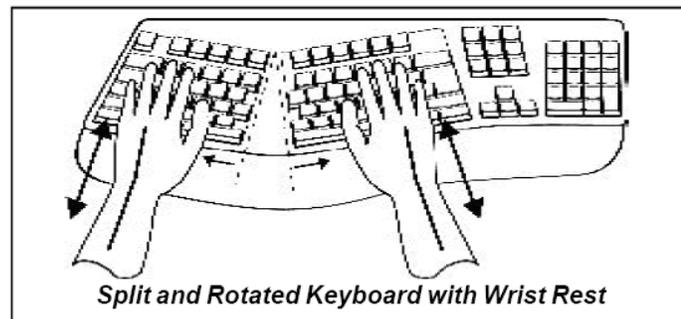
Figure 3: Fixed split keyboard (NIOSH, 1997-2)
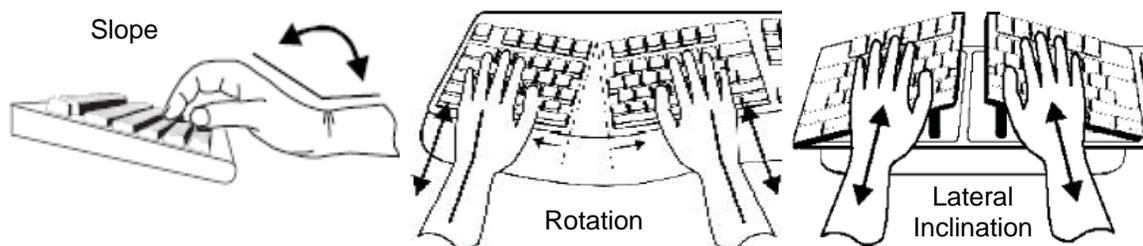
Figure 4: Planes for adjustment on split keyboard (NIOSH, 1997-2)

Typing postures on the standard keyboard are far from neutral, and these awkward postures can be avoided with a split keyboard. Split keyboards that either open to shoulder width or have a rotational angle of 10°-12.5° (Figure 3) position the wrist with neutral unlnar/radial deviation (Fagarasanu et al., 2005; Honan et al.,1995; Marklin et al., 2004; Zecevic et al., 2000). Fagarasanu et al. tested 30 subjects who could type at least 25 words per minute on 2 split keyboards, one fixed split keyboards with a rotational angle of 10°-12.5°and one contour split keyboard. They found these alternative keyboards promoted more neutral wrist ulnar/radial deviation (2005). In addition, a downward slope angle of 7.5° neutralizes wrist extension, and

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a lateral angle of 20°-30° reduces forearm pronation (Marklin et al., 2004). Postural benefits also lead other benefits such as increased comfort and decrease muscle activity.

Neutral wrist postures correspond to decreased muscle activity in the hand/wrist area and upper back (Marklin et al., 2004; Szeto and Ng, 2000). Szeto et al. tested10 subjects who typed for 30 min and found the normalized RMS values of EMG on the extensor carpi radialis was 7.4% MVC for the split keyboard and 8.1% MVC on the standard keyboard; the extensor carpi ulnaris EMG values were 9.4% with the split keyboard and 10.5% with the standard keyboard (Szeto and Ng, 2000). Extensor carpi ulnaris muscle activity was significantly lower on the fixed keyboard, but there was no significant difference in muscle activity for the extensor carpi radialis. These muscles are important in maintaining static wrist posture, while the flexor digitorum sublimis, flexor digitorum profundus, and extensor digitorum communis are prime movers of finger joints. In addition to the hand muscles, slight but significant decreases in muscle activity in upper trapezius and anterior deltoid have been reported for a fixed rotational angle keyboard (Strasser et al., 2004).

Since split keyboards can improve wrist postures and decrease muscle activity, corresponding decreases in pain and increases in comfort have been found. Cakir tested 26 subjects with two split keyboards with varying angles of rotation and found that both setups improved postural comfort, but most users needed up to 2 weeks to feel completely comfortable with the design (1995). Tittiranonda et al. found that 80 computer users with MSDs using alternative keyboards in the workplace had improved hand function and decrease in pain after six months (1999).

However, Swanson et al reported no significant differences in discomfort between a standard keyboard and alternative keyboards over a two day period, but reported discomfort was low in general (1997). Level of discomfort reported varies with the experience and health of the subject.

Split keyboards generally have ergonomic benefits over the standard flat keyboard, but these improvements usually come with some short-term decrease in productivity. Faragasanu et al. tested 30 subjects and found that when typing with the fixed split keyboard it reduced mean typing force by 58%, and after only 8 hours of training, subjects were able to type at 89% of their productivity on a standard QWERTY keyboard (2005). Skilled typists can regain productivity losses on split QWERTY keyboards typing within 10% of baseline productivity in several hours (Fagarasanu et al., 2005; Swanson et al., 1997; Zecevic et al., 2000). Fifty female clerical workers were able to type near initial QWERTY speed (within 10%) after a two day testing period (Swanson et al., 1997). After 10 hours of training, 16 subjects were able to type at 89% productivity (Zecevic et al., 2000). Little time is needed to regain typing speed on alternative keyboards, and typists may even be able to surpass QWERTY typing speed given the postural benefits of alternative keyboards.

1.3.3.3 Contoured Fixed Split

The contoured split keyboard is another alternative to the standard keyboard. The keyboard is split into two halves at shoulder width distance and keys are physically located in a bowl shape (Figure 5). The concave bowl shape was created to minimize travel distance for the fingers while placing the hands in a more neutral, safe working posture (Fagarasanu et al., 2005; Gerard et al., 1994).
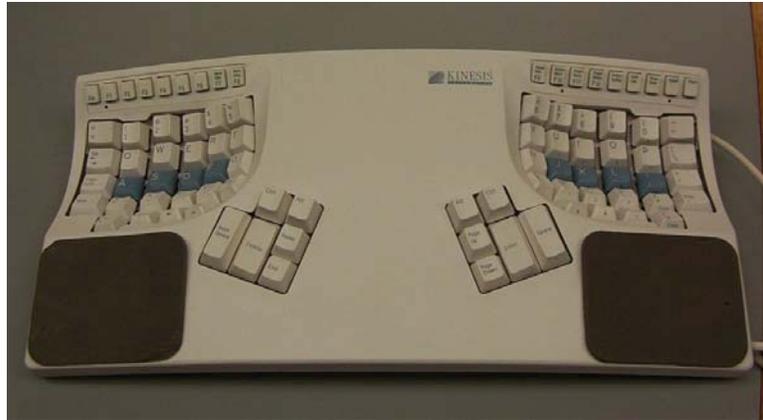
Figure 5: Kinesis ergonomic keyboard

The contour split keyboard has a unique shape that places the hand and wrist in a more neutral posture. It has been subjectively rated higher for comfort and preferred by typists over the standard keyboard (Chen et al., 1994; Smith and Cronin, 1993). Chen et al. tested 11 subjects with 4, 5 minute trials. Although subjects typed slower on the contour split keyboard than the QWERTY keyboard, it was subjectively rated higher for comfort. Furthermore, Smith and Cronin (1993) tested 25 subjects who could type at least 45 wpm with random letter typing for 2 hours. These subjects also preferred the contour split keyboard more than the QWERTY keyboard for comfort and usability. In the same Fagarasanu et al. study mentioned earlier (section 1.3.3.2), mean typing force was reduced by 42% for the contoured split keyboard compared to the standard keyboard (Fagarasanu et al., 2005). In the same Smith and Cronin study, 11 of the 25 subjects were tested for muscle activity in the extensor carpi ulnaris (used for ulnar deviation), flexor digitorum sublimis, and extensor digitorum (used for hand extension), pronator radii teres (used for pronation), and the deltoid. All muscles showed lower activity when using the contour split keyboard, but muscle activity in the extensor carpi ulnaris and the extensor communis digitorum was significantly lower. Gerard et al. (1994) tested

6 professional typists on 24, five minute trials. The muscle activity in the flexor carpi ulnaris, the extensor carpi ulnaris, the extensor digitorun communis, and the flexor digitorum sublimus was measured, and muscle activity in all of these muscles was significantly lower using the contour split keyboard than the QWERTY keyboard. Therefore, muscle activity in the muscles used for ulnar deviation and hand extension was significantly lower when using the contour split keyboard (Gerard et al., 1994; Smith and Cronin, 1993). The contoured split keyboard is another alternative to the standard QWERTY keyboard because it promotes a neutral wrist and hand posture, but users generally need more time to adjust to the shape of the keyboard than that of the fixed split keyboard (Fagarasanu, 2005; Smith and Cronin, 1993).

Several studies have reported typing speed on the contour split keyboard. Six professional typists were able to type with 72% of baseline QWERTY speed after 23 five minute trials (115 minutes) (Gerard et al., 1994). However, in another study, during pilot work 5 test subjects who were able to type 45 wpm or more were able to type at 86% productivity within an hour of using a contour split keyboard (Treaster et al., 2000). The unique shape of the contour split keyboard may impose initial typing challenges, but experienced typists can regain speed quickly and experience postural benefits (Gerard et al., 1994; Treaster et al., 2000). Initially, typing speed slows and error rate increases while typing on a contour split keyboard, but these improve with more experience (Chen et al., 1994; Fagarasu et al., 2005; Smith and Cronin 1993; Swanson et al., 1997).

1.3.3.4 Dvorak keyboard

The two keyboards described in the previous two sections have different physical geometry than the standard keyboard, but still maintain the QWERTY layout of the keys. The Dvorak keyboard, on the other hand, has the same physical shape as the standard keyboard, but letters are in different locations. Any keyboard can be changed to a Dvorak keyboard layout by placing tabs over keys and adjusting computer settings to reflect the Dvorak layout. Unlike the other alternative keyboards in this study, there is no research on the ergonomic benefits of using the Dvorak keyboard layout. No studies were found that specifically measured improvements in hand posture and muscle activity. Most Dvorak keyboard studies are more concerned with efficiency of typing.

Fifty years after the Sholes keyboard layout was established (the QWERTY design), August Dvorak realized that the placement of letters was obsolete because typewriter technology had advanced and machinery was able to keep up with exceptional typists (>100wpm). Therefore, he sought to design a more logical and efficient key layout. The simplified Dvorak keyboard was designed on the basis of data relative to the frequency of use of different letters and the frequency of two, three, four, and five letter sequences. All vowels and most frequently used consonants are on the home row of the Dvorak layout. This allows for faster typing since there is a high probability of vowels and consonants alternating (Martin, 1972; Dvorak, 1943). With the Dvorak keyboard layout, the right-hand does 56% of the typing versus 43% on the standard keyboard. Furthermore, 70% of typing is performed on the home row (where fingers naturally lie), minimizing movements for

fingers. Figure Figure 66 show how fingers are loaded with the Dvorak layout and the QWERTY layout. Typing errors with the Dvorak layout typically occur for long words with complicated spelling. Dvorak claimed that his keyboard layout could improve typing speed by 35%, and typists surveyed agreed they would not go back the QWERTY layout after learning the Dvorak layout (Dvorak, 1943). However, Norman and Fisher had 12 university students who could type 25 words per minute or less type 10 minute trials on each of three alternative alphabetical keyboards. On the Dvorak keyboard layout, subjects only typed about 5% faster than the standard QWERTY keyboard (1982). These authors concluded while novice typists may gain from the 5% increase in typing speed, it may not be as worthwhile for expert typists to invest time in learning the Dvorak layout (Norman and Fisher, 1982).
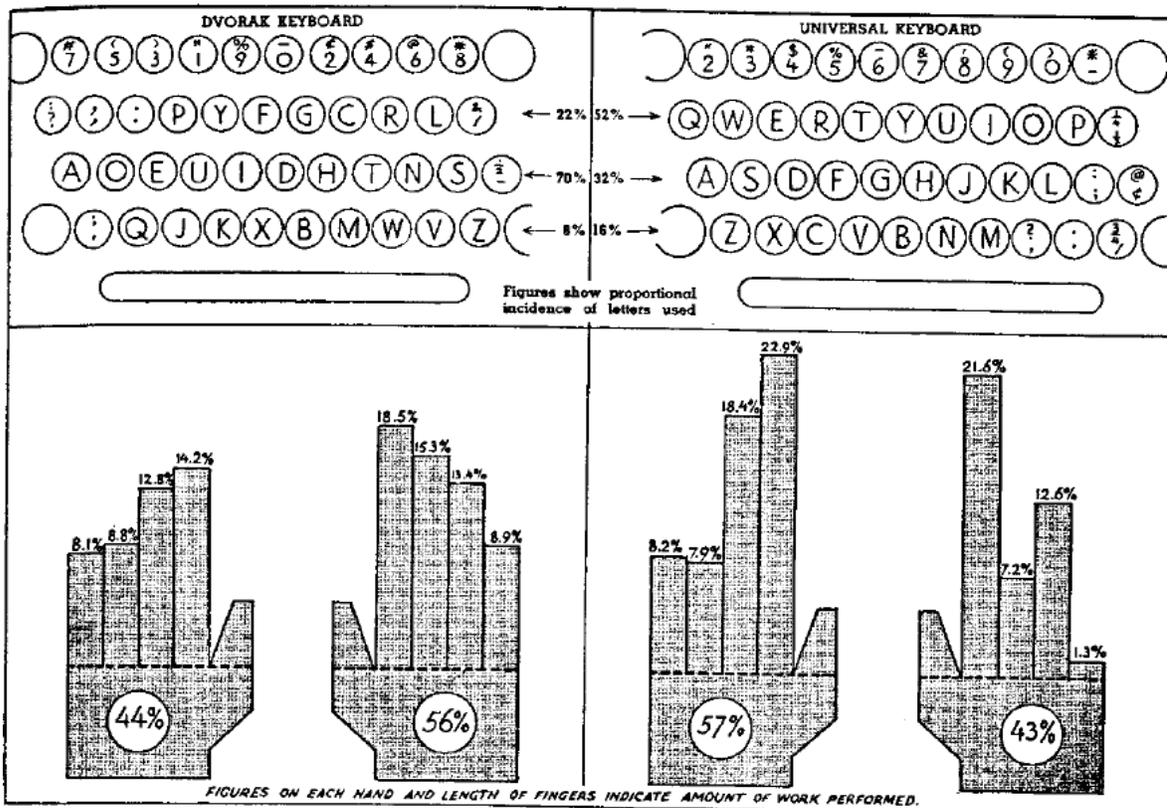
Figure 6: Comparative finger loads on the Dvorak keyboard (left) versus the standard keyboard (Dvorak, 1943)

Although Dvorak proved his layout to be superior to the QWERTY layout, it was unfortunately never accepted by the general population. Most people would have to relearn this layout and many are unwilling to do so. Visual search time of unfamiliar organization of keys has a greater effect on search time than placing several letters on each key (e.g. cell phone), so a new Dvorak keyboard user's typing speed will most likely be slowed by large visual search time (Sears et al., 2001). Although the Dvorak keyboard layout reduces finger travel and promotes faster typing speeds, there is little research to prove the ergonomic benefits of learning this new layout.

1.3.3.5 Chord Keyboard

The chord keyboard has both a unique location for keys/letters and a unique physical shape as compared to the standard QWERTY keyboard. Chord keyboards have far fewer keys than the standard QWERTY keyboard. On a chord keyboard, each letter has a specific key combination (single key or multiple keys) that are simultaneously pressed, similar to chords in music. Several different chord keyboards have been developed and tested (Beddoes and Hu, 1994; Eliam, 1989; Gopher and Raij, 1988; Kroemer et al., 1992). Chord keyboards can either be one-handed or two-handed, but most models are designed for one-hand use.

Although the chord keyboard is distinctly different from the standard QWERTY keyboard, the design principles address some of the fundamental problems of the standard keyboard and allow for a larger range of users. The chord allows users to type with one hand and complete other tasks with the other hand

(talk on phone, etc); also, it allows people with one limb to type all keys with one-hand users. Fingers always rest on home keys and do not move, as compared to the QWERTY which requires complicated finger and hand paths. Since chord keyboards are also small, they take up less desk space and are more transportable. The spatial patterns for the chord keyboard are organized guidelines and less complicated to identify and memorize; they also have many internal overlaps that assist in their reconstruction as opposed to the QWERTY keyboard that is composed of several isolated elements (Gopher and Raij, 1988; Hargraves et al.,1992; Noyes, 1983). The shape and key allocation on the chord keyboard are distinctly different than the standard QWERTY keyboard.

Most research on chord keyboards focuses on performance. In one study, ten subjects from the university population were able to memorize 59 chords for a two-handed chord keyboard (eight keys, one for each finger) within about 3 hours. Subjects attended 2 hour sessions each day for two weeks; the first week was the learning phase, and the second week was the testing phase. The average typing speed after 40 trials with 400-500 characters was 70 characters per minute (Kroemer et al.,1992). The same keyboard was used for a one-handed chord keyboard study (the left side was disabled), and five subjects were taught 18 chords. After an initial training phase, subjects were able to reach a typing speed of 170 characters per minute (cpm) after 60 hours of use (McMulkin and Kroemer, 1994). On a two hand chord stenograph with 10 keys (one for each finger and thumb), five subjects were able to type up to 53 words per minute (wpm) after only 40-50 hours

of training. These typing speeds were approximately within 10% of the subjects'

typing speeds on the QWERTY keyboard (Beddoes and Hu, 1994).

Subjects with no typing experience have also been investigated for chord

keyboard typing efficiency. Gopher and Raij tested fifteen subjects with no typing

experience and placed them into one of three groups: QWERTY, one-handed chord

keyboard, two-handed chord keyboard (the two-handed chord was two separate

one-hand chord keyboards, each could stand on their own). After 35 one-hour

training sessions, chord users could type 160 cpm (about 32 wpm) while QWERTY

users could only type about 105 cpm. For subjects with no typing experience, the

chord keyboard had a higher learning curve than the QWERTY keyboard (Gopher

and Raij, 1988). The chord keyboard has many benefits over the QWERTY,

especially for people with no typing experience.

1.3.3.6 Challenges with New Keyboards

One of the main objectives of this study is to provide insight into why

alternative keyboard are not used. Although there were several alternative keyboard

designs available, the QWERTY keyboard was standardized in 1966 (Hargraves et

al.,1992). The main reasons alternative keyboards have not been adopted are: cost,

initial productivity decrements, the learning process, and perspective of the user

(Gopher and Raij, 1988; Hargraves et al.,1992). Alternative keyboards are often

considerably more expensive than flat QWERTY keyboards, so postural benefits

must be shown to prevent injury or increase productivity to provide justification for

the initial keyboard cost. As presented in the previous sections, research has shown

significant postural and muscular benefits with several alternative keyboards. There

is a much larger population of keyboard users now than when many alternative

keyboards were introduced, and if the QWERTY remains the standard keyboard the

cases of MSDs, specifically CTS, will most likely continue to grow.

Since the QWERTY keyboard is the standard, most people have invested

time in learning and typing proficiently with it and are resistant to learn a new skill

since the standard keyboard is sufficient (Eliam, 1989). The transition to a new

keyboard is more difficult for skilled typists than novice typists because they have to

learn new motoric patterns (Cakir, 1995; Gopher and Raij, 1988; Martin, 1972).

Most studies reported subjects typed the fastest on the standard QWERTY

keyboard. Therefore, it is important to study the learning curve for alternative

keyboards to quantify the learning process and to assess the costs and benefits

associated with implementing alternative keyboards.

1.4 Learning Curve Theory

When a novel task is performed repeatedly, an individual acquires

experience. According to Teplitz, experience is a result of the following: becoming

familiar with the task, becoming familiar with the procedures and interactions with

other objects, improved manual dexterity, developing shortcuts to the task at hand,

developing a rhythm and pattern to the task, and reduced occurrences of stop and

start actions caused by errors in quality (Teplitz, 1991). Learning curve theory

provides a structured, mathematical approach to predicting how task time decreases

with more repetitions. It can be used to show how long it will take for a person to

reach a given level of performance on a task. As tasks become more complex,

learning time lengthens. The general learning curve calculation used to calculate

the rate that a worker learns to complete a task is (Konz and Johnson, 2000):

$Y_x = KX^N$

Learning rate: 2^N

Y_x: production time for Xth unit in sequence

K: time required for first unit

N: exponent leading to learning rate (2^N)

X: number of production units

Most tasks have elements of both cognitive and physical learning. Dar-El et

al. (1995) suggested a dual-phase learning model where in the early stages of the

model, cognition is the dominant factor; in later stages after more repetitions,

physical skills are the limiting learning factor. In this particular model, the learning

constant is not fixed, making the model complicated. While distinguishing cognitive

and physical learning in a model may be quite useful, the authors indicate that a

single and less complicated learning model could also explain the results (Dar-El et

al., 1995).

Productivity is important in manufacturing, and therefore several learning

rates for manufacturing tasks have been quantified in literature. The best estimate

for cognitive learning rate is .7, while physical is .9, but the combined learning rate is

somewhere in between (Konz and Johnson, 2000). For example, sorting cards into

compartments has a learning rate of .83 (83%), while machining and fitting small

casting has a learning rate of .74 (74%). In manufacturing where speed is very

important, studying learning rates for tasks gave insight on which manufacturing

processes needed to be studied to possibly improve efficiency (Konz and Johnson, 2000). In the same way, it is important for office workers to interact with environment in a way to maximize comfort and efficiency.

Researchers have quantified productivity of typing on alternative keyboards against a baseline QWERTY measure, but none have linked learning rates to physical, cognitive, and/or perceptual demands with learning rate. Dvorak extensively studied his new keyboard layout and the acquisition of that typing skill set, but technology and keyboard user population have changed since his research. Some chord keyboards have been studied with regard to learning rate, and have been graphically expressed, but researchers have not specifically quantified a learning rate with the learning curve formula (Gopher and Raij, 1988; Kroemer et al., 1992). Furthermore, some researchers have produced a best fit curve to the productivity curve to predict learning rate (Gerard et al.,1994; McMulkin et al.,1992). Therefore, this study will formally evaluate learning rate for four alternative keyboards.

1.5 Objectives of This Study

The objective of this study is to quantify learning rates for four alternative keyboards (fixed split, contour split, chord, and Dvorak) and understand how physical, cognitive, and perceptual demands affect learning rate by quantifying these measures.

Cognitively demanding tasks generally have slower learning rates than more physical tasks, and since the key allocation is unique on the Chord and Dvorak keyboards, it is hypothesized that learning rates for these keyboards will be slower

than the two alternative QWERTY keyboards. Physically demanding tasks have a learning rate close to 0.9, and since the physical location of the keys on the split keyboard is only slightly different than the standard keyboard, it is hypothesized that the split keyboard will have the highest learning rate.

2. Methods

2.1 Subjects

Twenty-five subjects (14 male, 11 female) were recruited from the university

population through word of mouth. Subjects ranged in age from 18-30 with an

average age of 24 years. The subjects were required to sign a university approved

Informed Consent Form (see Appendix A). All subjects were right-handed with

20/20 or corrected 20/20 vision. Potential subjects were excluded from study if they

had current or chronic back, shoulder, neck, or wrist pain. To reduce variability in

the data, subjects were required to be proficient typists and type of at least 25 words

per minute (Fagarasanu et al.,2005; Szeto et al., 2000); proficient typists were

assumed to be at steady state in QWERTY typing ability.

2.2 Equipment

2.2.1 Testing Equipment/ Keyboards

Subjects were tested on five keyboards for this experiment (Figure 7): 1)

standard QWERTY keyboard, 2) fixed split keyboard (Microsoft Natural, Microsoft

Corporation, Redmond, WA), 3) split contoured keyboard (Kinesis Ergonomic

keyboard, Kinesis Corporation, Bothell, WA), 4) Dvorak keyboard, and 5) chord

keyboard (BAT personal keyboard by Infogrip, Inc., Ventura, CA). The workstation

was setup according to HFES/ Standards (ANSI), and subjects were given foot rests

as needed (Figure 8). The fixed split keyboard (Microsoft Natural) has a split/

rotational angle of 12° and lateral inclination 10°. The contour split keyboard (Kinesis

25

ergonomic keyboard) had a split/ rotational angle of 12°, lateral inclination 20°, and

has 27cm between keypads for each hand.

Figure 7: Five keyboards were used in this study: standard QWERTY (not pictured), chord (top left), contoured split (top right), Dvorak (bottom left), fixed split (bottom left)
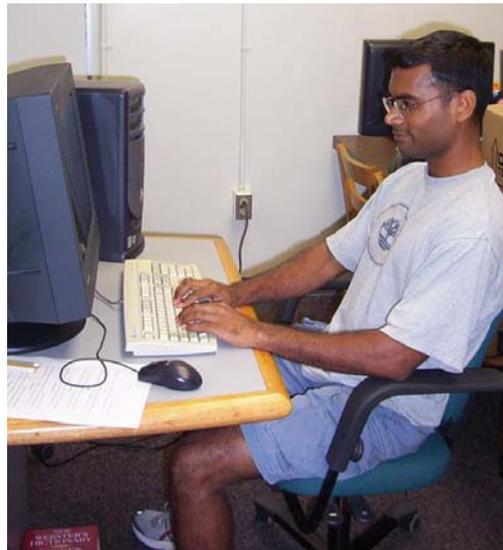
Figure 8: Experimental set-up

2.2.2 Data Collection Equipment

The typing trials were performed on a computer using the freeware typing program Stamina 2.0. After each trial, the experimenter recorded completion time (minutes, seconds), error percentage, and typing speed (characters per minute). The Stamina 2.0 software forces the typist to type the passage correctly. The passage moved across the screen in a line as typing progressed, and no movement occurred if the wrong key was pressed. The trial passage contained 225 characters including spaces and had all letters of the alphabet (according to frequency of use, Table 1), two commas, and three periods (Ridley et al.,1999). Table 1 shows the percentage of letter use in written work (Ridley et al., 1999), the percentage of letter use in the actual passage, and the difference between the two.

Table 1: Letter frequency

	Ridley	passage	difference		Ridley	passage	difference
A	7.89	8.33	-0.44	N	7.23	6.11	1.12
B	1.04	1.67	-0.63	O	7.68	7.22	0.46
C	3.43	2.22	1.21	P	2.34	1.67	0.67
D	3.6	4.44	-0.84	Q	0.37	0.56	-0.19
E	12.27	12.78	-0.51	R	6.04	6.11	-0.07
F	2.34	1.11	1.23	S	6.97	5.56	1.41
G	1.77	1.67	0.10	T	10.27	9.44	0.83
H	3.96	6.67	-2.71	U	3.12	2.78	0.34
I	7.86	7.22	0.64	V	1.21	1.11	0.10
J	0.14	0.56	-0.42	W	1.41	1.67	-0.26
K	0.53	1.11	-0.58	X	0.26	0.56	-0.30
L	3.87	4.44	-0.57	Y	1.44	2.22	-0.78
M	2.86	2.22	0.64	Z	0.1	0.56	-0.46

Subjective assessment data (Figure 9) were also collected. Subjects were asked to rate each alternative keyboard in comparison to the standard keyboard on an analog scale in three categories: physical demand, cognitive demand, perceptual

demand (see Appendix B). The survey was based on the form of the NASA-TLX

questionnaire (Hart and Staveland, 1988). Subjective assessments have previously

been adapted from the NASA-TLX (Ma, 2002). The visual analog scale was five

inches long, and a midline at 2.5 inches represented the QWERTY keyboard (any

score above 2.5 is rated "higher" in demand than the QWERTY keyboard and any

score lower than 2.5" is rated "lower" in demand than the QWERTY keyboard).

Figure 9: Subjective assessment of perceived workload

2.3 Experimental Design

2.3.1 Independent Variables

There was one independent variable, (KEYBOARD type) with four levels:

fixed split, contoured split, Dvorak, and chord.

2.3.2 Dependent Variables

The dependent variables in this study were: learning rate and demand. Cognitive demand, physical demand, and perceptual demand were all investigated.

2.4 Protocol

Each experimental session lasted approximately two hours. Sixteen subjects participated in the learning rate generation protocol, while nine more participated in the learning rate verification protocol. The experimental protocol checklist and experimental explanation are presented in Appendix C. Upon arrival, the subject was given a brief overview of the study objectives and protocol and was asked to sign the informed consent form. The experimenter confirmed that the subject was eligible to participate.

After the subject signed the informed consent form, the experimenter setup the adjustable workstation appropriately for each subject (using ANSI 100 guidelines). The subject was seated at 90° angles for the back, elbow, and knee. The top of the screen was adjusted to be in line with the horizontal line of sight. Footrests were supplied if needed. The experimenter explained the protocol in more detail. Once the subject understood how to use the typing program, experimentation began.

Each subject typed the same three sentence passage with Stamina 2.0 software for every typing trial. Subjects typed the same passage so only keyboard learning rate was assessed (and not the learning time for becoming familiar with the passage). Before typing trials, the subject was given one minute to review the passage. The subject was asked to type the passage ten times on a standard

QWERTY keyboard and to type as quickly as possible in order to record a baseline

QWERTY typing speed and allow the subject to memorize the typing passage. The

subject was given 15 seconds rest between each typing trial. Once the subject

finished the typing trials on the standard QWERTY keyboard, the subject typed the

same passage five times on each alternative keyboard (order of keyboard

presentation was completely randomized). The subject was briefly instructed on

how to use each keyboard and was given a "cheat sheet" showing specific letters

represented on each key for both the Dvorak and chord keyboards. After each set

of five trials, the subject completed a survey (Appendix B) and was then given 3

minutes rest.

2.4.1 Part 2: Learning Rate Verification

Nine additional subjects were asked to participate in testing to verify that five

trials were sufficient for learning rate calculations. Each subject performed 10 trials

on the QWERTY keyboard and 20 trials on one alternative keyboard. The subject

was given 15 seconds rest after each trial and 3 minutes in between each keyboard.

The subject was given one additional minute after each set of five trials on the

alternative keyboard. Three alternative keyboards were tested (chord, Dvorak, and

contour split) but each subject only experienced one alternate keyboard. The fixed

split keyboard was not used for this experiment as the learning rate because

subjects could type within 5% of baseline QWERTY speed with only five trials.

Therefore, there were three subjects that used each alternative keyboard.

2.5 Data Processing

2.5.1 Learning Rate

Learning rate represents the change in task performance time as a function of trial number. The standard calculation for learning rate was used, where the time for trial 1 and time for trial 5 are used to create the learning curve (Konz and Johnson, 2000) as calculated from the time-to-complete data. Here is an example of how learning rate was calculated for this experiment:

$$Y_x = KX^N$$

Learning Rate: 2^N

Y_x: production time for Xth unit

K: time required for first unit

N: exponent leading to learning rate (2^N)

X: total number of units produced

For example, say the time for the first trial is 86 seconds (K=86), and the time for the fifth trial is 50 seconds (Y=50), the learning calculation is

$$50 = 86(5)^N$$

$$\text{Log}(50/86) / \text{Log}(5) = N = 0.337$$

$$2^{-0.337} = 0.79$$

which is a learning rate of 79%.

2.5.2. Subjective Assessment Data

To provide a subjective assessment of each keyboard, subjects rated each keyboard along 3 dimensions. A visual analog scale was used and the length of the

continuous rating line was five inches, with a midline representing the standard

QWERTY keyboard at 2.5 inches (Figure 10). Each rating was measured from the

midline and given a score ranging from -40 to 40 (80 possible points, each point

representing 1/16 inch from midline). The scores were then normalized for each

subject across each category of demand for all keyboards (Ma, 2002). The largest

deviation from the center point was given a score of 1 (high) or -1 (low) depending

on the direction of deviation. For example, say for a particular subject the survey

score for physical demand on the fixed split keyboard is 1.5" away from the midline

in the negative direction. This would correspond to a score of -24. However, score

with the largest deviation in physical demand was the chord keyboard with a score of

32. Therefore, the physical demand score for the fixed split keyboard would be -

0.75   (-24/32), and the physical demand score for the chord keyboard would be 1

(32/32). Survey scores were normalized in order to reduce subject variability.
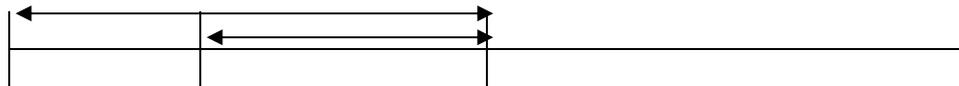
Figure 10: Analysis of survey question data

Low   High

2.6 Statistical Analysis

2.6.1 ANOVA

Analysis of Variance (ANOVA) was used to evaluate the effect of keyboard on

learning rate. All of the analyses were performed with SAS 9.0 (Cary, NC). The

assumptions of ANOVA were tested and confirmed using the graphical approach

described in Montgomery (2004). Three assumption tests were evaluated:

homogeneity of variance, normality, and independence of observation (see

Appendix D results). Homogeneity of variance was tested by plotting predicted

values of learning rate versus residual values of learning rate. These plots must

show no patterns or structure in order to use ANOVA. Normal probability plots of the

residuals were constructed in order to evaluate the distribution of the residuals.

Since the error is normally distributed, the plot resembles a straight line. Finally, the

independence assumption was tested to show proper randomization for the

experiment. The residuals were plotted in time order to ensure no definite trends or

patterns and that the experiment was sufficiently randomized (Montgomery, 2004).

Since the data met the assumptions, in all ANOVA analyses a p-value of less than

0.05 was the standard for significance. A Tukey-Kramer post hoc analysis was

performed to further evaluate keyboard effects.

Learning rate was analyzed with a one-way ANOVA. The linear statistical

model for this experiment was:

$$y_{ijk} = \mu + \tau_i + \beta_j + (\tau\beta)_{ij} + \varepsilon_{ijk}$$
$$i = 1 - 4, Keyboards$$
$$j = 1 - 16, Subjects$$

This equation represents a mixed model, where τ represents the fixed effect

(keyboard) and β represents the random effect (subject).

2.6.2 Correlation Analysis

Correlation analysis was used to determine how physical demand, cognitive

demand, and perceptual demand related to learning rate. The survey scores were

normalized by category for each subject across all four alternative keyboards. To

examine interactions specifically between physical demand, cognitive demand, and

perceptual demand, the scores were added (pd+cd, pd+p, cd+p, pd+cd+p) and

analyzed. Each survey category (pd, cd, p, pd+cd, pd+p, cd+p, pd+cd+p) was tested in SAS to find possible correlations between learning rate and demand (Pearson correlation coefficients and p-values were calculated).

3. Results

The range in QWERTY typing speed for all subjects was 170 cpm – 474 cpm (about 34 wpm – 95 wpm, assuming an average of 5 letters per word).

3. 1 Learning Rate

There were no violations for the homogeneity of variance, normality, or independence assumptions. The results of the subsequent ANOVA procedure showed a significant effect of keyboard type on Learning Rate (F=23.25, p<.001) (Figure 11). The learning rate for the split keyboard was 90.4% and significantly different from the learning rates for the other three keyboards which all had learning rates of less than 80% (chord: 77.3%, contour split: 76.9%, Dvorak: 79.1%).
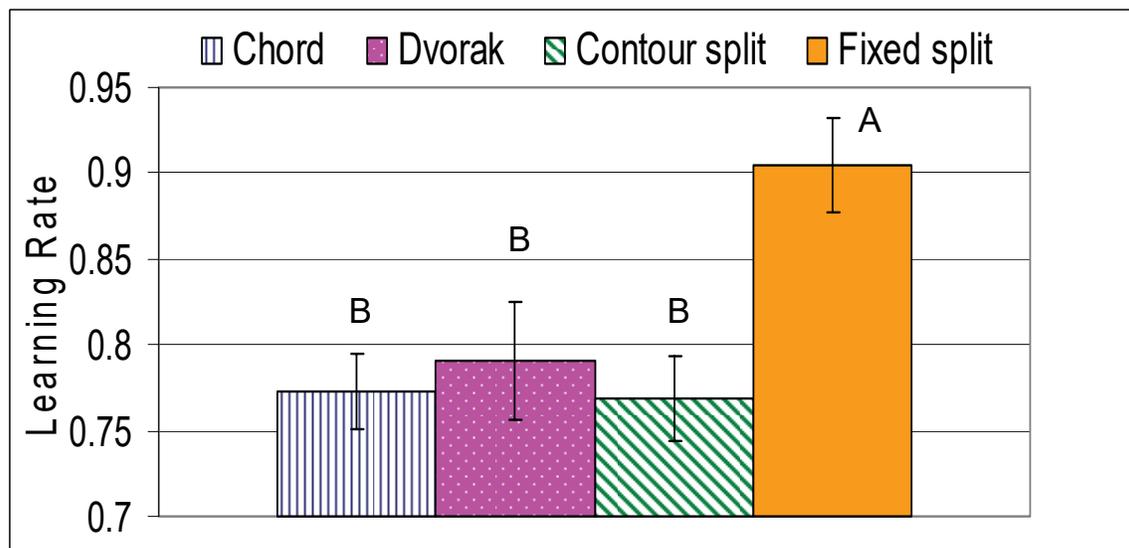
Figure 11: Learning rate by keyboard type. Columns with the same letter were not statistically different.

Figure 12 shows the average time across subjects to complete each trial. The actual values of time for each trial, percent time for each trial, and percent error are in Table 2. The trials for the two keyboards that were not the QWERTY layout (Dvorak and chord) were much slower than the other two alternative keyboards with

the QWERTY layout. The average time for the QWERTY trials was 40.2 seconds, and the average time for the 5th trial on the split keyboard was 42.4 seconds (only 5% slower than QWERTY).
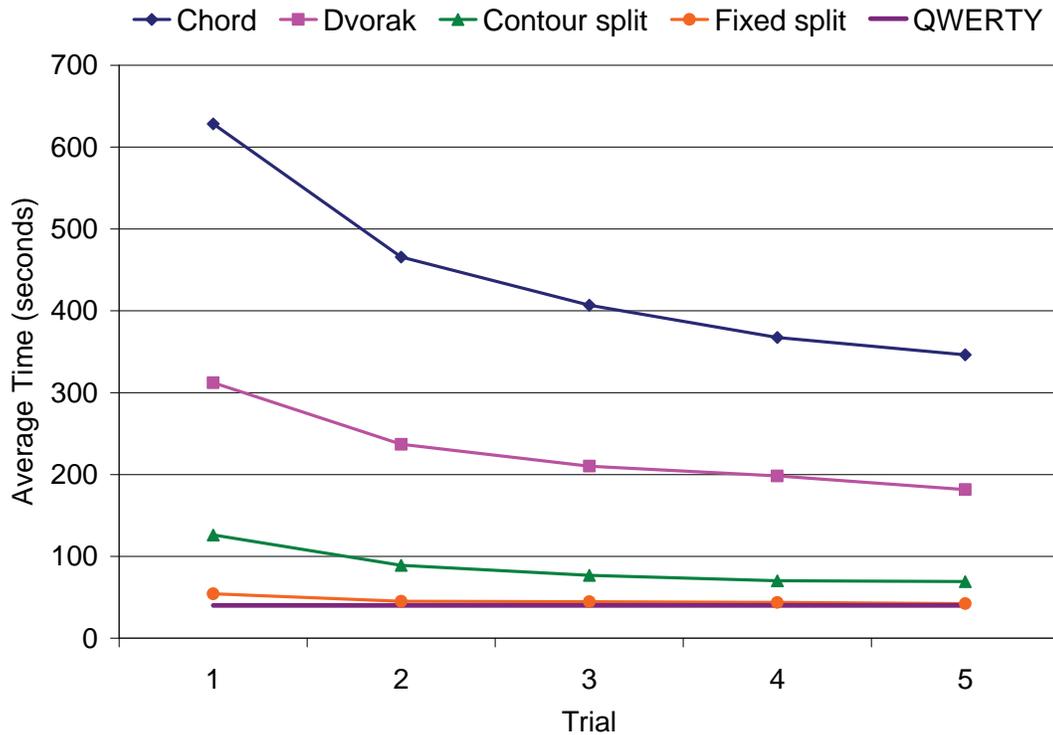
Figure 12: Average time to complete trials

Figure 13 shows the average error for each trial. Subjects had much higher error percentages with the chord keyboard than the other three keyboards. Error rates declined with each trial on the chord, Dvorak, and contour split keyboards, but there is little change in error rates on the fixed split keyboard.
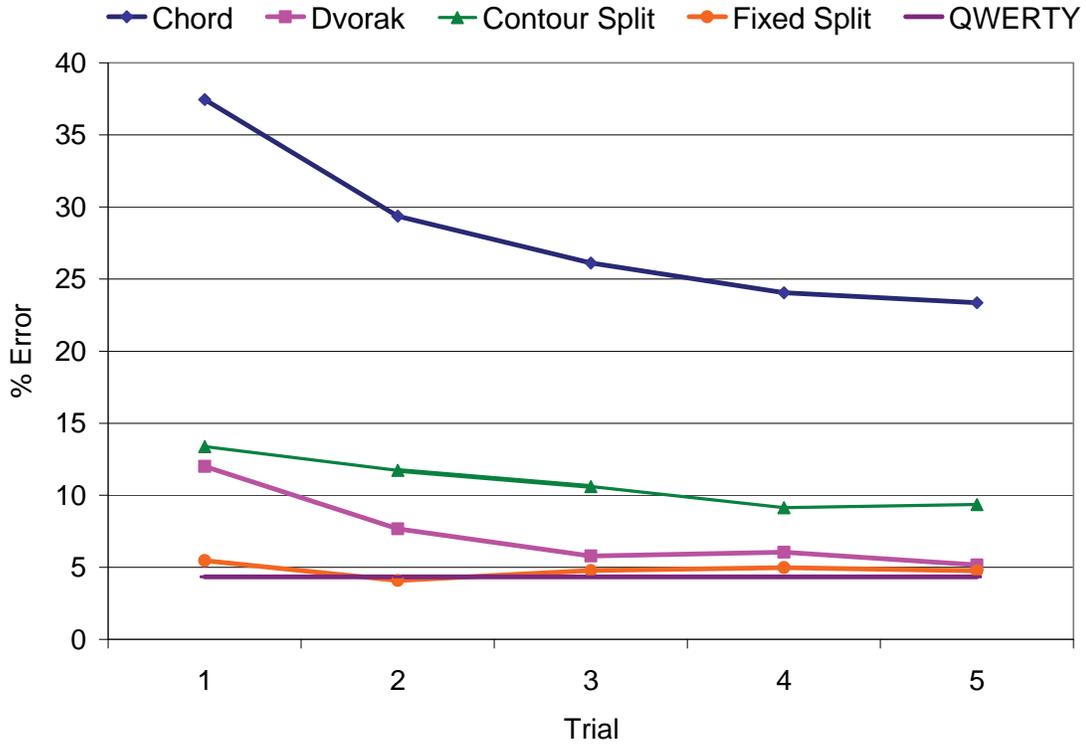
Figure 13: Average percent error for each trial

Table 2: Time (seconds), % time, and % error for each keyboard

Chord			Dvorak		
time (sec)	% time	% error	time (sec)	% time	% error
628	100	37.5	312	100	13.4
465	74.6	29.4	236	71.2	11.7
406	65.2	26.1	210	60.5	10.6
367	58.9	24.1	198	55.1	9.1
346	55.3	23.4	181	54.6	9.4
Contour Split			**Fixed Split**		
time (sec)	% time	% error	time (sec)	% time	% error
126	100.	12.0	54	99.6	5.5
89	76.6	7.7	45	82.5	4.1
76	67.6	5.8	44	82.1	4.8
70	63.7	6.1	43	81.5	4.9
69	58.6	5.2	42	79.2	4.8

Figure 14 shows the percent time to complete each trial, with trial 1 as the slowest

(set at 100%). This shows comparable performance improvements (learning curves)

for each keyboard. The fixed split keyboard learning curve is much flatter than the

other three keyboards, so the learning rate is much higher (90%). This means that fewer trials are needed to reach baseline QWERTY speed on the fixed split keyboard than on the other three keyboards. The most significant drop in time for trials one to two is for the Dvorak keyboard (almost 30%).
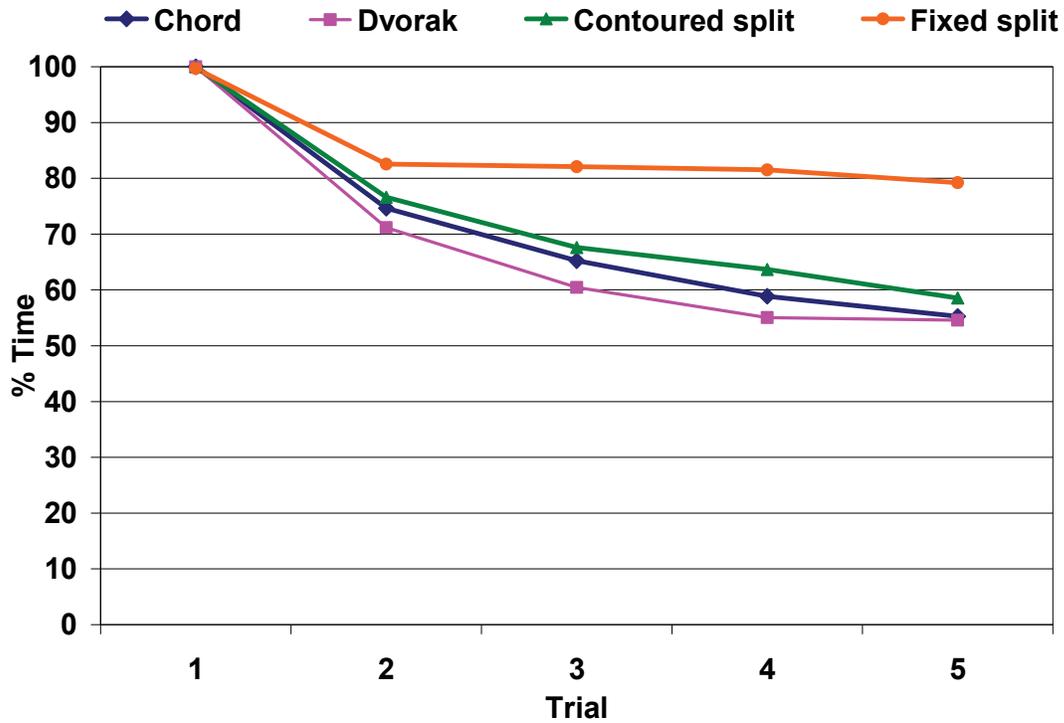
Figure 14: Average time to complete each trial

Figure 15 and Table 3 show data from the second part of experimentation wherein subjects performed the 20 trials on the three alternative keyboards. The goal was to compare the calculated learning rate after 5 trials with that of 20 trials to provide evidence that 5 trials were sufficient to generate a stable estimate of the true learning rate. Table 3 shows the results of this testing, and these tests confirmed that for the subjects who complete 20 trials, 5 trials were sufficient because there is no statistical difference in the means of learning rate for 5 and 20 trials. For each

trial, there is less than 2% difference in the mean learning rate of 5 trials and 20

trials.

Table 3: Analysis of learning rate

Learning Rate	5 trial		20 trials		p-value
	Mean	St Dev	Mean	St Dev	
Chord	0.77	0.075	0.78	0.037	0.43
Contour Split	0.79	0.076	0.79	0.053	0.50
Dvorak	0.86	0.048	0.86	0.013	0.46

Figure 15 shows the gradual flattening of the learning curves with more trials. On

the contour split and chord keyboards, the 20th trial was on average 60% faster than

the first trial. This is a large improvement for less than an hour of typing time with

the keyboard.
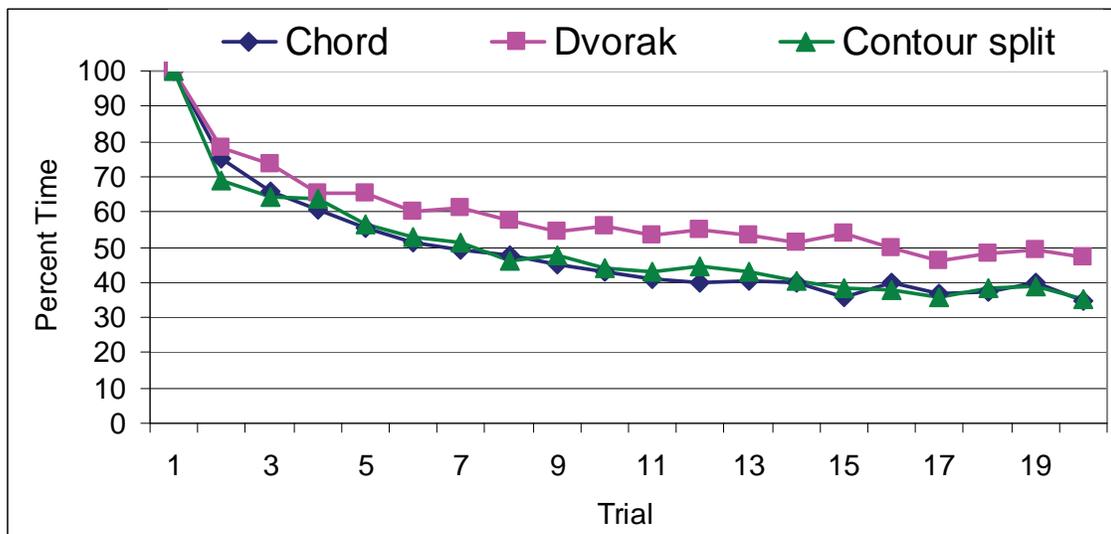
Figure 15: Average percent time to complete 20 trials

The time to complete 50 trials and 100 trials was estimated using the learning rates

for each keyboard. Since the average time for subjects on the QWERTY keyboard

was 40 seconds, these results show that given enough practice on the fixed split and

contour split keyboards, subjects could possibly surpass their productivity on the

QWERTY (Table 4) in relatively little time (less than 50 trials).

Table 4: Estimated time to complete

	Actual Time		Estimated Time		
	5 trials	20 trials	20 trials	50 trials	100 trials
Chord	346.3	195.0	211.3	153.3	120.8
Dvorak	181.8	138.7	118.4	89.9	73.4
Contour split	69.1	44.0	41.4	29.8	23.3
Fixed split	42.4	--	--	32.3	29.8

3. 2 Subjective Assessment of Demands

All of the subjective assessment parameters (Table 5) significantly correlated with learning rate. The negative correlation means that a higher survey score relates to a lower learning rate. Therefore, more demanding tasks (whether the challenge is cognitive, physical, or perceptual) correspond to slower learning.

Table 5: Correlation results

	Correlation Coefficient	P-value
Cognitive	-0.43	<0.001
Physical	-0.33	0.0073
Perceptual	-0.29	0.0209
Cognitive*Physical	-0.45	<0.001
Cognitive*Perceptual	-0.41	<0.001
Physical*Perceptual	-0.37	0.0023
Cognitive*Physical*Perceptual	-0.45	<0.001

There were statistically significant differences in demand for each of the keyboards (F=11.19, p<0.001). The average normalized survey scores (Table 6: Average normalized survey scoresTable 6 and Figure 16) show that most subjects felt the chord keyboard was the most cognitively and physically demanding while the Dvorak keyboard was the most perceptually demanding. The chord keyboard was significantly more cognitively demanding than the other three keyboards, and the contour split and Dvorak keyboards were significantly more cognitively demanding than the fixed split keyboard. The chord keyboard was rated as statistically more

physically demanding than the fixed split keyboard. Finally, the Dvorak keyboard

was significantly more perceptually demanding than the contour split and fixed split

keyboards. The chord keyboard was also significantly more perceptually demanding

than the fixed split keyboard. The fixed split keyboard was rated to be almost the

same as the QWERTY in every category (score 0), but subjects rated it slightly

physically less demanding than the QWERTY.

Table 6: Average normalized survey scores

	Cognitive	Physical	Perceptual
Chord	0.88	0.61	0.60
Dvorak	0.49	0.35	0.84
Contour Split	0.35	0.31	0.37
Fixed Split	0.05	-0.06	0.03
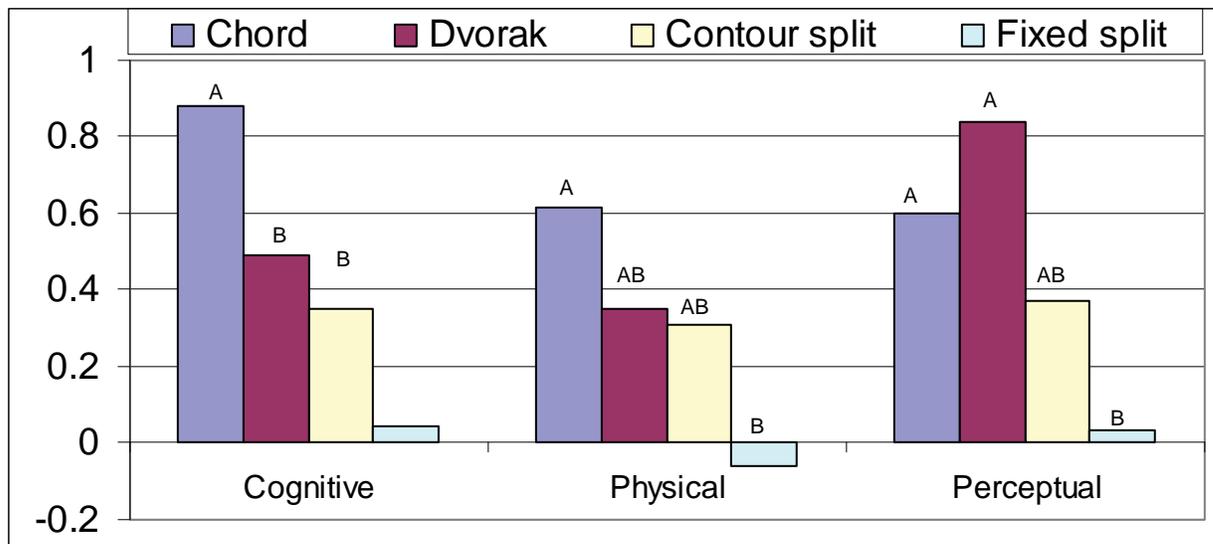
Figure 16: Subjective assessment of the physical, cognitive, and perceptual demands as a function of keyboard type

4. Discussion

Learning time is often presented as a change in productivity. Productivity is an important measure for implementing an ergonomic intervention. If the training time is too long, companies and employees are often not inclined to use interventions (Reid, 2005). The faster/higher the learning rate for a particular intervention or the closer it is to 1 (100%), the faster a person will reach steady state productivity (less training time). While some studies have documented changes in productivity for each of the different keyboards in this study, no research has formally applied learning curve theory to alternative keyboards.

The alternative keyboards produced a range of typing speeds. Typing speed on both the fixed split and contour split keyboards was much faster than typing speed with the Dvorak and chord keyboards. This is almost certainly a result of the unfamiliar key layout on the Dvorak and chord keyboards. The fixed split keyboard had the highest learning rate and smallest productivity decrement with initial use. The objective of this study was to quantify learning rates for four alternative keyboards and quantify how physical, cognitive, and perceptual demands affect learning rate.

4.1 Learning Rate and Subjective Assessment

Learning rate provides a structured, mathematical approach to documenting how task time lessens with more repetitions of a task. It follows the equation $Y=ax^b$. As the learning process occurs, the amount of progress for each trial lessens, but each trial takes less time (Teplitz, 1991). In the same way, when people learn to use alternative keyboards, with more time they are able to type faster. The learning

rates for each keyboard in this study were documented. The learning rate

percentages for each keyboard were: chord 77.3%, contour split 76.9%, Dvorak

79.1%, and fixed split 90.4%. Previous research has estimated that the learning rate

percentage for a physical task is about 90%, while the learning rate for a cognitive

task is about 70% (Konz and Johnson, 2000). The learning rates for the contour

split, chord, and Dvorak keyboards fall between 70% and 90% meaning that these

are both cognitive and physical learning tasks ranging in complexity. Tasks can also

be categorized as simple or complex, with more complex tasks having lower learning

rates. The learning rates for the current study indicate that the chord, contour split,

and Dvorak keyboards have elements of both physical and cognitive learning, while

the fixed split keyboard can be characterized as a physical learning task. Konz and

Johnson compiled learning rates documented in literature for common tasks (Table

7). Complex tasks such as truck body assembly have lower learning rates, while

physical tasks such as screwdriver work have high learning rates.

Table 7: Learning rates for common tasks

Learning Rate	Task Description
68	Truck body assembly
72	Complex 300 hour/unit assembly
80	Precision bench assembly
83	Power sawing
84	Cigar Making
90	Punch press operation
95	Screwdriver work

Since only the physical shape of the keyboard was different (maintained

QWERTY key layout) for the fixed split and contour split keyboards, these were

assumed to be more physical intervention tasks. Given the learning rate of 90.4 %,

the fixed split keyboard was shown to be well-characterized as a physical learning

task. However, the learning rate for the contour split keyboard was 76.9%, far from the expected physical task change learning rate of 90%. This might indicate that the contoured nature of this keyboard required some additional resources beyond a simple physical learning task.

In addition to the quantification of learning rate, this study also attempted to quantify the amount of physical, perceptual, and cognitive demand required for learning each keyboard and tried to relate this demand to learning rate. Demand was asked in the following way:

- Cognitive Demand: How much mental activity required (e.g. remembering, thinking deciding, and planning)?

- Physical Demand: How much physical activity was required (e.g. finger coordination, awkward postures (shoulder, elbow, fingers), muscle force/tension, awkward reaches with fingers)?

- Perceptual Demand: How much perceptual activity was required (e.g. looking, searching, detecting, recognizing, and being aware of the physical location of the keys)?

These survey parameters were adapted from the standardized subjective survey, the NASA-TLX (task load index) survey. The subjective assessment was presented as an analog rating scale in order to capture sensitivity within the amount of demand required for each keyboard. However, in order to tailor the subjective assessment to this study, a midline representing QWERTY demand was added (Figure 10, Figure 11).

The learning for most tasks has both a cognitive and physical learning time (Dar-El, 1995). This is reflected through the correlation analysis between learning rate and subjective assessment, where a higher survey score related to a slower learning rate regardless of the type of demand. Cognitive learning can take more time that learning motor skills, corresponding to a lower learning rate. All of the keyboards tested in this experiment have proven postural and muscular benefits over the standard keyboard, but all were rated higher or the same in physical, cognitive, and perceptual demand during the learning phase. Once subjects were able to reach steady state on each of the keyboards, it would be preferred that each demand rating was less than QWERTY (< 0) on the survey, since the point of alternative keyboards is to be less demanding than the QWERTY. However, this response would most likely not appear during the learning period. Since there were significant differences in quantified demand between keyboards, it shows that the subjective assessment was responsive to differences in physical, perceptual, and cognitive demand on the alternative keyboards.

4.2 Assessment of Alternative Keyboards

4.2.1 Fixed Split Keyboard

The fixed split keyboard is the most basic alternative keyboard. Given that key allocation was the same as the standard QWERTY keyboard, the only difference from the standard keyboard was the physical shape of the fixed split keyboard. The change in shape allows the wrist and hand to be in a more neutral posture while typing. The fixed split keyboard was assumed to be a physical intervention task, and therefore have a higher learning curve than the remaining keyboards. This would

implicate a learning rate around 0.9 (90%) (Konz and Johnson, 2000), and, in fact, the learning rate for the fixed split keyboard was found to be 90.4%, supporting the original hypothesis. The fixed split keyboard had a much higher learning rate than the other three keyboards (all < 80%). Subjects found little difference in demand on the fixed split keyboard from the standard keyboard, as it was rated to be as physically, cognitively, and perceptually demanding as the QWERTY keyboard (score of 0 in Figure 16). These survey ratings corresponded to a high learning rate since there is little difference in demand between the two keyboards. The average rating for physical demand on the fixed split was slightly less than QWERTY, so the different physical shape of the fixed split keyboard was not a large obstacle for most subjects.

The high learning rate on the fixed split keyboard means less learning time and little lost productivity. Subjects quickly regained typing speed on the fixed split keyboard in this study. Subjects were able to type within 5% of baseline standard QWERTY speed with only five trials on the fixed split keyboard. In general, the trials on the fixed split keyboard were one minute or less, so it only took subjects only five minutes of typing to regain baseline typing speed. This is much faster than previously reported studies. Some studies reported typing speed on the fixed split keyboard was within 10% of standard after 8 hours of training (Fagarasu et al., 2005) and 11% after 10 hours of training (Zecevic et al., 2000). In a different study, after two days of a data entry task, subjects were typing at almost the same speed as the standard keyboard (Swanson et al., 1997), but typing speed was measured over a 75 minute work period for this study. Some differences in this study and

those above are the length of each trial and the pool of subjects for each study. By using the learning rate data, time to reach baseline QWERTY productivity can be estimated. The learning rate for the fixed split keyboard predicts that subjects could surpass baseline QWERTY typing speed after only 50 trials, less than 45 minutes of typing. Although it is doubtful that typing speed on the fixed split keyboard would significantly surpass typing speed on the standard QWERTY keyboard, an increase in typing speed could possibly be attributed to decreases in muscle activity needed for typing and more neutral postures. Studies have reported improved comfort with split keyboards in the lab and in the office environment (Cakir, 1995; Tittiranonda et al., 1999). The results of this study illustrate that a fixed split keyboard should be a relatively easy ergonomic intervention to introduce to into the workplace with little learning time for skilled typists, and in fact, this is the most widely accepted alternate keyboard design.

4.2.2 Contour Split Keyboard

The contour split keyboard maintains the QWERTY layout, and only the physical shape of the keyboard is different from the standard keyboard. The unique bowl-shape of the keyboard is said to promote a more neutral typing posture for the hand and wrist. In addition to the fixed split keyboard, the contour split keyboard was assumed to be a more physical intervention task. However, the learning rate for the contour split keyboard was 76.9%, far from the expected physical task change learning rate of 90%. Since the learning rate with the contour split keyboard is much lower than the learning rate on the fixed split keyboard, it takes more trials to reach steady state. The bowl shape (Figure 6) of the contour split keyboard placed the

hands in a 20° lateral incline, and while the keys are in the same general order of the standard QWERTY keyboard (aside from the thumb keys), the keys on the contour split keyboard are not diagonally separated in rows as on the standard keyboard. This may have presented more perceptual demand (looking, searching, detecting, recognizing, and being aware of the physical location of the keys) shown with a normalized survey score of 0.372. Cognitive demand was rated at 0.31, and physical demand was rated at 0.35, showing that subjects found this keyboard considerably more demanding than the QWERTY keyboard. However, these subjective assessment scores were much lower than those on the chord and Dvorak keyboards, but the learning rates for all three keyboards were similar. Therefore, the subjective assessment may not have captured some of the challenges presented with the contour split keyboard.

While the learning rate of the contour split keyboard was the lowest of all four keyboards, the average typing speed on the contour split keyboard at baseline was second in to the fixed split keyboard. Subjects were able to type within 10% of baseline productivity (44.0 sec to 40.2 sec) after 20 trials or about 30 minutes of typing with the contour split keyboard. Subjects also adapted to the contour split keyboard quickly, typing within 10% of QWERTY speed after 20 trials (less than 30 minutes). Other studies with a contoured fixed keyboard have found it takes much longer for subjects to adapt to the alternative keyboard (Fagarasu et al., 2005; Gerard et al., 1994). Gerard et al. found that subjects could type within 72% proficiency within 115 minutes, and after eight hours of training Fagarasu et al. (2005) found that subjects could only type at 44% of speed on a standard keyboard.

However, more in line with the results of this study, Treaster et al. (2000) found that 5 pilot subjects were able to type at 86% productivity within an hour of using the contour split keyboard. Swanson et al (1997) found that after two, 7 hour work periods typing speed on the contour split keyboard was close to baseline QWERTY measures. These authors suggested that previous studies did not have long enough testing period to examine productivity on the contour split keyboard, but subjects in this experiment only needed about 30 minutes (20 trials) to be within 10% of baseline QWERTY.

Previous studies have used several types (in the lab and regular secretarial work) and lengths of typing tasks to quantify typing speed. With the calculation of learning rate, long testing periods are not needed. Using the learning rate calculation, typing speed on the contour split keyboard was estimated to be faster than baseline QWERTY speed after just 50 trials. Since the keys are not lined up diagonally as they are on the standard keyboard, fingers have less travel time (xx pinky and ring finger?). This could possibly allow users to type marginally faster on the contour split keyboard than the standard keyboard. Given similar postural and muscular benefits to the fixed split keyboard, it is unclear what the advantages of the contour split keyboard are over the faster learning time and less demanding fixed split keyboard. The results do show that the contour split keyboard could also be implemented into the workplace with little learning time for skilled typists.

4.2.3 Dvorak Keyboard

The Dvorak keyboard was assumed to be a more cognitive intervention. The location of keys on the Dvorak keyboard is different from the QWERTY setup, but

the physical shape of the Dvorak keyboard tested in this experiment was the same as the standard flat QWERTY keyboard. The Dvorak keyboard was rated high in all three demand categories. The learning rate for the Dvorak was 79.1% while a learning rate closer to 70% was expected (Konz and Johnson, 2000). However, the main cognitive process required for the Dvorak keyboard was memory because of different letter locations. There was little information processing needed. This could account for the higher than expected learning rate. While the Dvorak keyboard was thought to be a more cognitive intervention, the physical location of the keys was different. This proved to be more physically challenging than the QWERTY keyboard, which could be a result of subjects lack of proficiency forcing them to perform "hunt and peck" typing (since they had not memorized the order of the keys). Performing "hunt and peck" operations is more physically demanding that touch typing. The Dvorak keyboard was rated the most perceptually challenging (score of 0.84) than the other three keyboards, and significantly more challenging than the contour split and fixed split keyboards. Subjects were constantly looking, searching, and struggling to be aware of the physical location of the keys as in the definition of perceptual demand, so the perceptual demand rating was not surprising. There was probably some amount of negative transfer for this task, since subjects were proficient QWERTY typists and expected keys to be in that location. Because the shape of the Dvorak keyboard tested in this experiment was the same as the QWERTY, subjects seemed to automatically try to type with the QWERTY layout and had to really focus to use the Dvorak layout. This keyboard was also more cognitively challenging than the QWERTY keyboards (score of 0.49).

Trial times were much slower on the Dvorak keyboard given the high levels of perceptual and cognitive demand. Dvorak claimed that once subjects were proficient with the Dvorak keyboard they typed 35% faster (Dvorak, 1943). However, other studies suggested that novice typists were at most 5% faster with the Dvorak keyboard, and it would not be worthwhile for expert typists to learn the new layout (Norman and Fisher, 1982). In current study, subjects were able to type the trial in 138 seconds (99 cpm), over a minute and a half slower than trials with the QWERTY keyboard. The estimated trial time after 100 trials is 73 seconds, still much slower than the standard QWERTY keyboard. It is unclear how much training and how many trials would be necessary to reach baseline QWERTY typing speed. There are proven benefits with the Dvorak layout (less finger travel time, improved finger loading), but it is unclear if it would be worthwhile for proficient QWERTY typists to learn this layout. It is possible to join the physical benefits of the fixed split or contour split keyboards with the Dvorak layout, and therefore the benefits of both types of alternative keyboards could be utilized.

4.2.4 Chord Keyboard

Like the Dvorak keyboard, the chord keyboard was assumed to be a cognitive task intervention. With only 7 keys, the number and location of keys is quite unique from the standard QWERTY keyboard. Subjects were able to rest their hands in one place to perform typing, as opposed to the standard keyboard where a large amount of finger travel is necessary. The learning rate for the chord keyboard 77.3%, again higher than the expected 70% for a cognitive task. The chord keyboard required high amounts of cognitive function (remembering, thinking, deciding, and planning)

for each trial, and it was rated as the most cognitively (0.88) and physically (0.61) challenging of all four keyboards. The physical difference in the number of keys forced subjects to coordinate fingers to press keys together for each letter (most characters required more than one key to be depressed simultaneously).

The physical and cognitive challenges on the chord keyboard produced slow trial times. While trials on the chord keyboard were still much slower than the QWERTY keyboard after 20 trials (195 seconds versus 40 seconds) for this experiment, other studies have reported different productivity results. Gopher and Raij reported that inexperienced typists were more proficient with a chord keyboard than a standard keyboard after 35 one hour sessions (1988). Subjects were also able to type within 10% of QWERTY speed on a two-hand chord stenograph after 40-50 hours of use (Beddoes and Hu, 1994). Kroemer et al. asked subjects to memorize 59 chords on a two-handed chord keyboard, and the average typing speed after 40 trials, 400-500 characters each, was 70 cpm (Kroemer et al., 1992). In this study, after 20 trials, subjects were able to type the 225 character passage at a speed of 69 cpm. This speed was achieved after only 2 hours of typing time, much less time needed than those subjects in Kroemer et al. 1992. The same keyboard in Kroemer 1992 was used for a one-handed chord keyboard study (the left side was disabled), and five subjects were taught 18 chords (numbers and symbols). After an initial training phase of 60 hours, subjects were able to reach a typing speed of 170 cpm (McMulkin and Kroemer, 1994). The projected trial time on the chord keyboard after 100 trials is 120 seconds, or an estimated typing speed of 112 cpm. This estimated time is still much slower than the QWERTY keyboard.

Although training time is longest for this keyboard, it allows a wider range of users (only requires one hand) to type. The results of this study show the chord keyboard is a viable alternative keyboard.

4.3 Limitations to Research

There are a few limitations to the current study. First of all, the work was completed in the lab with a three sentence passage where subjects are solely focused on completing the typing task. The learning curves for implementing these keyboards for everyday tasks could be different because office workers are generally confronted with tasks aside from typing. Secretaries are not necessarily constantly typing throughout the entire day, and sometimes work is broken into segments (potential for learning remission). Plus, office workers can be distracted from typing by trying to do more than one task (e.g. answer the phone). These external tasks and stimulations would probably produce some learning remission. Furthermore, all subjects in this study were from the university population with an average age of 24. Keyboard research has a range of subject populations from university students to secretarial workers to workers from a temp agency. Comparisons of typing productivity with this study to other studies are important, but college students generally have more formal education (relating to cognitive function) than office or secretary workers. Although it is important to keep those differences in mind when comparing typing speed, it is more important to consider this when examining learning rate. College students and recent graduates are challenged cognitively each day, so they are most likely more adaptable to learning new concepts or tasks. It was probably easier for the students in this study to

memorize patterns and different key allocations than it would be for office workers. Higher cognitive function would probably be compared to a higher/faster learning rate. The subject population should also be considered with the demand ratings. Also, it is important to examine the average age of participants in this study to those in other studies. People in their 20s, the average age group for this study, have been exposed to computers and keyboard use for most of their lives. This could hinder subjects from being open to learning new keyboarding tasks, but also help since they are so familiar with computers. Subject population needs to be considered when examining the results of this study.

The survey ratings were adapted from the NASA-TLX work load index. Since the learning rate for the contour split keyboard was in line with those on the Dvorak and chord keyboards, and these keyboards were rated more demanding in all three categories than the contour split, some measure may have been missing from the survey. The perceptual demand category was created to capture the demands associated with the unique shape and key layout of the contour split keyboard. The similar ratings for each category on the contour split keyboard may reflect that subjects were unsure which category to rate the challenges associated with learning the contour split keyboard.

4.4 Future Research

Ergonomic interventions are created to minimize the workload for the worker. However, one frequent excuse for not implementing ergonomic interventions is the learning time. Therefore, it is important to quantify learning rate to show the actual learning time/ lost productivity time. Future research could include classifying other

ergonomic interventions as this study did: by learning rate and task demand. Also,

more keyboard work could be done to quantify learning rates in actual work places.

Given the outside stimuli in the office environment and different subject population,

learning rate results could differ from the ones found in this study and would be more

applicable.

5. Conclusion

Since many people are exposed to computer keyboards on a daily basis, options other than the standard flat QWERTY keyboard need to be investigated. There should be an accepted alternative to the standard keyboard that considers both keyboard safety and user productivity. Unfortunately, too many people associate alternative keyboards with long learning and adjustment times, and the goal of this study was to quantify the learning time to make alternative keyboards more approachable.

Learning curve theory was successfully applied to the implementation of alternative keyboards. Sixteen subjects typed five trials on each of four alternative keyboards in order to quantify learning rate and type of demand. Physical, cognitive, and perceptual demand was also quantified for each keyboard through a subjective assessment. Nine more subjects performed 20 trials on one alternative keyboard and verified that five trials to calculate learning rate were sufficient.

The calculated learning rate for the fixed split keyboard (90.4%) was significantly different from the learning rates for the other three keyboards (chord: 77.3%, contour split: 76.9%, Dvorak: 79.1%). The average time for the QWERTY trials was 40.2 seconds, and the average time for the 5th trial on the split keyboard was 42.4 seconds (only 5% slower than QWERTY). Learning rate negatively correlated to all types of demand (physical, cognitive, and perceptual), so learning rate was slower with higher demand, regardless of the type of demand. The chord keyboard was the most cognitively demanding, while Dvorak keyboard was the most perceptually demanding. Subjects typed considerably slower on these two

keyboards. However, the chord, Dvorak, and contour split keyboards all had similar

learning rates. Alternative keyboards have postural benefits that can reduce

incidence of MSDs and can be implemented in the workplace with only an initial

change in productivity.

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Appendix

Appendix A
IRB form
North Carolina State University
INFORMED CONSENT FORM for RESEARCH

Title of Study : Learning Curve Analysis for Different Types of Ergonomics
Keyboards

Principal Investigator : Allison Anderson

Faculty Sponsor: Dr. Gary A. Mirka

You are invited to participate in a research study. The purpose of this study is to evaluate learning curves for different types of ergonomic interventions.

INFORMATION
If you agree to participate in this study, you will be asked to perform following tasks.
You will be asked to type the same 3 sentence passage on seven different keyboards. You will be asked to type the passage 10 times on a standard QWERTY keyboard and 5 times on the six other keyboards. After completing the five trials on each type of keyboard, you will be asked to complete a survey where you describe what you found difficult in using this keyboard. This research study should take no more than 2 hours.

LIMITATIONS
You must be at least 18 years of age to participate in this study. You should not participate in this study if you have any chronic or current pain in your shoulders, upper back, arms, neck, and hands. All subjects must be right-handed, have 20/20 corrected vision, and type at least 25 words per minute.
If this describes you, please initial here: _____

RISKS
You may experience minor discomfort as a result of static posture and repetitive typing during the trial, but you should not experience more than a dull ache. Please let the experimenter know if you experience pain.

BENEFITS
The study may provide a better understanding of learning rates for the implementation of different types of ergonomic interventions.

CONFIDENTIALITY
The information in the study records will be kept strictly confidential. Data will be stored securely and will be made available only to persons conducting the study unless you specifically give permission in writing to do so otherwise. No reference will be made in oral or written reports which could link you to the study.

EMERGENCY MEDICAL TREATMENT
There is no provision for free medical care for you in the event that you are injured during the course of this study. In the event of an emergency, medical treatment may be available through Student Health Service on campus or through the 911 emergency response service.

CONTACT
If you have questions at any time about the study or the procedures, you may contact the researcher, Allison Anderson, at the Ergonomics Lab,Daniels room 445, North Carolina State University, or [919-834-4383]. If you feel you have not been treated according to the descriptions in this form, or your rights as a participant in research have been violated during the course of this project, you may contact Dr. Matthew Zingraff, Chair of the NCSU IRB for the Use of Human Subjects in Research Committee, Box 7514, NCSU Campus (919/513-1834) or Mr. Matthew Ronning, Assistant Vice Chancellor, Research Administration, Box 7514, NCSU Campus (919/513-2148)

PARTICIPATION
Your participation in this study is voluntary; you may decline to participate without penalty. If you decide to participate, you may withdraw from the study at any time. If you withdraw from the study before data collection is completed your data will be returned to you or destroyed at your request.

CONSENT
"I have read and understand the above information. I have received a copy of this form. I agree to participate in this study with the understanding that I may withdraw at any time."

Subject's signature_____   Date _____


Investigator's signature_____   Date _____

Appendix B

SUBJECTIVE RATING OF PERCEIVED WORKLOAD
Indicate the level of demand experienced for each of these factors during the last experimental trial by drawing a straight vertical line on the scale directly below. The midline represents the demand for the QWERTY keyboard.
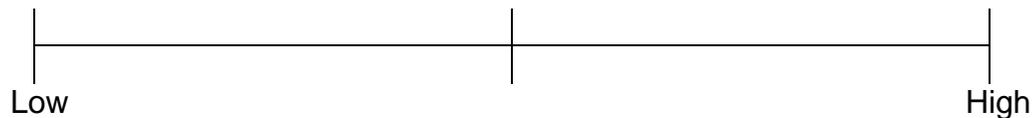
Physical demand

How much physical activity was required (e.g. finger coordination, awkward postures (shoulder, elbow, fingers), muscle force/tension, awkward reaches with fingers)?

|⊢————————————————|————————————————⊣|

Low   High
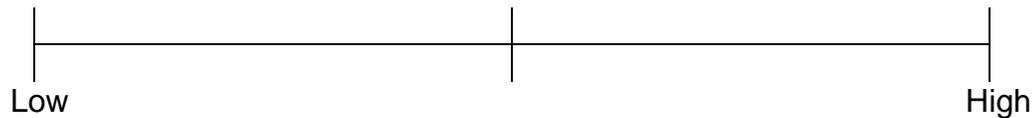
Cognitive demand

How much mental activity was required (e.g., remembering, thinking, deciding, planning)?

|⊢————————————————|————————————————⊣|

Low   High

Perceptual demand

How much perceptual activity was required (e.g. looking, searching, detecting, recognizing, and being aware of the physical location of the keys)?

|⊢————————————————|————————————————⊣|

Low   High

Appendix C
Script

Before experiment:
You are participating in a project to investigate learning rates for different ergonomic keyboards. This experiment should take no longer than two hours. Please feel free to ask me questions anytime.

In order to participate in this experiment you should not have any chronic or current pain in your back, neck, shoulder, arms, or hands. You should also have 20/20 vision (or 20/20 corrected vision). You will be asked to type on 7 different keyboards with 5 trials each (qwerty will be 10). You can see them all over there (dvorak, chord, vertical/ mirror, floating arms, split, kinesis). If you feel discomfort at any time, please let me know immediately. After completing all trials for each specific keyboard, you will be given a break from typing and will be asked to complete a written survey. Please be as specific as possible.

Here is the consent form. Please read over it carefully, and sign and initial in the appropriate places. Please ask any questions you might have.
Get age of subject

You will type the same 3-sentence passage throughout the duration of this experiment. **Please type as accurately and fast as possible.** Be sure the notice the some of the unusual spelling of words in the passage. The specific typing program for this experiment makes you type the passage perfectly. The passage will not move on until you type the correct letter. Please be sure to watch the computer screen.
Here is the passage you'll be typing today. Again, this program forces you to type the passage perfectly. If you misspell a word, the passage will not continue until you have typed the correct letter. The program will record the time it takes you to complete the passage and it will calculate characters per minute, time, and error %.

Please read over the passage before we start.

Emalion and Staition were walking near the cold, icy water. She observed the quick fox jump over the lazy and the stupid dog. Emalion, nine years older than her brother Staition, thought to herself this must be a special day.

Do you have any questions?

Please remember to type as fast and accurately as possible. Remember that you must type this program perfectly→ be sure to watch the screen/ passage to make sure it's moving with your typing.

Do qwerty trials- break for 3 minutes

Before each of the next 6 keyboards:
Please remember to type as fast and accurately as possible. Remember that you must type this program perfectly→ be sure to watch the screen/ passage to make sure it's moving with your typing.

After 1st non-qwerty keyboard trials
Here is a copy of the written survey you'll be taking today. Please read over the description of each category. Please use this and compare your demands with the demands of typing on the standard qwerty keyboard.

Before chord and dvorak keyboard: Here is a "cheat sheet" that represents the keys for each letter. Please use this when necessary, but remember to type as accurately and fast as possible.

Experiment Check List
All keyboards are clean and set up

Typing Program is up and running

All worksheets are printed out
6 NASA TLX surveys
IRB Consent Form
Cheat Sheet
Record Sheet
Subjects qualifications are verified (proficient typist, see 20/20, right-handed)

Keyboard order is randomized

Find out about NASA TLX / qwerty

Laptop screen angle

Appendix D: Graphs for Assumptions of ANOVA

1. Test for Normality of Results
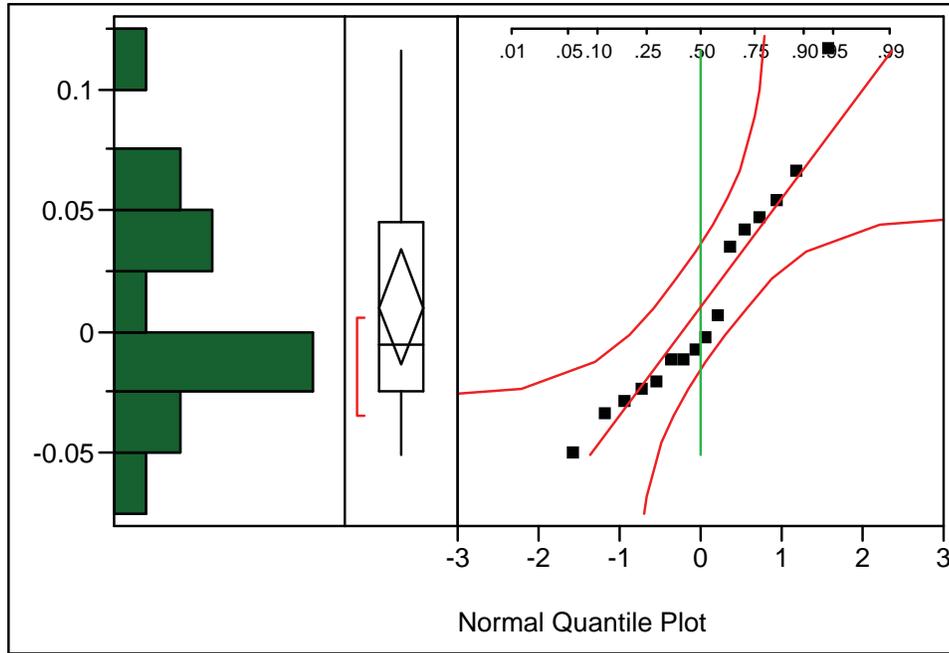
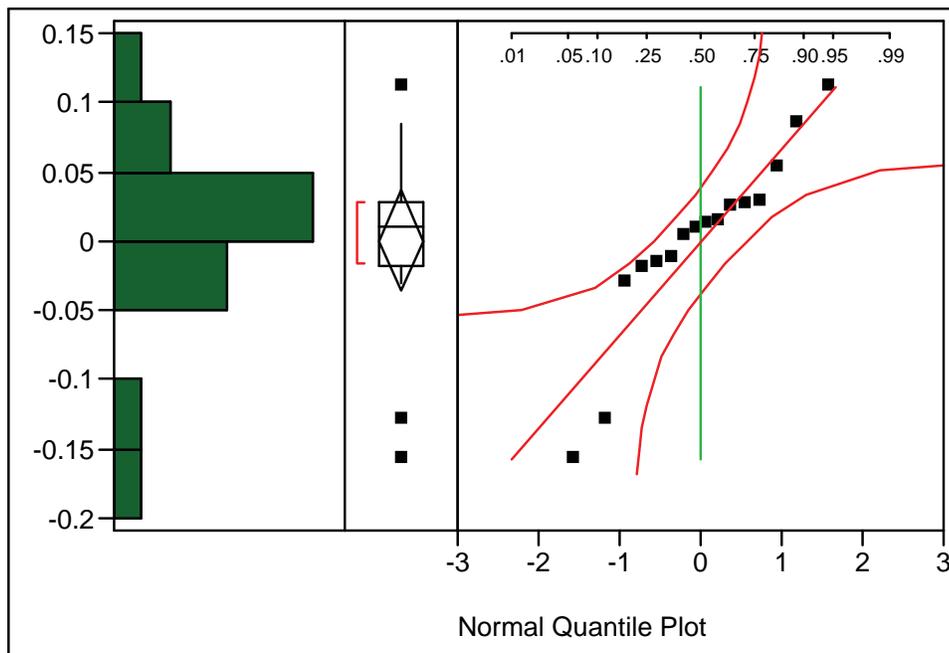Figure 17: The normal quantile plot of the residuals of the chord keyboard

Figure 18: The normal quantile plot of the residuals for the Dvorak keyboard
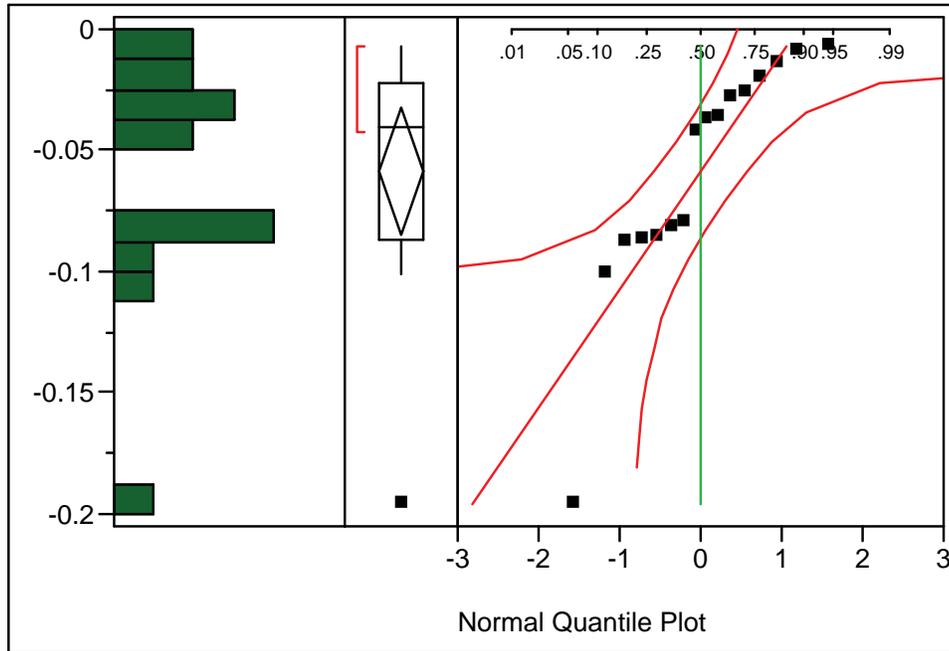
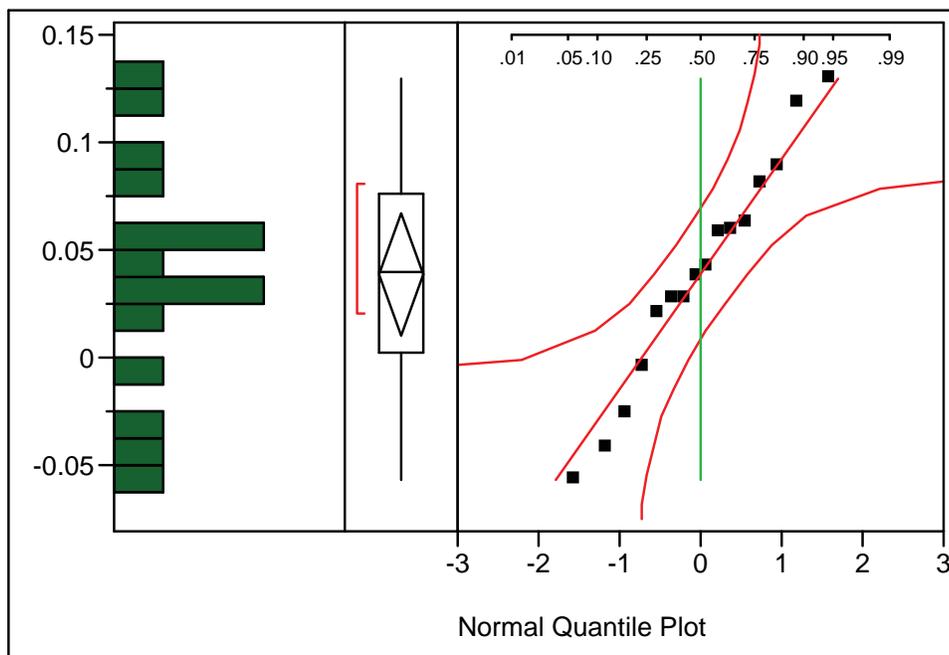Figure 19: The normal quantile plot of the residuals for the contour split keyboard

Figure 20: The normal quantile plot of the residuals for the split keyboard
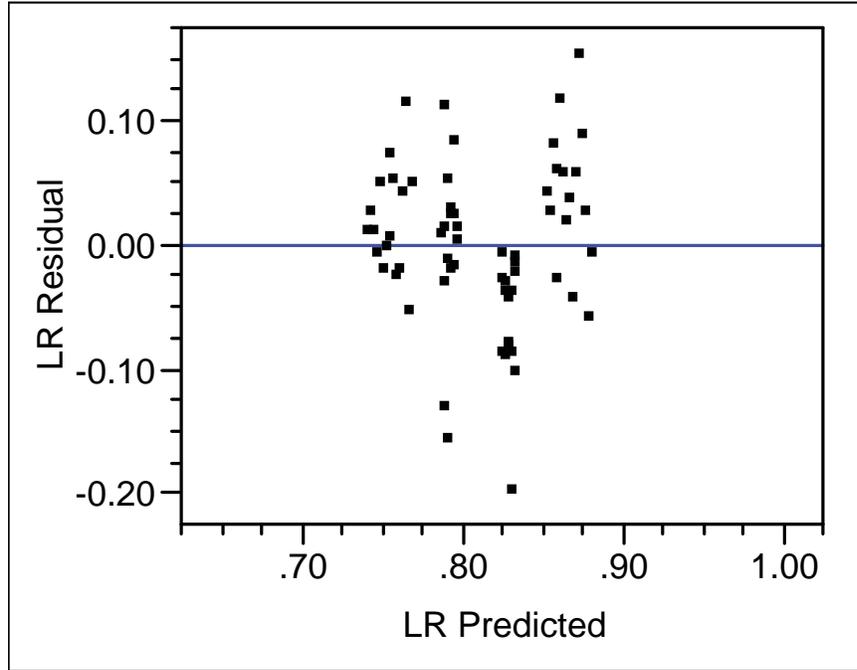
2. Test for Homogeneity of Variance

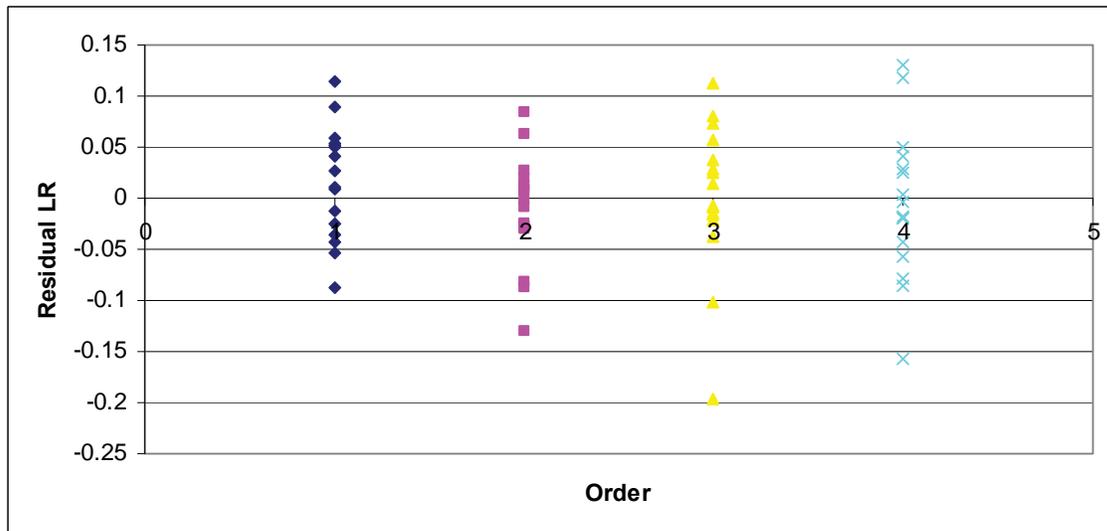Figure 21: Test for homogeneity of variance
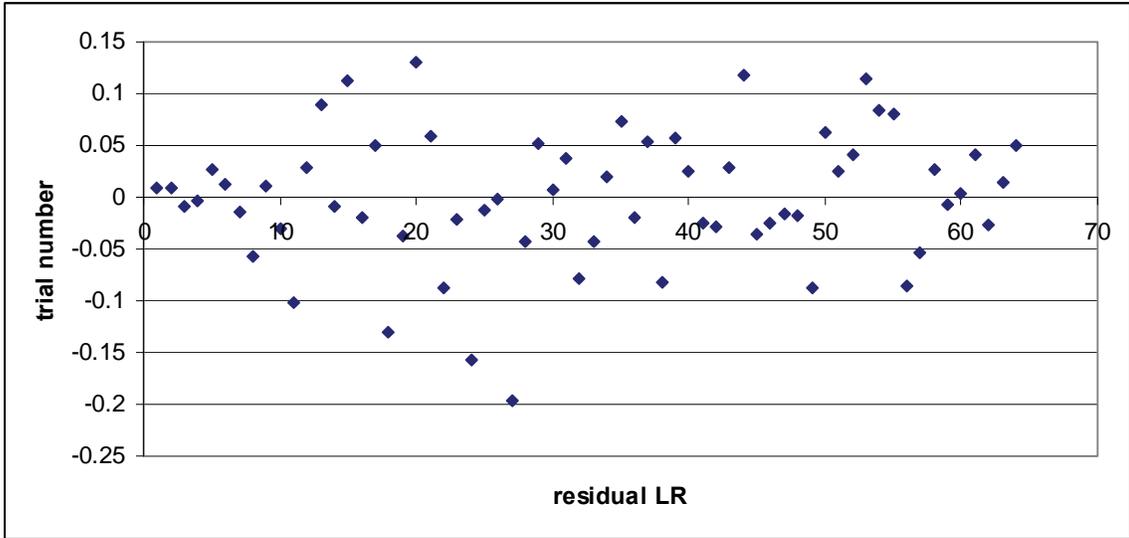
3. Test for Independence

Figure 22: Residuals of learning rate as a function of order of keyboard

Figure 23: Residuals of learning rate as a function of trial order (subject order)