An Atlas Ergonomics White Paper

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An Evaluation of a Totally Split Compact Keyboard and its Impact on Posture, Discomfort, and Performance

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Introduction
A review of the background information that led to this study and the subsequent goals established for the project.

Methods
The process used to collect postural, discomfort, and performance data pre- and post- implementation of split keyboard.

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80 employees participated in the study. The characteristics of the population are presented.

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The postural, discomfort, and performance outcomes are presented and the probable influencers are discussed.

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A review of the relationships learned and recommendations.

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A list of the research articles referenced throughout the paper.

INTRODUCTION

In a literature review released in June 2008 in the journal Human Factors, Dr. David Rempel provided a very simple statement in the title of the paper – The Split Keyboard: An Ergonomics Success Story. This paper provided a historical review of the design and testing of various split keyboard designs, and the many positive results that have been seen in various studies. The positive results are seen both from the ergonomics perspective of improvements in posture and reductions in discomfort, and the economic success of a split keyboard being the best-selling aftermarket keyboard (Rempel, 2008).

The best research on split keyboards has focused on variables that can be manipulated to result in some ergonomic benefit. Figure 1 illustrates the characteristics of a hypothetical split keyboard that can in principle be modified to affect the posture and comfort of the user (Tittiranonda et al., 1999). The distance of the split, opening angle (γ), fore/aft angle (α), and tenting angle (β) all have a direct impact on level of wrist extension, ulnar deviation, and pronation required to position the hands on the keys. The ability to adjust these parameters allows an employee to adopt the keyboard to their stature and task, whereas a non-adjustable keyboard will generally require the employee to adopt their body to the equipment.

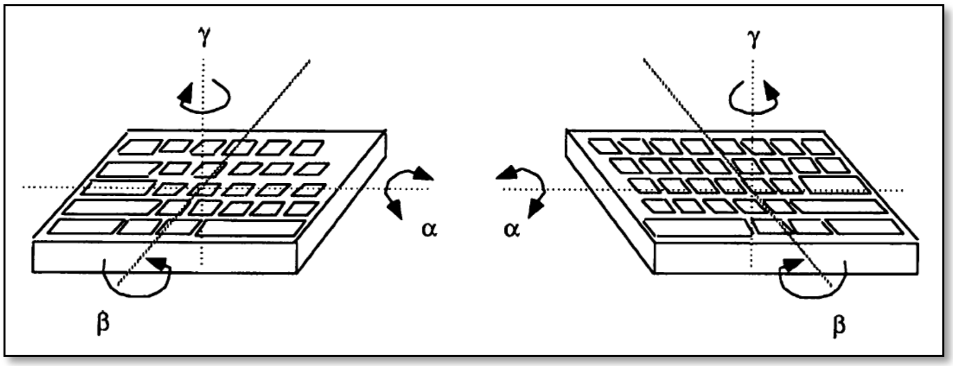


Figure 1: Keyboard Configuration Variables

An important finding of Tittiranonda et al. is that the actual keyboard design and implementation of ergonomic features makes a big difference in its effectiveness. In their study, two adjustable products (one of which was completely split) were less effective than a non-adjustable, fixed-split design. Unfortunately the actual adjustments created for participants using the adjustable keyboards in this study were not reported.

A variable not specifically studied by Tittiranonda et al. was the impact of mouse use on the discomfort associated with computer work. The presence or absence of a numeric keypad on the right side of the keyboard can greatly affect posture and comfort for mouse use. Previous work by this research group (see Rempel 2008) has shown that mouse usage can be an even bigger source of pain than keyboard usage.

In previous work published by Atlas (February, 2007) related to obesity in the office environment, it was noted that the introduction of a fixed-split keyboard had a positive impact on comfort. Figure 2 illustrates results from a series of four follow-up surveys in this study asking about hand/wrist discomfort. The data showed a significant improvement over time for employees of all sizes. Due to the fact that the split keyboard was primarily recommended for employees of larger stature or in higher classifications of obesity, the positive impact of the split keyboard was illustrated by the reduction in discomfort seen in these populations.

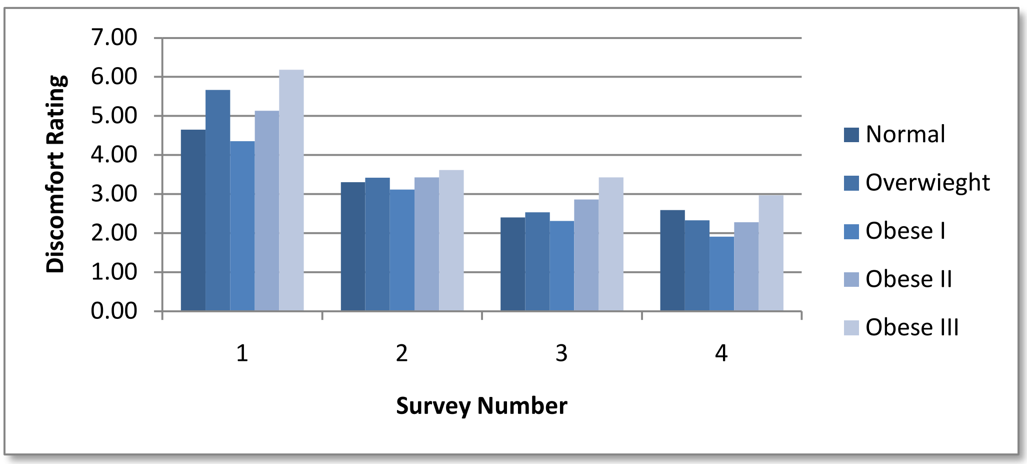


Figure 2: Impact of Training on Employee Hand/Wrist Discomfort

The results of this initial work completed by Atlas has allowed for the continued justification of recommending split keyboards for employees of larger stature. Given the fact that split keyboards were not regularly recommended for employees of average or smaller stature, the value of this product for addressing the discomfort for the overall population is unclear. Most research completed within a laboratory setting has not answered this question of broad-based positive impact as they have either used small population samples or short-term exposure to the keyboarding conditions. The 6-month study by Tittiranonda et al. (1999) did show that employees using a fixed split keyboard design experienced a decrease in discomfort after 4.5 months of keyboard use. A fixed split keyboard minimizes the ability to adopt the keyboard to personal preferences, but it does promote a hand position that is closer to neutral for most users compared to a traditional keyboard. However, the interaction of keyboard/mouse interaction and impact of the numeric keypad (which is removed or embedded in compact keyboards) has not been studied in this context.

The objective of the current study was to explore the comfort and postural benefits of an adjustable and completely split compact keyboard, under conditions where the users were allowed to optimize their own configurations. We provided participants with a simple keyboard configuration and clip on/clip off accessories to adjust the front opening angle and tenting, or to choose complete separation, in any combination. Then we observed what they did at the beginning and periodically during the study.

The key questions we asked in this study were:

1. Do people of various statures note a positive effect of using an adjustable, totally split keyboard, where effect is defined as posture, discomfort, and performance?
2. Given an adjustable split keyboard, will a person modify the configuration of the keyboard to achieve a positive effect (i.e. will the person move beyond the conventional and familiar keyboard configuration)?

METHODS

Participant Recruitment

Participants were recruited from several locations within the campus of a large software manufacturer. An email blast was used to invite employees to participate in the study, and highlighted the time requirements and expected duties of a participant. Participant responses were screened based on the following criteria:

1. Must be free of any significant pain or current injury at the start of the study.
2. Must be using traditional or wave configuration keyboard.
3. Must work on keyboard a minimum of 20 hours per week.
4. Workstation must be equipped to support good, ergonomic postures.
5. Minimal adjustments to workstation are required to optimize posture.

Ergonomics Awareness Training

Upon acceptance into the project, each employee was provided with 30 minutes of ergonomics awareness training to prepare them for the upcoming data collection. This training included the following topics:

1. Definition of ergonomics
2. Proper set-up of office workstation
3. Proper posture while working in office
4. Installation of data logging software

Baseline Data Collection

Participants were instructed to return to their desks and load the data logging software onto their computers. They were then instructed to work with their normal set-up for the next 4 weeks to collect baseline data related to performance and discomfort.

Data Logging of Keyboard Activity

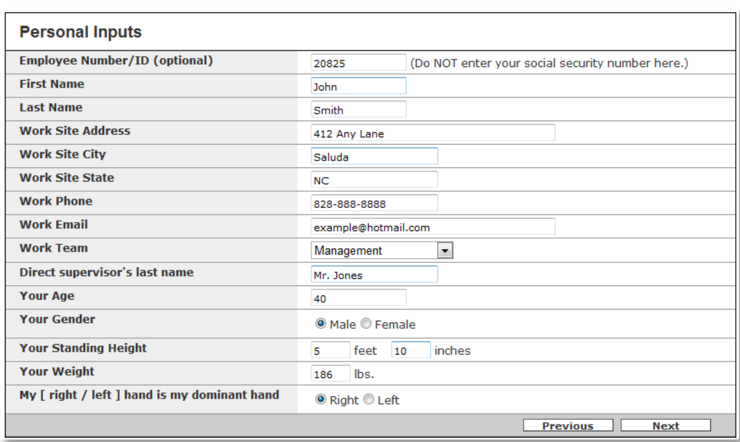
Data logging software was installed on each participant's computer which monitored input from the keyboard and mouse, measured through low level Windows OS events. Use statistics were monitored and sent to a server database via the internet several times per day where statistics were summed by day for each user. Data storage and retrieval was conducted via server side scripting and a SQL relational database. The data logging software was operational on each participant's computer for the complete 5-month duration of the project.

Baseline Collection of Demographic and Discomfort Data

Initial collection of demographic and discomfort data was obtained at the end of the 4-week baseline period. Collection occurred at the end of the baseline period to allow for any variation in discomfort that may occur as a result of the awareness training to stabilize.

Demographic and discomfort data was collected using Atlas Ergonomics' web-based office ergonomics assessment software. An employee survey addresses both workplace conditions and discomfort in an attempt to gather data relevant to ergonomic risk in the office environment. Each question within the survey was designed to assess different elements of office ergonomic risk, and has been chosen based on current research and standards.

Prior to assessing work-related and discomfort factors, an employee is asked to provide basic information to assist in classifying their demographics, and to provide guidance for the selection of appropriate solutions. Figure 3 provides an example of one of the demographic survey pages, where information such as gender, age, height, and weight are collected.



Personal Inputs

Employee Number/ID (optional)	20825 (Do NOT enter your social security number here.)
First Name	John
Last Name	Smith
Work Site Address	412 Any Lane
Work Site City	Saluda
Work Site State	NC
Work Phone	828-888-8888
Work Email	example@hotmail.com
Work Team	Management
Direct supervisor's last name	Mr. Jones
Your Age	40
Your Gender	Male Female
Your Standing Height	5 feet 10 inches
Your Weight	186 lbs.
My [right / left] hand is my dominant hand	Right Left

Previous Next

Figure 3: Employee Demographic Information

Figure 4 provides examples of the discomfort-related questions that an employee will fill out during the next part of the survey. Discomfort is assessed using a health index which is a combination of frequency and severity of symptoms on a 5-point scale using 2 decimal points of accuracy. The multiplicative value of these discomfort variables (F x S) is rated as low, moderate, high, and extreme.

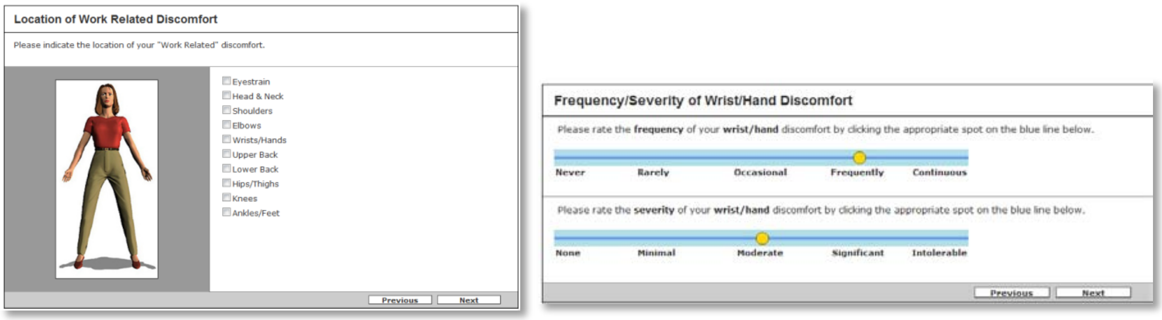


Figure 4: Location, Frequency, and Severity of Discomfort

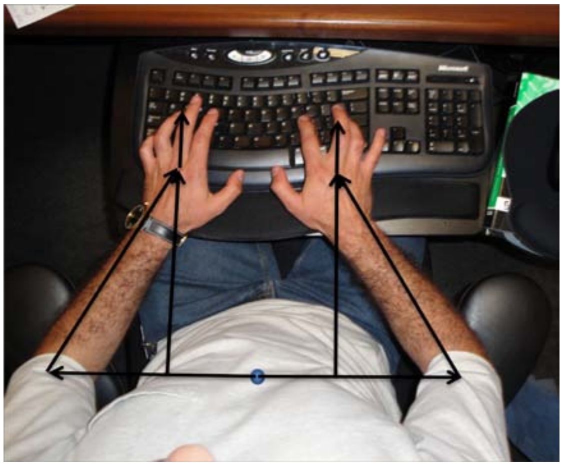
Once the data has been submitted by the employee it is available in raw format that can be downloaded into an MS Excel spreadsheet for analysis and review.

Anthropometric Variables

Several measurements of the participants were taken to help document their postures, and any influence that body dimensions may have in adopting postures on the keyboard. The primary posture of interest within this study was ulnar deviation. Therefore, the measurements taken were designed to help evaluate this posture and any influencing factors.

The first measurement that was taken from each employee was elbow-to-elbow breadth. This measure was taken with the participant in a standing posture with their elbows held at 90 degrees. A tape measure was used to measure the distance between the centers of each elbow joint. The proximal end of the ulna (olecranon) was used as the bony landmark. The breadth of the elbows provided an indication of the starting point for the forearms, and therefore the line of approach for the hands and wrists as they address the keyboard.

To measure ulnar deviation in a wrist, the angle is measured by drawing a line from the forearm through the wrist, and then a second line from the wrist through the 3^{rd} digit of the hand. Ulnar deviation is the angle seen between these two lines. To determine the effect of the keyboard on ulnar deviation, the 3^{rd} digit must be sitting on the home row of the keyboard; the left and right 3^{rd} digits will be resting on the D and K keys respectively. The elbow breadth of the individual (line of approach) combined with the target coordinates for the digits (keyboard configuration) present the workplace conditions that dictate hand posture while keying. Figure 5a and 5b illustrate the measurements and keyboard characteristics measured within the study. Each participant's hands were photographed from above to allow for measurement of the angle of ulnar deviation; a goniometer was used to measure the angle from the digital image collected.



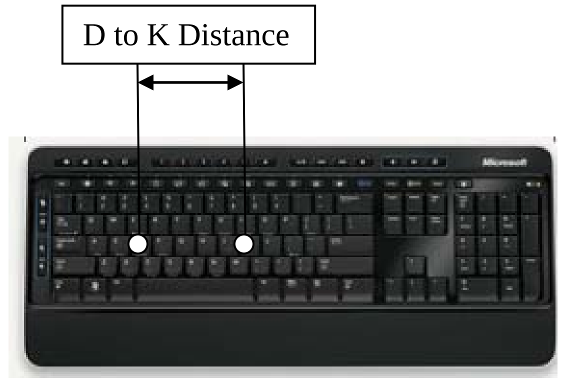


Figure 5a: Anthropometric Measurements **Figure 5b: Keyboard Measurements**

Split Keyboard Awareness Training

Upon completion of the baseline period the experimental split keyboard was distributed to participants. The keyboard used in this project was the Freestyle Solo plus the VIP kit, which includes clip on tenting modules and padded palm supports. The tenting modules allow the keyboard to be vertically lifted at an angle of 10 or 15 degrees. These accessories allowed the participants to modify the set-up to their preference for performance and comfort. Participants were provided with 20 minutes of instruction on how to assemble the keyboard and encouraged to try various configurations to determine a set-up that provided optimal performance and comfort. Figure 6 provides sample images of potential configurations that the participants could adopt.

Tethered **Tethered & Splayed**

Totally Split **Tented, Totally Split, Palm Rests**

Figure 6: Split Keyboard Configurations

Split Keyboard Anthropometric Variables

Participants were provided 4-5 weeks to work with the split keyboard and adopt a preferred configuration and posture. A follow-up visit was performed for each participant where images of hand position and keyboard layout were collected (see Figure 7). Additionally, the actual configuration of the keyboard was documented and the D to K distance (i.e. split) of the keyboard was recorded. Measures of ulnar deviation were taken from the digital images and compared against the baseline data to determine any changes in hand position.

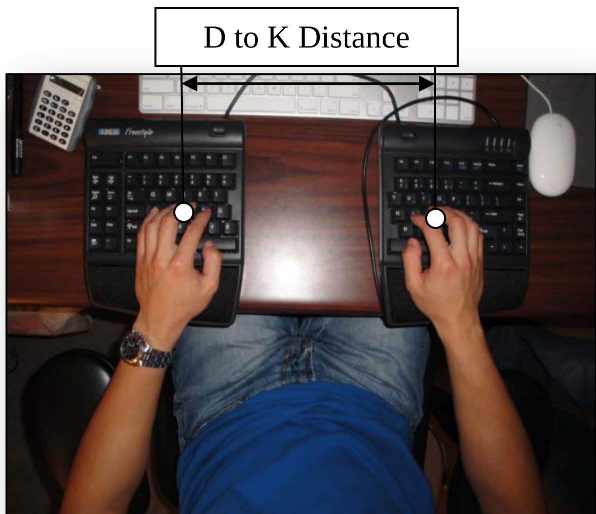


Figure 7: Follow-up Measure of Hand Posture and Split Keyboard Configuration

Final Collection of Discomfort Data

A second collection of discomfort data was obtained at the end of the 5-month test period. Follow-up discomfort data was used to measure any changes that were noted after exposure to the split keyboard.

Exit Survey

Participants were asked to fill out an exit survey at the end of the project to gather feedback on the project. Questions related to the keyboard design and uses were gathered to guide any future modifications to the model. Questions related to keyboard acceptance were gathered to determine potential market use of the product.

PARTICIPANTS

The participants recruited for this study were from a software manufacturing company. A total of 80 participants were recruited from various locations throughout the campus of the organization. The population included relatively significant computer users, with average computing hours of 6.62 hours/day.

The average age of the participants was 40.8 with a range of 21.3 to 60.3 years; the population had relatively equal representation of all age groups from 20-55 years old, with lesser representation in groups >55 years. The average tenure of the group was 5-10 years, with a range including participants with < 3 months employment through to participants with >20 years. The distribution of gender was 57% male and 43% female.

Figure 8 presents the breakdown of the study population based on body mass index or BMI. This data illustrates a population that is overall healthier than average, with a significantly higher percentage of normal and overweight individuals and significantly fewer obese individuals when compared with population norms. These numbers vary greatly from the information collected by the Center for Disease Control on distribution of the United States population by weight classifications.

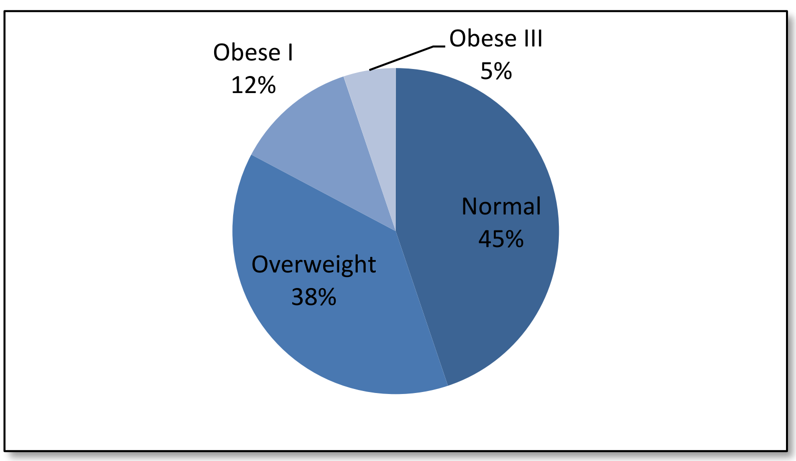


Figure 8: Distribution of Population by BMI

RESULTS & DISCUSSION

Posture

The model illustrating the measurements needed to determine ulnar deviation (see Figure 5a) illustrates the fact that body size has a direct influence on the angle of approach of the forearms and the level of ulnar deviation. To account for the influence of body size on hand posture, the results of the wrist angle measurements were divided classifications based on the BMI scale. As noted in the participant section, the study population had individuals that fell into the normal, overweight, obese I, and obese III classifications.

The measurements of ulnar deviation illustrated a significant improvement in posture using the split keyboard. Figure 9 illustrates that the degree of ulnar deviation was reduced across all BMI levels, with the greatest reduction seen for the obese III individuals. Additionally, an interesting trend was found where the level of ulnar deviation for the left hand was frequently lower than that of the right hand. On average this difference was 8.25 degrees. The digital images of the participants showed a frequent habit of employees to sit with their bodies skewed to the right side of the keyboard, which may have been a response to reduce the reach to the mouse. This postural shift increases the ulnar deviation of the right wrist during the keying motion as the line of approach has been altered.

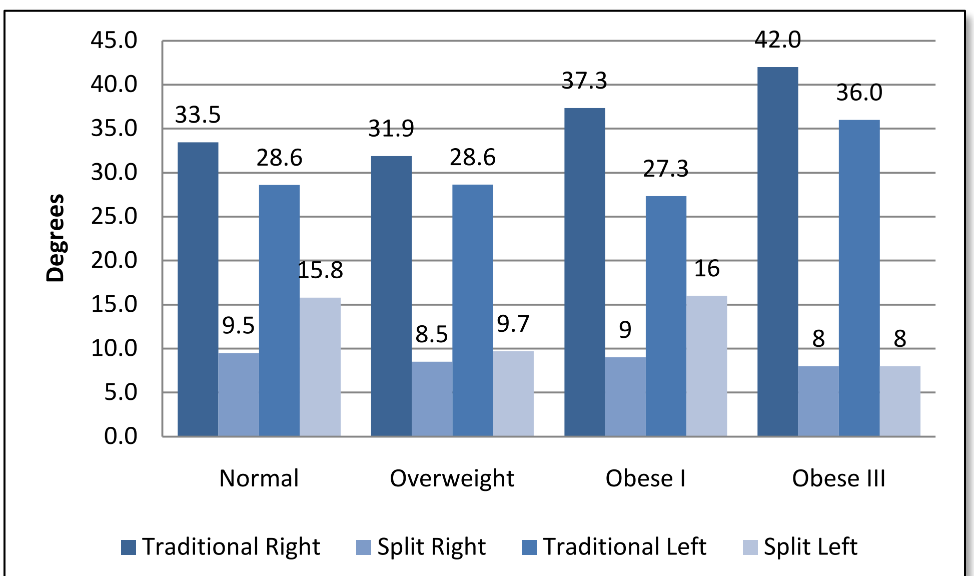


Figure 9: Ulnar Deviation Angles for Traditional and Split Keyboard

Figure 10 illustrates the percent improvement in ulnar deviation when participants moved from the traditional to the split keyboard. The higher level of improvement on the right side further illustrates the asymmetrical postures of the wrist, and also demonstrates that the split keyboard appears to address the reach requirements for the keyboard and the mouse. The experimental keyboard does not have a numeric keypad as a standard item, which also affects the reach requirements of the right arm and therefore further assists in positioning of the wrist. The improvement for obese III participants was symmetrical and significant, indicating that the split keyboard was able to successfully address the postural needs of larger participants. The data clearly shows a dramatic effect for participants of all sizes, which suggests a broad range of impact for a split keyboard design.

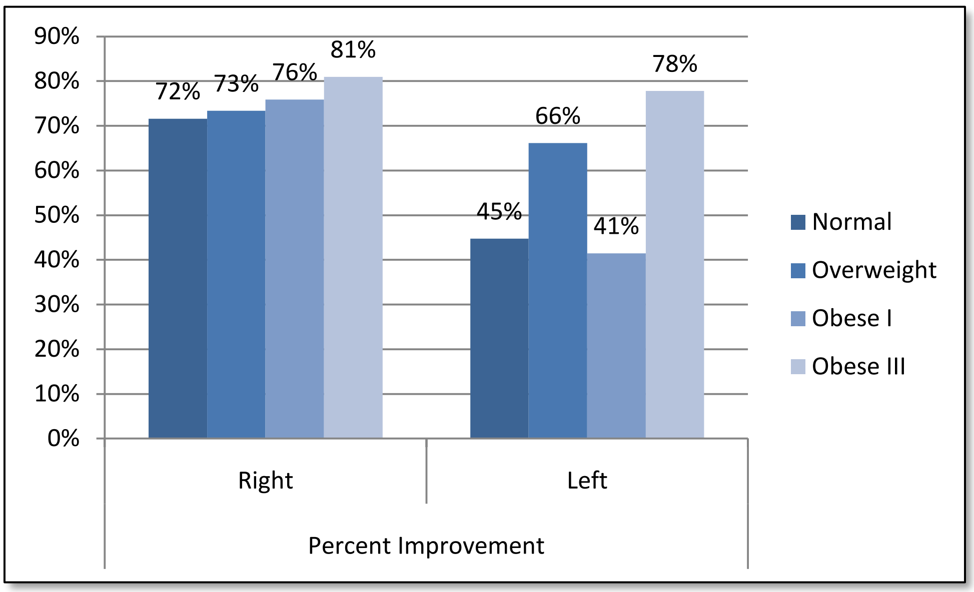


Figure 10: Improvement in Ulnar Deviation Using Split Keyboard

Keyboard Positioning

The postural data illustrated a clear difference in posture between standard and split keyboard use. If the improvement is to be tied directly to the keyboard design, then the split keyboard configurations adopted by the participants would need to illustrate changes that would directly impact wrist posture. As illustrated in Figure 6, the split keyboard can be used in a configuration that mimics a standard keyboard with the sole difference being the removal of a numeric keypad. If this configuration was the dominant choice, then the conclusion would be less positive towards a split keyboard design versus simply a keyboard design without a numeric keypad.

The follow-up review of the participant set-ups in conjunction with the exit survey (Figure 11) illustrated that 92% of participants actually used the keyboard with some level of split, with 24% using the keyboard with its sections widely spread apart.

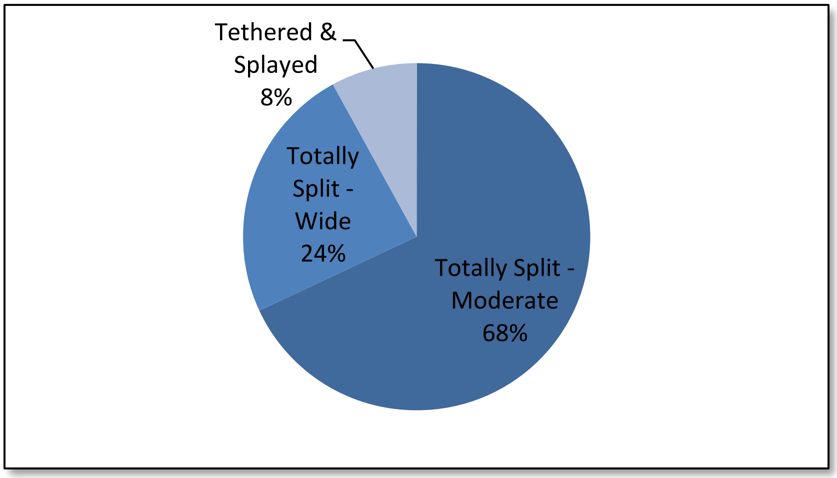


Figure 11: Preferred Final Configuration of Split Keyboard

These subjective results from the exit survey were confirmed by the actual measurement of the D-K distance between the two portions of the split keyboard. Figure 12 illustrates that the average split for all sizes of individuals was between 7.63-11.38 inches. The two red lines on the graph illustrate the D-K distance for the standard keyboard (3.75") and the Microsoft Natural keyboard (5.5"). Based on these keyboard measurements, approximately 90.1% of participants preferred a split keyboard configuration with a D-K distance greater than that provided by the Microsoft Natural.

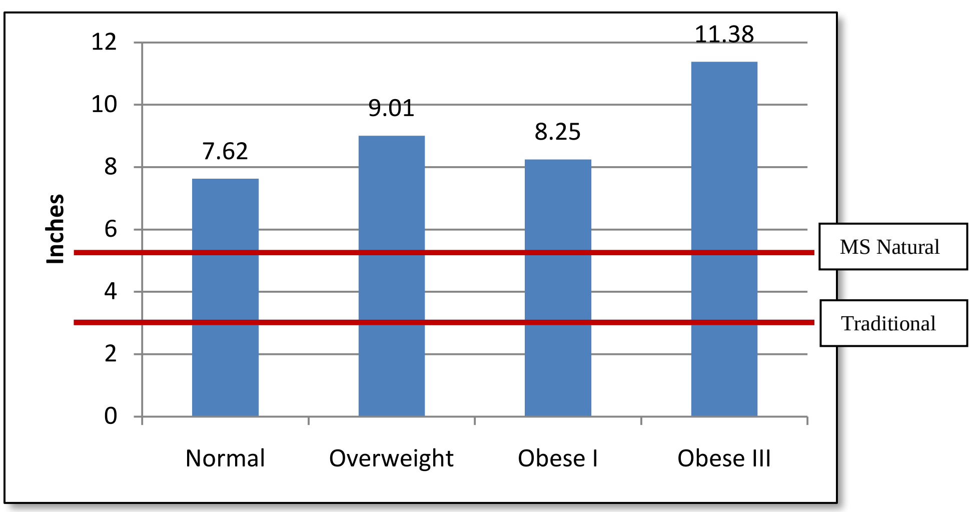


Figure 12: Average D-K Distance for Split Keyboard

There are two factors that need to be considered when looking at the D-K distance preference of the participants. Some of this distance is related to stature, while the influence of the armrests of the office chair and the keyboard tray must also be considered.

Figure 13 shows the results of the exit survey where 75% of the participants indicated that they used the armrests of their chair on a regular basis; 54% of the respondents indicated that they used the armrests always. A single chair design was used within the host organization, and the armrests of this chair had a breadth of 20.5”. Based on the elbow breadth measurements taken of the participants, 63% of the participants would need to abduct their shoulders in order to use the armrests on the chair. Considering the number of participants that did use their armrests (75%), this means that approximately 48% of the study population worked with their arms abducted while using the keyboard; working in abduction results in a change in the angle of approach of the forearms for these individuals. For these participants, chair design and the use of armrests became the primary influencer of wrist angle while typing, instead of anthropometrics. With an increase in the angle of approach of the forearms, these participants may have been more inclined to split the keyboard further apart to counter the effect on their wrist posture.

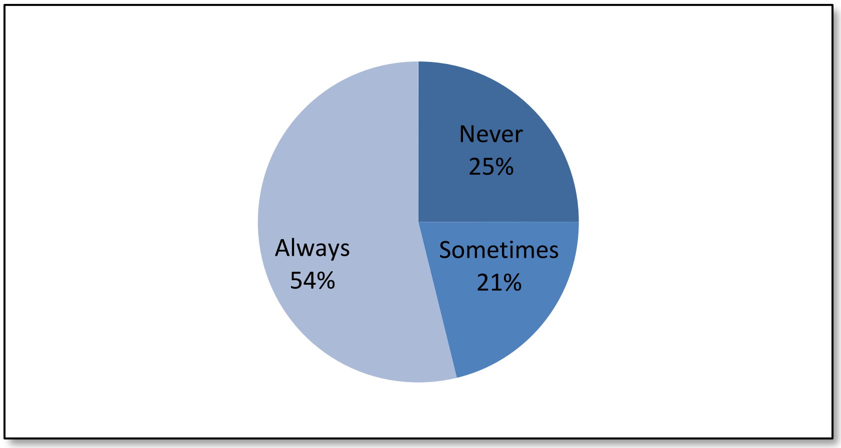


Figure 13: Level of Armrest Use

The use of keyboard trays within the host organization fell within an average range (base on previous Atlas research). Survey and observation indicated that approximately 42% of participants worked with a keyboard tray, and 58% worked with their keyboard on the desk top. Comments from the exit survey indicated that many keyboard tray users would have split their keyboard wider apart if not for the limitations in the size of the keyboard tray. An average keyboard tray is approximately 20” wide, and the test keyboard is 15.375” wide. This would allow the participants to spread the keyboard portions apart 4.5”; adding the 5” of distance to the D and K keys on the keyboard, this would allow for a maximum D-K separation of 9.5” on the keyboard tray. If participants wanted to achieve a greater split in the keyboard than this distance, the average values noted in Figure 12 may be underestimated.

The final keyboard configuration option that participants could choose was the vertical lifters. The 10-15 degree vertical lifts are designed to reduce the pronation of the forearm, bringing the wrist closer to a neutral position. As a keyboard is moved into a higher tenting angle, the ability to view the keys and the transition to this newer configuration may become more challenging.   At the end of the testing period 48% of the participants were using some degree of tenting of the keyboard. Breaking this data down based on BMI classifications, Figure 14 illustrates a high level of use of this tenting feature for all participants. This result indicates that the choice to tent the keyboard and minimize pronation may be less a factor of anthropometrics, and more a feature of preference, comfort, and performance.

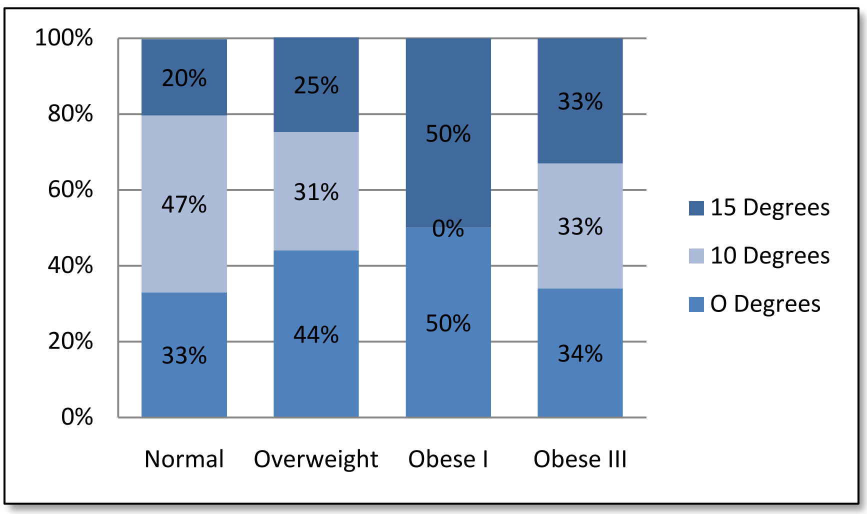


Figure 14: Level of Keyboard Tenting by BMI Classification

Discomfort

Given the results of the keyboard configuration measurements and the exit survey data collected, it is clear that anthropometrics, workstation accessories, and furniture all have an influence on the final set-up preference of the participants. A critical outcome of the choices made by the participants is whether their new keyboard configurations had a positive effect on comfort. The results of the follow-up discomfort survey showed a 16.67% reduction in the prevalence of discomfort within the study population. Due to the nature of the discomfort survey, if a participant indicates that they have discomfort in any body part at any level of severity, they would be considered to have discomfort.

Therefore, the 16.67% reduction indicates that 13/80 participants were free of any discomfort at the end of the test period.

Figure 15 provides a breakdown of discomfort by body part, and shows the percent reduction in discomfort for each area. The data shows a moderate effect of 17-18% reduction for the wrists/hands and shoulders, and no reduction for the elbows. This reduction in discomfort falls closely with the 29% reduction in hand/wrist discomfort noted in a previous Atlas white paper (December, 2008) detailing the impact of products on discomfort. In this paper, the ability of an employee to maintain a neutral wrist position resulted in a reduction in discomfort over employees working in awkward postures. This previous paper further illustrated that exposure time was a dominant factor related to discomfort. Although posture is improved by the new keyboard configuration, the duration of typing per day, static positioning of the wrist and the repeated motion of typing remain. These exposure variables appear to be contributing to any lingering discomfort within the wrists/hands.

The larger discomfort changes seen in this study were in the head/neck, upper back, lower back, and hips/thighs. This impact on the major areas of the spine may be related to the observed change in posture created by splitting the keyboard apart. Splitting the halves of the keyboard apart allowed the participants to reposition their upper extremity and change how they reached for the keyboard. The splitting action worked to eliminate horizontal abduction of the shoulder resulting in retraction (i.e. removal of rounded shoulder position); the decreased reach requirements resulted in an ability to sit back in the chair while typing. The results of the discomfort surveys illustrate that this opening of the upper body appears to have a positive effect on posture and comfort.

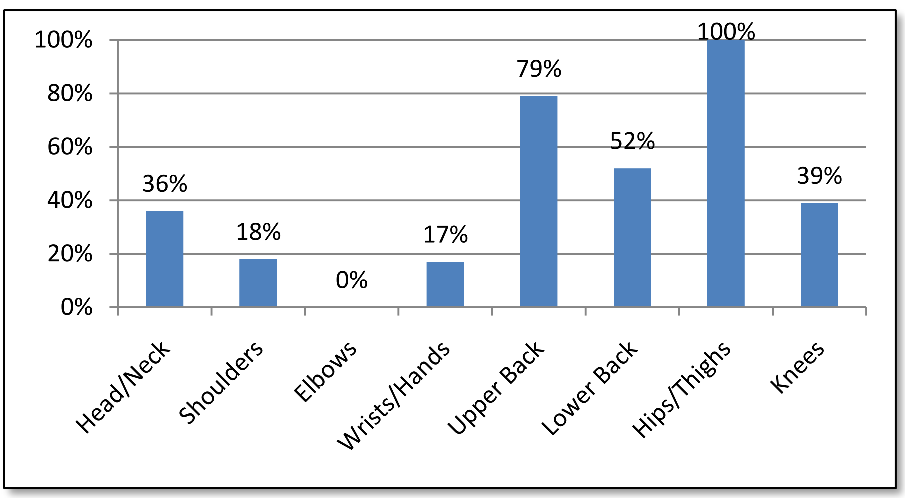


Figure 15: Percent Reduction in Discomfort Using Split Keyboard

Performance

In order to change the design and size of a standard keyboard, small changes in key location or size must be used to make up for the lost space. For users that have been accustomed to the design and layout of a keyboard, these changes may require some time to adapt to. A final measurement of the effect of changing to a new keyboard configuration is the performance of the participants as they move from the standard to the new keyboard.

The data logging software used within this study tracked keying rates throughout the entire timeframe of the project. Figure 16 provides the average keys per minute (and standard deviation) for the participants, and illustrates these rates for both the standard and split keyboard. A transition period is noted on the graph, which is the week where the split keyboards were distributed to all participants; this period is highlighted due to the fact that it took a week for all participants to transition to the split keyboard. The data shows that there is little variation in the performance of the participants throughout the length of the study. The analysis does not show any significant improvements or reductions in performance.

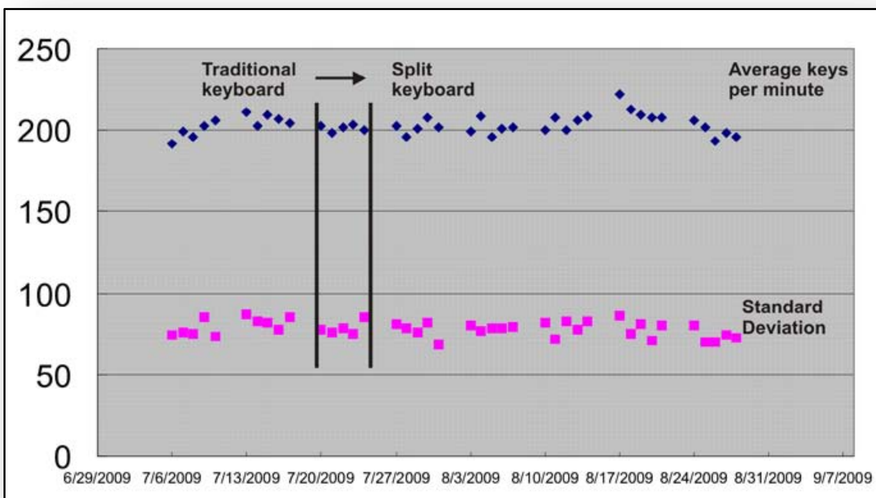


Figure 16: Average Keying Rates for Standard and Split Keyboard

CONCLUSIONS

One of the goals of this study was to determine whether people of different statures would experience any positive effects from using an adjustable split keyboard. The results related to posture, discomfort, and performance illustrated that a positive effect was seen for participants of all sizes and shapes.

Wrist posture, as measured by the angle of ulnar deviation, was shown to significantly improve for all participant groups, resulting in a moderate decrease in discomfort. This moderate reduction in hand/wrist discomfort posed an interesting question regarding the key influencers of discomfort while keying. The postural data showed that most employees were working near a neutral wrist position, and the high use of the tenting feature indicated that close to 50% of the population were in positions that reduced the level of wrist pronation. Therefore, it appears that factors such as exposure time and repetition rates, or the fact that typing still involves a certain level of pronation, are having a lingering influence on hand/wrist discomfort.

Using a set-up with the keyboard sections split apart was shown to be a significant preference of the participants, which worked towards answering the second question within this study. Participants did change their keyboard configurations to an extent that it was dramatically different from the conventional keyboard. In fact, the level of split chosen by participants was often greater than that provided by the fixed split keyboards on the market. This split preference resulted in significant reductions in upper body and low back discomfort. This result that was also noted in previous work by Grandjean et al. (1981; presented in Rempel, 2008) where their participants had a greater tendency to lean back in their chairs when using a split keyboard. The primary focus for keyboard design has always been around the hand/wrist and forearm position, but it appears that the overall postural effect of minimizing the reach distance to the keyboard halves is a positive result worth noting.

The effect of such workstation elements as the keyboard tray and the chair armrests cannot be ignored when looking at the results of this study. To further understand the preferences of individuals and the postural changes that would be seen by using a split keyboard, additional research would need to control these factors. Performing a field study like this project, where all factors are not under strict control, provides some insight into the interconnection of all the workplace elements.

A constant concern with the introduction of split keyboards, both from a company and employee perspective, is the level of acceptance of the users and any potential impact on performance. The performance data illustrated that the keying rate of the users could be maintained as they transitioned to the new product. Regardless of performance, acceptance of a new product such as a keyboard can be influenced by the challenge of learning the new keyboard configuration. Figure 17 shows the results from the exit survey that indicated that approximately 96% of the population was willing to keep or give the new keyboard a longer trial period. The length of this study allowed the users to adapt to the new keyboard configuration and determine if it can fit their needs. Research has shown that short term exposure to a new keyboard often leads towards rejection, but longer durations of exposure lead toward neutrality and acceptance (Rempel, 2008).

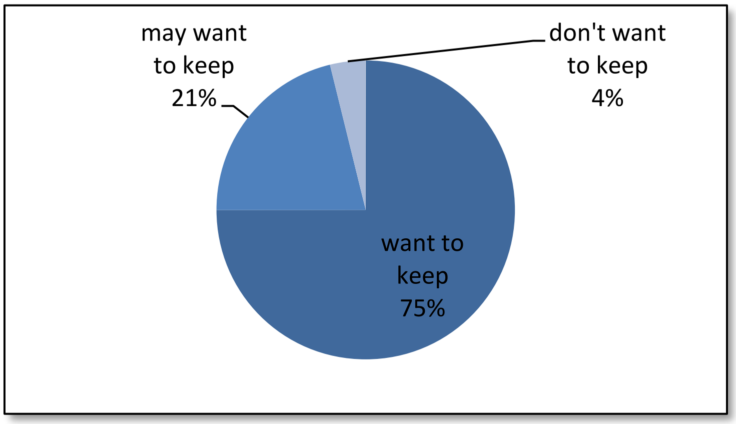


Figure 17: Acceptance Level of Split Keyboard Design

Additional research would be required to determine the level of acceptance of a more diverse population than used in this study. A group of experienced programmers tends to have a higher than average skill level on the keyboard, which may have allowed them to adapt to the change more easily. Conversely, the feedback from the study indicated that they were very particular about any changes to the location of keys due to the long term keying habits they had adopted. Given this critical characteristic, the high level of acceptance has a positive reflection on the postural and comfort benefits of the design.

The results of this study provide further positive feedback on the value and use of the split keyboard as an ergonomic solution in the office environment. Additional research is required to help answer the lingering questions noted in the study, but the positive results support the idea of continuing to push in this direction.

If there are any questions or comments related to this paper, they should be directed to info@atlasergo.com.

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