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The Effect of training, aim pattern and target type on the ergonomics and efficiency of handheld scanners

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The Effect of Training, Aim Pattern and Target Type on the Ergonomics and Efficiency of Handheld Scanners

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M.S. DEGREE THESIS

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Abstract

Handheld scanning is a prevalent industrial task that is prone to injury due to the repetitive motion of the task. Studies conducted with Rochester Institute of Technology and Honeywell have sought to discover the ergonomic and efficiency benefits of various scanning technologies and methods. One factor not fully investigated in these earlier works is the effect of training on the proper use of scanners. This thesis study compares trained and untrained user performance and ergonomics during a series of scanning tasks using a hand held omni-directional scanner. Comparison is based on such variables as target type (image that is scanned), aiming pattern (image projected from scanner) and time stress (self-paced versus time stress paced). Through this study is the potential to assess the value of training on efficiency and ergonomics during hand held scanner use.

A trained and an untrained group (each consisting of eight subjects) performed scanning tasks daily for ten days. Wrist postures and task completion times were recorded throughout the study as well as perceived comfort and usability. Results show that the untrained group tended to have greater wrist deviations and thus poorer ergonomics overall. With the exception of the first day, the trained and untrained groups did not differ in terms of efficiency. As a result of this first day difference, level of training seemed to affect efficiency over time resulting in a quick learning curve for the untrained group. There was a significant aim pattern-target type relationship for both training groups in terms of ergonomics and efficiency. Results suggest aim pattern preference was a function of training level. Under time stress, the effect on ergonomics depended on wrist posture and training level, but the trained group tended to have a more detrimental effect to ergonomics than the untrained group. As expected, efficiency increased under time stress, but time stress had no significant effect on perceived usability and comfort.

Table of Contents

List of Tables

List of Figures

Section 1

Introduction

Barcode scanner use has increased significantly in recent years, becoming an important tool in a wide variety of industries. Examples of industries that have become heavily reliant on this technology are retail and manufacturing, in the form of grocery check-out scanners, hand-held scanners and Portable Data Terminals (PDTs). These industries have also faced high incidents of work-related musculoskeletal disorders, particularly affecting the upper extremities. Heavy use of hand held scanners is an example of the repetitive motions which often result in this increase in incidents of injury to the wrist. With such a reliance on scanners in industry and the high incidence rates for this type of injury, it is important to realize the possibility for improvement to not only device design, but also to how the user uses the device. Despite the presence of design features that minimize ergonomic risk and increase efficiency, such as the pistol grip shape and omni-directionality, the benefits of these features may not be fully utilized without proper training. It is necessary to determine the value of training in terms of ergonomics and efficiency in order to benefit from this design and help decrease injury.

Studies conducted with Rochester Institute of Technology and Honeywell have sought to evaluate the ergonomic and efficiency benefits of various scanning technologies and methods. These studies have successfully accomplished many of Honeywell's objectives such as discovering the benefit of using an omni-directional scanner. However, these previous studies did not fully consider how user training influences the manner in which the scanner is used.

This thesis builds on the results of these previous studies with the additional consideration of training.

The main focus of this thesis is to evaluate the ergonomic effects and efficiency benefits of training workers on the proper use of an omni-directional scanner. Overall, it is proposed that training will result in increased efficiency, less wrist deviations and generally better ergonomics when compared to those without proper training. Furthermore, the study seeks to assess whether the effects of training are at all modulated by factors previously investigated, pertaining to scanner design and target type.

Section 2

Literature Review

2.1 Scanning

There are two main types of scanners used in industry today. The first is the in-counter barcode scanner typically found in grocery stores, where an item is moved across the scan window and the imager reads the barcode. Of this design, there is a single window model, with the imaging window usually embedded horizontally into a counter, and a two-window bi-optic scanner, in which there is a vertical as well as horizontal window. The major wrist motions required for this scanning task are dynamic in nature; the wrist and forearm are in constant motion.

The second type of scanner is a hand held design often found in retail and manufacturing and will be the focus of this study. For this design, the user holds the scanner and aims the optical aiming pattern at the target. Depending on the design, the user may then need to depress a trigger style button for the imager to read the target or the target may be read automatically. The hand held scanner uses either a linear or area imager. A linear imager reads only linear barcodes and the scanner line, the aim pattern projected, must be aligned horizontally with the length of the barcode for readability. The area imager uses two-dimensional imaging and as a result is omni-directional. A wider variety of target types can be read with the area imager and this scanner is capable of reading the target at any orientation. The major wrist motions required for this type of scanning task are static in nature, since the wrist and forearm remain in various postures for longer periods of time, while the user waits

for the scanner to read the code (Marshall & Mozrall, 2007). Because wrist motions are minimized, repetitive motion is reduced, which results in improved ergonomics.

For more than two decades, considerable awareness of and concern for work-related repetitive motion injuries has been present, especially in industries with higher incidence rates of such injuries. According to the Bureau of Labor Statistics (2006) in 2006, of all injury and illness in the manufacturing industry, 32.9% was to the upper extremities with injury to the finger, hand and wrist accounting for 15.1%, 5.3% and 5.7%, respectively of those injuries. Additionally, of all injury and illness in the retail trade industry, 21.8% was to the upper extremities with injury to the finger, hand and wrist accounting for 8.4%, 4.1% and 4.1%, respectively of those injuries. One such occupation in the retail industry, cashiering, has shown high incidence rates for wrist injury. Grocery check-out scanning, a light and repetitive motion manual material handling (MMH) task, involves moving items with low force exertion repeatedly for an average of 45-50-% of customer transaction time (Lehman, Psihogios, & Meulenbroek, 2001). As a result, numerous studies have been conducted on the ergonomic effects of scanning on cashiers.

Wrist motions have been analyzed to determine the best scanner check-out design to minimize potential injury. Results have been similar for numerous studies, (Lehman & Marras, 1994, Marras, Marklin, Greenspan, & Lehman, 1995, Lehman, Psihogios, & Meulenbroek, 2001) which concluded a two-window, or bi-optic scanner is ergonomically better than a single window scanner. This design superiority is due to the significantly larger scanning space in which an item can be placed in virtually any orientation. Scanned items do not need to be rotated and thus reduced wrist deviation results. Use of bi-optic scanners by cashiers results in

significantly reduced wrist deviation, wrist acceleration and muscle activity compared to use of a single window scanner. While these check-out style scanners are very different from hand held scanners, there are still important implications that can be ascertained from check-out scanner research. For example, research has shown under utilization of the bi-optic scanner design despite it being ergonomically better. In Lehman and Marras' study (1994), all subjects used the bi-optic scanner design to perform a series of standard grocery check-out scanning tasks. Despite all subjects scanning with this two-window design, fourteen of the thirty-two subjects did not utilize its two-window functionality. As a result, these fourteen people had significantly higher peak wrist accelerations than the subjects who used both windows. Additionally, their productivity was significantly lower than for the two-window users. Although an improved design was present, there was no quarantee that its functionality was being utilized.

Window design scanners have received significantly more attention in regards to research than have hand held scanners. However, significantly more people use hand held scanners in industry. The use of handheld scanners is increasingly present in a wide range of industries. High usage rates in such industries as retail, manufacturing and shipping are due to the fact that handheld scanners provide easy, convenient and reliable product tracking and verification methods. As a result of scanner prevalence, product design of scanners has strived to improve scanners in terms of efficiency and ergonomics. Physical design considerations such as weight and grip shape help improve ergonomics. The concept of area imaging and thus omni-directionality is a major technological design consideration that helps to not only improve ergonomics, but also efficiency.

Despite the numerous benefits to scanners, it is important to understand their inherent limitations. Although a low exertion task, the nature of scanning results in repetitive motion, which is a major cause for Musculoskeletal Disorders (MSDs). Improvement to scanner design has resulted in increased efficiency, but at a potential cost to ergonomics due to the resulting heavy reliance on scanners in industry, and thus repetitive motions of the wrist. With increased reliance on hand held scanners, it is therefore important to assess ways that the scanner design can be changed to help ergonomics as well. Because scanners are vital in many workplace settings, it is crucial to determine the best ways to incorporate them for use. The intended use based on design, and the actual use in the workplace is a concept that needs to be further investigated to determine the ways in which ergonomics and efficiency can further be improved.

In a study conducted by personnel from Rochester Institute of Technology (RIT) and Honeywell (Marshall & Mozrall, 2007), ergonomic and efficiency benefits were evaluated for linear versus area scanners as well as for various aiming patterns of area scanners. Scanning tasks were completed using three major target types: Linear barcodes, Data Matrix symbols and PDF (Portable Data File) symbols. In addition, five aiming patterns were analyzed in combination with these target types. Wrist position was monitored in the flexion/extension and radial/ulnar planes as subjects performed simulated scanning tasks. Time to complete the scanning task was also measured. Despite only minor wrist posture differences between the use of each scanner type, there was a significant reduction in task completion time for the area imager. Subjective ratings also showed strong preference for the area imager. Among the aiming patterns used for the area scanner, there was no significant difference between scan

time or preference and only significant difference in wrist extension between two of the aiming patterns. Changing the target type resulted in larger ulnar deviation for PDF codes and larger wrist extension for linear codes. For radial deviation and wrist flexion there was no significant difference between targets.

Results from Marshall and Mozrall's (2007) study imply that area imagers increase efficiency in barcode scanning. Significant differences were not found between aiming patterns, but there were wrist posture differences depending on barcode type. Although some conclusions can be made, analysis is not complete since wrist motion in the pronation/supination plane was not measured. The rotation of the forearm is a significant motion during hand held scanning and additional data on this motion could enhance the results found in this study. Other factors such as the orientation of the barcode or training could also augment this previous work and provide added insight into scanner usability.

As previously stated, handheld scanners are used heavily in such industries as retail, manufacturing and shipping. Scanners have become a necessary facet of such industries. Curiously, few published studies are present, especially to analyze the validity of their intuitive use and inherent design. It is therefore important to assess the task of scanning as well as the scanner design in terms of ergonomics and efficiency.

2.2 Cumulative Trauma Disorders

Cumulative Trauma Disorders (CTDs), also known as repetitive motion injuries, are disorders of the body's tendons and nerves caused by repeated exertions and excessive movements (Armstrong, 1986). Trauma can result in such disorders as carpal tunnel, tendonitis, and De Quervain's disease. According to the Bureau of Labor Statistics, in 2006 MSDs accounted for

30.2% of cases for days away from work due to injury or illness. Repetitive motion accounted for the highest number of median days away from work due to injury or illness (19 days), but had a fairly low incidence rate of 4 cases per 10,000 workers. Conversely, 23.3% of injury by body part was attributed to the upper extremities, with the upper extremities having the second highest incidence rate for injury at 30 cases per 10,000 workers with the median number of days of missed work at 7. Second only to the shoulder, the wrist is the body part associated with the highest median number of days away from work due to injury with an incidence rate of 5 cases per 10,000 workers. Carpal Tunnel Syndrome accounted for 29% of those injuries to the wrist. Repetitive motion injury is clearly prevalent in industry. Because of the long recuperation time for repetitive motion injuries, specifically wrist injuries, and due to the high incidence rate of injury to the upper extremities, it is important to continue research to help improve work conditions in any way that can possibly reduce injury (Bureau of Labor Statistics, 2005, Bureau of Labor Statistics, 2006). CTDs are becoming increasingly prevalent as technology becomes more reliant on repetitive, precision movement over long periods of time. Specific attention has been given to the wrist in relation to hand held devices designed to create greater efficiency, convenience and ease of use. Despite their good intentions, these devices still pose possible harm due to repeated use over time.

An example of how technology can induce MSDs is computer use and its effect on the upper extremities. Products such as the computer mouse and keyboard have been designed for increased productivity while also considering ergonomics. However, there is an association between mouse and keyboard use and Cumulative Trauma Disorders as has been shown by extensive study (Serina, Tal & Rempel, 1999; Dennerlein & Johnson, 2006; Gerr, et al., 2002).

During keyboard use, the wrists rest in a non-neutral posture which is characterized by greater wrist ulnar deviation as well as forearm pronation. During mouse use, there is greater wrist extension and less postural variability. (Serina, Tal, & Rempel, 1999). The resulting repetitive motions and sustained postures for such extreme wrist deviations are comparable to wrist motions in industrial jobs with high risk of CTDs. Dennerlein and Johnson, (2006) found that mouse intensive tasks require large extension in the forearm and wrist and keyboard intensive tasks result in ulnar deviation in the forearm and wrist. Gerr et al (2002) tracked new hires after starting a job that consisted of at least fifteen hours a week of computer work. Within the first month, 32% of those newly hired employees showed symptoms of musculoskeletal disorders, and more than 50% reported symptoms during their first year. These studies show the ergonomic results of non-neutral wrist and forearm postures and suggest that such motions should be evaluated as possible risk factors for CTDs. Similar to the keyboard and computer mouse, the productivity gained with hand held scanners also comes at a cost associated with CTDs.

It has been well established that extreme wrist deviations in repetitive tasks can cause CTDs (Bernard, 1997). Complex wrist deviations constitute wrist deviation in more than one axis. These complex wrist deviations are common in industrial tasks and are a likely cause for CTDs as well. There is a relationship between this complex wrist motion on wrist range of motion capacity. More specifically, radial deviation range of motion is significantly affected by the degree of flexion or extension present. When wrist extension is present, radial deviation capacity is greatest. When wrist flexion is present, radial deviation capacity range of motion is lowest, by over 30%. As a result of complex wrist motions that result in the wrist joint

approaching its range of motion limit, there is greater stress to the joint and greater chance of injury (Marshall, Mozrall, & Shealy, 1999). The combination of extreme and complex wrist deviations, which is also common in the use of hand held scanners, compounds the likelihood of CTDs.

An important factor in hand tool use, which hand held scanners can be considered, is their design in regards to musculoskeletal disorders. Injuries typically associated with hand tool use include carpal tunnel syndrome and muscle strains of the lower arms, hands and wrist. Extreme or awkward posture places added strain on the tissues and musculoskeletal structures that comprise the joint, increasing the likelihood of injury. There are some basic strategies that can be followed in hand tool design in order to minimize the chance for injury. A critical consideration of hand tool design is anthropometry. Designs should be based on human body dimensions, such as hand dimensions incorporated into handle length, grip span and trigger length. In general a straight, neutral wrist posture is best and preferred (Goetsch, 1999). In order to have a neutral wrist during tool use, the correct grip type should be used in the design. In the case of hand held scanning, the pistol, or power grip is often utilized. For the pistol grip type, the tool handle is perpendicular to the forearm axis and the direction of the motion or force is typically parallel to the forearm axis. Removing twisting of the tool by designing the tool to function in line with the force applied or motion of the task promotes this neutral posture (Goetsch, 1999). The pistol grip is the correct grip type for the hand held scanner since it keeps the wrist straight and neutral. Additional design considerations for hand tools in general, which the hand held scanner design attempts to follow, are to ensure the grip area is contoured to the palm of the hand, and that the tool can be used in either the right or the left hand (Konz, 1990).

A design consideration specific to the hand held scanner is its omni-directionality feature, which removes the need for twisting the forearm during scanning. Hand tools such as hand held scanners that consider ergonomic risk in their design can greatly minimize the occurrence of CTDs.

For many industrial tasks, the upper extremities tend to be the most frequently used body part. As a result of frequent and often times repetitive motion, trauma to the tendons and nerves in the form of CTDs can occur. Consequently, numerous studies have been conducted to analyze motions of the upper extremties to help develop an understanding of the relationship between wrist motion and injury. Research into this relationship, specifically in regards to hand held devices, could help to identify factors about product design that aid in minimizing ergonomic risk. Study on this topic, especially for those tasks and hand held devices that have not been thoroughly studied, such as hand held scanners, is of great importance.

2.3 Training

In industry, attention to worker safety and health is evident from the existence of such organizations as the National Institute for Occupational Health and Safety (NIOSH) or the Occupational Safety and Health Administration (OSHA). These organizations have been created to ensure proper working conditions and methods. Working environments are analyzed to help ensure workers are performing within a capable work capacity, and are safe and comfortable while doing their job in regards to workstation, tool design and the general work environment.

An important factor in aiding workers in performing safely and efficiently is training. The first effort in any work environment should always be to design out any potential problems, yet this is often not completely effective. Thus, training becomes necessary to provide instruction

to overcome whatever inherent design limitations may exist. A great deal of research has been completed on the effects of training and the differences between a trained and untrained worker. One of the objectives of Ergonomics is to train workers to use better and safer working habits, which can reduce the risk of MSDs. Additionally, efficiency can be increased when such habits are properly followed.

Training is used to show people the proper use of tools or the proper techniques that may not be intuitive. Additionally, training is used in the absence of an aid to show workers techniques to minimize risk, such as proper lifting techniques. There are many training methods. One basic method for training is a lecture type format in which information is passively conveyed about a topic in order to help someone understand that topic. Other methods are more engaging and include demonstration or hands-on learning as well as information about a topic. Studies show that as the method of training becomes more engaging, the effects of the training increase, in terms of acquired knowledge and reduction of injury and illness. In general, the most engaging hands-on training methods have been shown to be three times more effective than the least engaging or lecture style training methods and this hands-on training is most effective in reducing injury and illness (Burke, Sarpy, Smith-Crowe, Chan-Serafin, Salvador, & Islam, 2006).

The concept of training and the study of its effectiveness is a general topic and conclusions from such research can easily be applied to a wide range of biomechanical tasks. In order to demonstrate the effects of training on ergonomics and efficiency, the biomechanical task of lifting and the associated techniques has been utilized. The previously mentioned lecture-style training is often the predominant training method for lifting tasks in industry

however it is not always the best method, as Lavender, Lorenz and Andersson (2002) sought to demonstrate in their study on lifting techniques. They question whether such a teaching technique is always effective since research shows these classical techniques to be largely ineffective in decreasing injury. Training of proper lifting techniques for example traditionally includes the anatomy of the back, what types of stresses the back can handle, and what good lifting techniques are. In reality, a great deal of lifting training in industry has been largely ineffective in actually preventing back injuries. (Burke, Sarpy, Smith-Crowe, Chan-Serafin, Salvador, & Islam, 2006).

Lavender, Lorenz and Andersson (2002) question informational lifting training in favor of the addition of motor skill training in which practice and muscle memory help to teach proper lifting technique. Additionally, they suggest that adopting these safer techniques is dependent on a lifestyle change, or conscious choice by the lifter, since these techniques are often perceived to increase handling time. Results of Lavender, Lorenz and Anderssons' study show that proper lifting techniques significantly reduce spinal loading without significantly increasing handling time. A final fact to consider is their suggestion that other factors such as the perception of time pressure inherent in the job may adversely affect lifting techniques and posture. Lavender, Lorenz and Andersson point to the theory that regardless of training, if a worker feels they must work quickly, their perception of time pressure will negatively impact working posture.

Before further investigating the significance of training, validation that novice and experts differ in terms of ergonomics and efficiency is necessary. Observation has indicated differences between lifting techniques of highly trained and novice workers. Research shows

further evidence of these differences biomechanically. In MMH lifting, both novices and experts reduce trunk asymmetries; however experts also reduce knee flexion and general asymmetries on the knee. Overall, expert methods result in less energy expenditure and are safer (Gagnon, Plamondon, Gravel, & Lortie, 1996).

If experts are considered to be safer and more efficient while at work, it is important to verify their methods against those of novices. Such was the case in a study completed by Gagnon (2005). Expert lifting techniques were analyzed and found to reduce loading on the back, decrease back asymmetries due to foot pivoting, and reduce the required mechanical work through decreased load transfer duration, decreased trajectory and decreased knee flexion. To validate these expert lifting techniques, as well as to develop improved training methods, novices observed both experts and novices performing lifting tasks, taking special note of footwork, load maneuvers and body posture, in order to compare and improve upon their own techniques. Using this training method, the novices were able to alter their techniques to more resemble that of an expert, thus improving back loading and mechanical work, as well as validating the expert techniques.

Several studies have demonstrated that training can be beneficial to ergonomics and efficiency within the context of using ergonomically designed products. In a study conducted by Houwink, Hengel, Odell, and Dennerlein (2009), two groups of subjects, one with training and one without training, performed a set of pointing tasks with both a standard and alternative computer mouse. Results show that for both groups, wrist and forearm posture differed between uses of the two mouse types. With both groups, the alternative mouse showed less postural deviation. However for the trained group pronation was lower overall and ulnar

deviation was lower with the alternative mouse. EMG values for all wrist motions were lower with the alternative design for the trained group, but there was no difference in muscle activity between mouse types for the untrained group. Performance or task completion time, was slower for the alternative mouse and untrained group, but there was no difference in completion time between mouse types with the trained group. This study shows that training is necessary for the full benefits of an ergonomic design to be realized by a user when first using the product. Training has clearly resulted in ergonomic and efficiency benefits.

Atlas Ergonomics (Atlas Ergonomics, 2006), a company that collects data on employee discomfort and evaluates individual equipment use, discovered that merely providing the best ergonomic furniture to an office environment is not sufficient. One-thousand full-time office employees were surveyed before and after an ergonomic evaluation, workstation alteration and training on those alterations to discover levels of discomfort and knowledge regarding their office furniture features. Employees among three companies experienced 18-33% reduction in maximum discomfort within one month of the changes and 45-60% reduction within nine months. Prior to training and adjustments, 20% of employees had little to no knowledge about their furniture, while 45% had good knowledge. Nine months after the evaluation, 7% had little to no knowledge and 70% had good knowledge. This case study demonstrates that simply providing ergonomically designed products is not adequate to preventing musculoskeletal discomfort and injury. Education and training about the products is necessary for the benefits to be fully realized.

Prior research shows a distinct difference in performance and technique between trained and untrained workers. Such research implies varying levels of training can affect

performance in terms of ergonomics and efficiency. Additionally, the benefits of ergonomic product design features are better utilized when training of such features occurs. Expert user methods can be used to help train novices in a format that directly engages the user, such as practice of proper techniques and observation of expert versus novice task completion or product use. These types of training methods are potentially the most effective in reducing ergonomic risk and increasing efficiency.

2.4 Conclusion

As is evident from past research, Cumulative Trauma Disorders of the wrist are prevalent in industry and it is beneficial to study repetitive tasks in order to better understand the ways in which the ergonomic risk factors can be reduced. Hand held devices are a major cause for such disorders, with their characteristic frequent, repetitive movement. High rates of wrist injury can be found in such industries as retail, where scanning is prevalent. Numerous studies have been completed on wrist and arm motion of cashier scanning. However, little work has been completed in other industries where hand held scanning is present, such as manufacturing and shipping. Subsequently, certain aspects of the scanning process have not been investigated, such as level of training, or the resulting wrist deviations from the various possible target types or aiming patterns of the scanner. Such knowledge would be useful in an age where scanners are heavily used for product tracking as well as in package delivery. Information learned from such a study, as well as general knowledge about omni-directional scanners could be vital training material for scanner users and useful information for product designers.

Technology has increasingly strived to improve performance and ergonomics of the scanning task. Many scanners are omni-directional. This design feature is meant to help both

performance and ergonomics. Although this feature is present, utilization is dependent on the extent to which workers have been trained to use it. Omni-directionality, like many design features of numerous products, is not always common knowledge and is not necessarily intuitive. Additionally, general use of a barcode scanner requires initial acclimation, to become aware of the angle and distance range at which the scanner must be placed in order to read a target. There is no assurance that design features will be utilized. Training is therefore vital to increase the likelihood of correct product use, in the safest most efficient way possible. Analysis of wrist motion trends during scanning use as well as proper training in the use of scanners could potentially decrease the incidence of injury as well as increase efficiency.

Section 3

Methodology

3.1 Experimental Objective

A primary objective of this study was to determine if training has an effect on the use of an omni-directional hand held scanner. Specifically, the goal was to determine the benefit of training for hand held scanner use in terms of ergonomics and task efficiency. An additional objective was to determine whether these training effects are mitigated by other scanner design factors including aim pattern and target type.

3.1.1 Hypotheses

Based on the experimental objective, the following hypotheses are proposed.

- Training will result in increased use of the omni-directional functionality, thereby reducing wrist deviation and improving ergonomics, while also improving efficiency during scanning tasks.
- Over time, the performance of untrained subjects will approach that of trained subjects in terms of ergonomics and efficiency.
- Regardless of training level, time pressure will cause subjects to reduce the use of omni-directionality, resulting in negative effects on ergonomics.
- Aiming pattern preference will be a function of training level.

3.2 Experimental Overview

This study utilized a repeated measures experimental design with 16 subjects. The experiment duration was ten days with a two-day break at the half-way point (12 days total). The experiment consisted of two tasks, a Self-Paced Task and a Time-Stress Paced Task, which are described in detail in Section 3.6.5 and Section 3.6.6. The Self-Paced Task was performed each of the ten days. The Time Stress-Paced Task was performed after The Self-Paced Task on the fifth and tenth day. An outline of the experiment schedule is shown in Table 3.1. Subjects were counterbalanced (half were assigned to the Trained Group and half were assigned to the Untrained Group) based on level of training at entry into the study. The study was conducted within a seven-week time span.

All subjects performed one replication of The Self-Paced Task with each aiming pattern, each day, resulting in ten replications per aiming pattern per subject overall. The order in which the aiming patterns were used each day was randomized. Subjects performed one replication of Task 2 with each aiming pattern, on the designated days (fifth or tenth), resulting in 2 replications per aiming pattern per subject overall. For Task 2 the order in which the aiming patterns were used each day was identical to the order used for that day during The Self-Paced Task.

Task	Day 1	Day 2	Day 3	Day 4	Day 5	Break Day	Break Day	Day 6	Day 7	Day 8	Day 9	Day 10
Self-Paced	X	X	X	X	X			X	X	X	X	X
Time Stress-Paced					X							X

Table 3.1: Experiment Schedule

3.3 Subjects

The Trained Group had 8 subjects (3 male, 5 female) and the Untrained Group had 8 subjects (6 male, 2 female), totaling 16 subjects (9 male, 7 female) participating in the study. All subjects were right handed, college age, undergraduate or graduate level engineering students. Subjects were paid for their participation after successfully completing the study. It was necessary to ensure a group of completely inexperienced hand held scanner users for the Untrained Group, therefore half of those participants selected were required to have no scanning experience. If a subject had any experience with hand held scanners, they were placed in the Trained Group.

3.4 Independent Variables

3.4.1 Group (Training Level)

Group type was an independent variable consisting of two levels (Trained and Untrained). Subjects participated in either the Trained Group or the Untrained Group, but not both. Criteria for placement in a group were based on level of experience with hand held scanner use. If a subject answered affirmatively to having experience in hand held scanner use, they were placed in the Trained Group. If a subject answered that they had no experience with hand held scanner use, they were placed in the Untrained Group. Participants were accepted based on the above categorization and the availability of remaining slots in that group, until both groups had the predetermined and equal number of subjects. The Trained Group received barcode scanning training prior to the start of the experiment and the Untrained Group received no training regarding barcode scanning.

3.4.2 Subject

Subject was an independent variable consisting of 16 participants. Because of the natural variability between participants, this variable was blocked in the within subject ANOVA design. Because half of the subjects participated in the Trained Group and half in the Untrained Group, this variable was also nested within the Group independent variable for the between subject ANOVA design.

3.4.3 Aiming Pattern

Aiming pattern was an independent variable consisting of 5 levels (LED, Bracket, Grid, Crosshair, and Bulls-eye). Visual depictions of these patterns are shown in Figure 3.1. The Crosshair, Bracket, Grid and Bulls-eye Aim Patterns were projected in a red light and the LED Aim Pattern was projected in a green light. These aiming patterns are predominant choices available to display as an optical pattern when using a scanner. Such patterns are used to align the scanner and target for proper reading of the target. Five hand held area image scanners were supplied by Honeywell. The scanners were identical pistol grip area image scanners; however each displayed a different aiming pattern for the purposes of the study. Figure 3.2 below depicts an image of one of the scanners used in the study. During the Self-Paced Task and the Time Stress-Paced Task, subjects were asked to perform the tasks five times, once with each of five hand held scanners, each displaying one of the five aiming patterns. The order in which subjects used each aiming pattern was randomized by day.

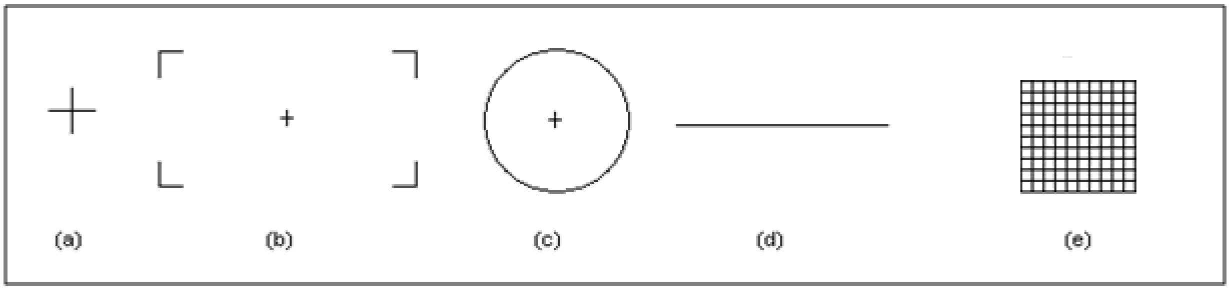
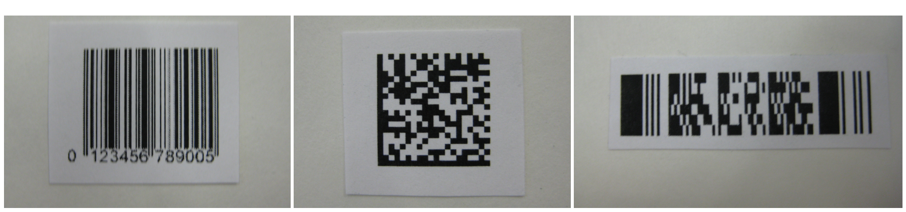


Figure 3.1: Representation of Scanner Aim Patterns (a) Crosshair (B) Bracket (c) Bulls-eye (d) LED (e) Grid

Figure 3.2: Example of Hand Held Scanner

3.4.4 Target Type

Target type was an independent variable consisting of three levels (Linear, Data Matrix and Portable Data File (PDF) codes). Examples of these targets can be found in Figure 3.3. These target types are major code technologies frequently used in industry. During the Self-Paced Task and the Time Stress-Paced Task, subjects were asked to scan three scan boards, with one containing only linear codes, one containing only Data Matrix codes, and one containing only PDF codes. The order in which each target type scan board was scanned was randomized.



(a) (b) (c)

Figure 3.3: Target Types (a) Linear Barcode (b) Data Matrix (c) PDF

3.4.5 Day

Day was an independent variable consisting of ten levels for the Self-Paced Task and two levels for Time Stress-Paced Task. Subjects performed The Self-Paced Task Monday through Friday for two consecutive weeks, resulting in 10 weekdays in succession. Subjects performed the Time Stress-Paced Task on the fifth and tenth day (Fridays) of their respective experiment.

3.4.6 Task

For the Time Stress-Paced Task the independent variable *Task* is used to compare the Self-Paced Task and the Time-Stress Paced Task in order to assess the effect of Time Stress on ergonomics and efficiency. Further information regarding the Self-Paced and Time Stress-Paced Tasks can be found in Sections 3.6.5 and 3.6.6, respectively.

3.5 Dependent Variables

3.5.1 Forearm Pronation/Supination Deviation

Forearm pronation/supination deviation average was a dependent variable in both Tasks. The average deviation was calculated for each of the four rows of each of the scan boards. Forearm deviation was recorded as a means of tracking ergonomics. Depictions of the range of motion for forearm pronation/supination deviation can be found in Figure 3.4 below.

3.5.2 Wrist Flexion/Extension Deviation Average

Wrist flexion/extension deviation average was a dependent variable in both Tasks. The average deviation was calculated for each of the four rows of each of the scan boards. Wrist deviation

was recorded as a means of tracking ergonomics. Depictions of the range of motion for wrist flexion/extension deviation can be found in Figure 3.4 below.

3.5.3 Wrist Radial/Ulnar Deviation Average

Wrist radial/ulnar deviation average was a dependent variable in both Tasks. The average deviation was calculated for each of the four rows of each of the scan boards. Wrist deviation was recorded as a means of tracking ergonomics. Depictions of the range of motion for wrist radial/ulnar deviation can be found in Figure 3.4 below.

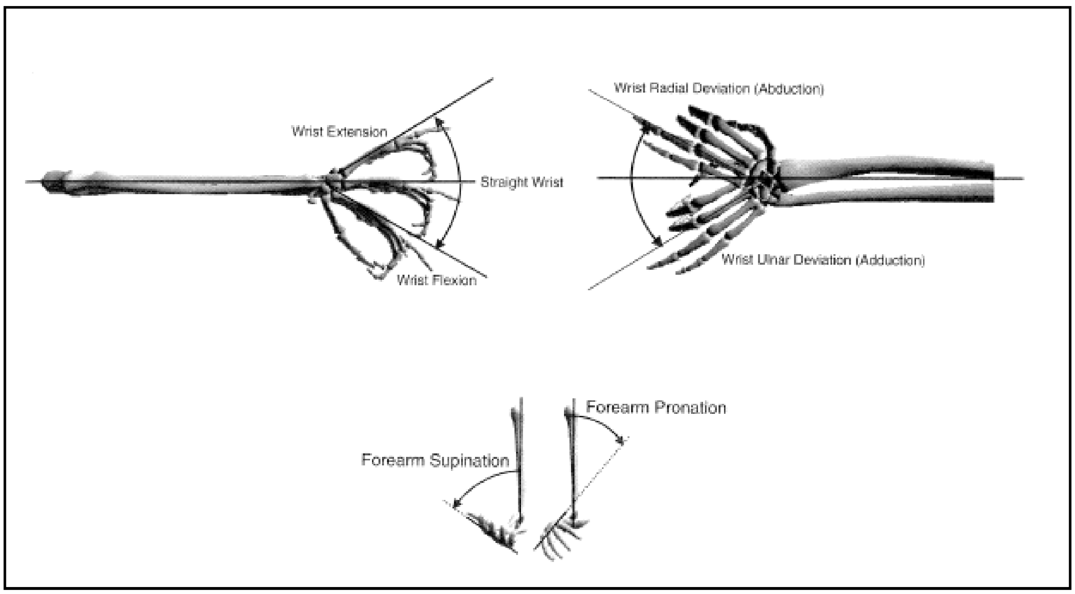


Figure 3.4: Angle Definitions for the Wrist and Forearm (Delleman, Haslegrave, & Chaffin, 2004)

3.5.4 Scan Time

Completion time was a dependent variable in both Tasks. Time to complete each Task was recorded, as well as broken down further to record the time to complete each scan board. Time was recorded as a means of tracking efficiency.

3.5.5 Subjective Aiming Pattern Rating for Perceived Comfort

Subjective aiming pattern rating for perceived comfort was a dependent variable in both Tasks. After performing a task with an aiming pattern, subjects were asked to rate the scanner on a five-point Likert scale (Appendix A) in terms of how comfortable the scanner was during use in performing the task. Prior to the start of the experiment, instruction was given on use of the scale. Subjects were instructed to rate the aiming patterns with open ended criteria, not restricting their perceived comfort ratings to any particular guidelines. Perceived comfort was recorded in order to determine the relationship between wrist and forearm deviations, aim pattern and perceived comfort.

3.5.6 Subjective Aiming Pattern Rating for Perceived Usability

Subjective aiming pattern rating for perceived usability was a dependent variable in both Tasks. After performing a task with an aiming pattern, subjects were asked to rate the scanner on a five-point Likert scale (Appendix B) in terms of how easy to use the scanner was while performing the task. Prior to the start of the experiment, instruction was given on use of the scale. Subjects were instructed to rate the aiming patterns with open ended criteria, not restricting their perceived usability ratings to any particular guidelines. Perceived usability was recorded in order to determine the relationship between wrist and forearm deviations, training, aim pattern and perceived ease of use.

3.5.7 Subjective Aiming Pattern Rank

Subjective aiming pattern rank was a dependent variable in both Tasks. After performing a task with all five aiming pattern, subjects were asked to rank the five aiming patterns in order of preference. Subjects physically reordered the scanners to reflect their preference. Subjects were instructed to rank the aiming patterns with open ended criteria, not restricting their preferences to be based on simply comfort and usability. Aiming pattern rank was recorded in order to determine the relationship between wrist and forearm deviations, training and aiming pattern preference.

3.6 Experimental Procedure

3.6.1 Overview

Data collection occurred at the Rochester Institute of Technology in the Human Performance Lab. Subjects were directed to this lab for all aspects of the study, from informed consent through participation. Discounting first-day explanation and protocol, at the beginning of each test day subjects entered the Human Performance lab and instrumentation was attached to the dominant hand. The given tasks for the day then proceeded. Since there were five different aiming pattern types, there were five hand held scanners present for the subject to use, each programmed to display one of the aiming patterns. After completion of the task with a given aiming pattern, subjects were asked to rate the comfort and usability using a 5-point Likert scale. The task was repeated until all aiming patterns were used to perform the task and subsequently rated and ranked.

3.6.2 Informed Consent

Subjects were informed of the nature of and background information for the study, as well as the basic procedure to be followed. They were informed of the risks inherent in the study, and shown the instrumentation to be used for data collection. Subjects were then required to read and sign an informed consent form approved for use by the Institutional Review Board of Rochester Institute of Technology (Appendix C).

3.6.3 Instrumentation

Subjects were given instruction while two electrogoniometers where attached to the wrist and forearm of the subject's dominant hand according to the instrumentation's instruction manual. For measurement of wrist flexion/extension and radial/ulnar deviation, the Biometrics SG65 sensor was used. This two-axis goniometer measured angular movement in two planes simultaneously. For measurement of forearm pronation/supination deviation, the Biometrics Q150 sensor was used. This sensor measured angular movement in only one plane. All attachments were made using medical grade double-sided adhesive tape. Data were collected using DataLINK, a subject worn, Data Acquisition System that accompanies the Biometrics instrumentation which allows for collection of both analog and digital data (Biometrics Ltd., 2002). Figure 3.5 and Figure 3.6 depict attachment of the goniometry sensors to the wrist and forearm. Forearm and wrist deviations were recorded in degrees for the entirety of each Task at 1000Hz (1000 samples per second).

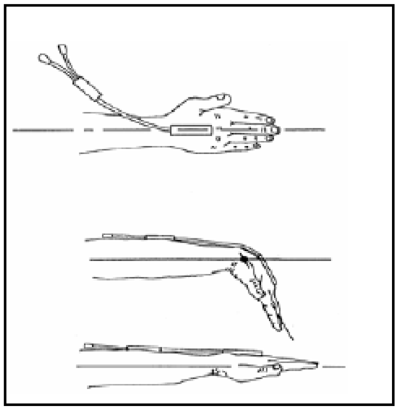


Figure 3.5: Goniometry Attachment for two-axis sensor (Biometrics Ltd., 2002)

Figure 3.6: Goniometry Attachment for two-axis and single-axis sensors

A set of scan boards was used for the objective of the scanning tasks. A scan board is a white, matte, standard size poster board consisting of four rows and five columns of targets, totaling 20 targets per board. A set of scan boards is three scan boards, one for displaying each of the target types. Two sets of scan boards were used to ensure no scan board effect was present so they did not affect the results of the study. Within each of the two sets, the orientation of the targets was randomized such that the orientation of the target in the first column of the first row was identical for all three boards within a set. Orientation had five levels- horizontal, vertical left, vertical right, 45 degrees left, and 45 degrees right. Target orientation was randomized to ensure varied orientation between the subject and target during scanning. An example of a Scan Board is shown in Figure 3.7

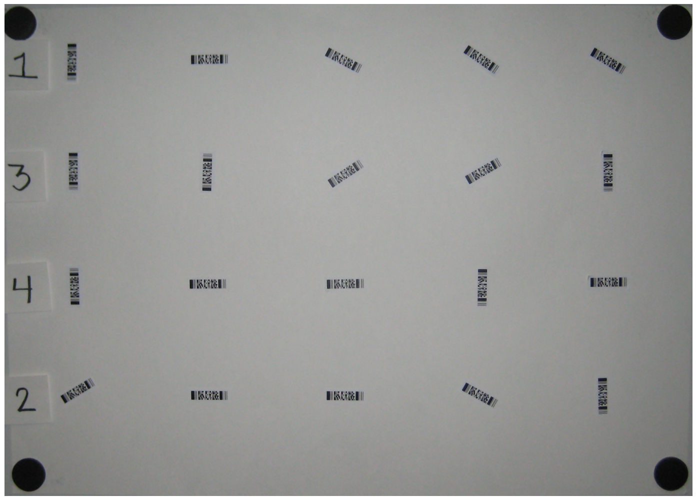


Figure 3.7: Example Scan Board: PDF Scan Board

Scanning was completed with four identical Hand Held Products laser area image scanners and one Hand Held Product LED area image scanner provided by Honeywell. Each scanner projected a different Aim Pattern, but all scanners were capable of omni-directional scanning.

3.6.4 Training

The level of training a subject received depended upon which Group they were in, Trained or Untrained. Studies show that as the method of training becomes more engaging, the effectiveness of training increases, in terms of acquired knowledge and reduction of injury and illness (Burke, Sarpy, Smith-Crowe, Chan-Serafin, Salvador, & Islam, 2006). Since there were only two levels for Training – Training present and Training not present, the Trained Group was given as much training as possible within the scope of the study. After instrumentation was set up for data collection, the Trained Group received instruction regarding hand held scanning

functionality and use. This training was given on the first day of the experiment only. Information was provided on basic hand held scanner functionality and the Trained Group was told that the scanners were omni-directional and thus the scanner did not need to be rotated to match the orientation of a target. As a result, subjects were told that their wrist could remain neutral throughout the scanning tasks. Because the Trained Group received engaging training, a label was also placed on each of the scanners as an additional vehicle for information to be conveyed to the subjects. This label was a visual reminder of the omni-directionality benefit and provided refresher training throughout the study. This label was considered part of Training and was only placed on the Trained Group's scanners. An image of the label can be found in Figure 3.8

Figure 3.8: Caution Label

Instruction on task completion was given then demonstration of proper scanning technique was completed and subsequently, subjects were instructed to practice proper scanning methods using the different aiming patterns, on the different target types. Subjects were instructed to continue practicing until they felt comfortable with the scanning task, usually taking no more than five minutes to practice. This concluded the training session for the Trained Group.

While the Trained Group received in-depth instruction and demonstration of the scanner's functionality and had significant opportunity to practice scanning beforehand, the Untrained Group of subjects received no information or training except for basic hand held scanner functionality and instruction on task completion.

3.6.5 Self-Paced Task

The focus of this study was on characteristics of the scanning process. Consequently, simulated scanning tasks using scan boards (Section 3.6.3) were used. The Self-Paced Task consisted of scanning a set of scan boards, one at a time, from left to right. Within each scan board subjects were instructed to scan the rows in the order denoted next to each row, from left to right. An image depicting task setup can be found in Figure 3.9 below. Data collection began at the start of a verbal cue and ended with the task when the subject completed scanning all three scan boards. The Self-Paced Task was then repeated four times for the remaining aiming patterns.

The Self-Paced Task was completed every weekday for ten days. After instrumentation was set up for data collection, subjects were positioned for the start of the task and given the first of five scanners for use. The top row on each scan board was placed at eye level. Subjects were instructed to complete the task at a normal, comfortable pace, as if the task was their fulltime job. Upon hearing a verbal cue, subjects were to begin the task.

Figure 3.9: Experiment Set-up (Both Tasks)

Data collection consisted of reading in wrist and forearm deviation in the three planes of movement previously described in Sections 3.5.1, 3.5.2 and 3.5.3. Additionally, a digital event marker was used to signify specific points during the task. Events flagged with a marker were the start and finish of the task as well as the end of each row and start of each board, totaling 15 markers for every Task completion. Task completion time was recorded concurrently with angular movements using the same software. An example of the graphical display resulting from data collection can be found in Figure 3.10. The vertical lines signify the digital event markers. The top-most data trace represents Ulnar and Radial Deviation. The middle data trace represents Pronation and Supination. The bottom-most data trace represents Flexion and Extension.

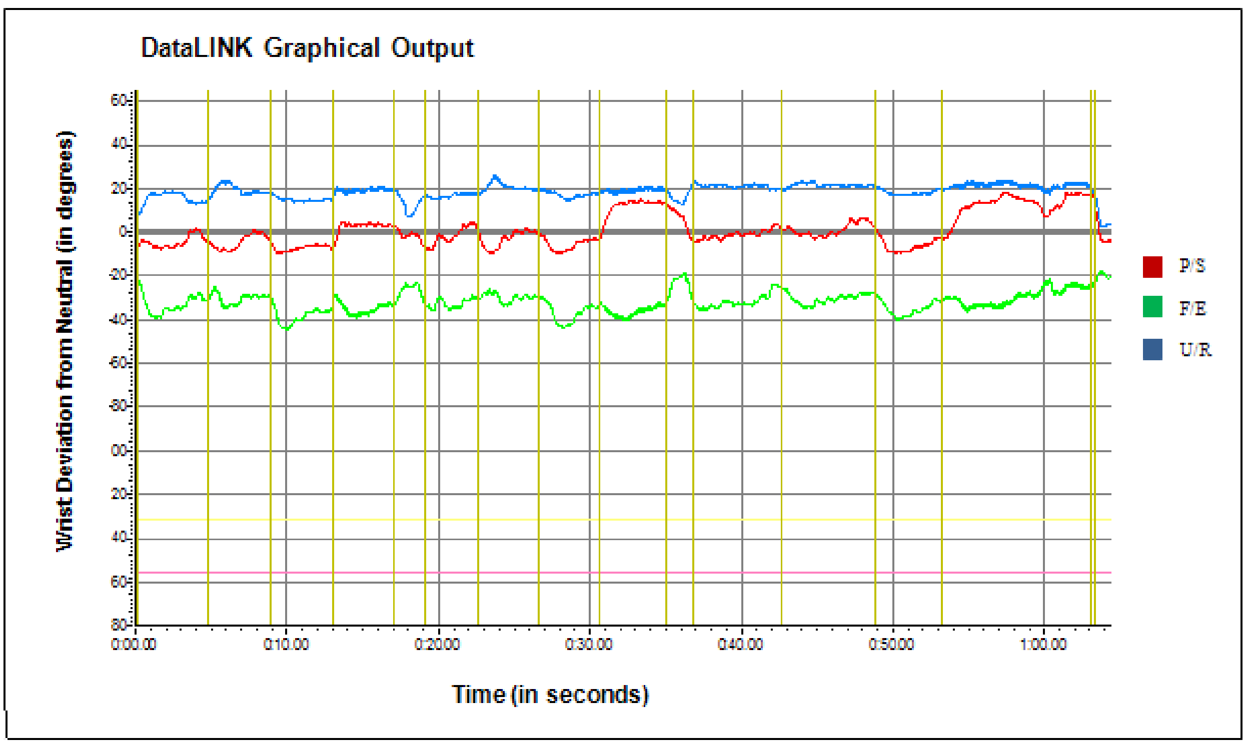


Figure 3.10: DataLINK Graphical Output

3.6.6 Time Stress-Paced Task

The Time Stress-Paced Task was completed on the fifth and tenth day of the experiment after completion of the Self-Paced Task. The Time Stress-Paced Task is identical to the Self-Paced Task with the exception of initial scanning instructions. Instead of being asked to perform at a comfortable pace, subjects were instructed to complete the task as fast as possible. Subjects were told their task completion times from the Self-Paced Task for the given day for a given aiming pattern, with a goal of completing the Time Stress-Paced Task faster than the Self-Paced Task.

3.6.7 Subjective Rating and Rank

After completing the Self-Paced Task for a given aiming pattern, subjects were asked to rate the aiming pattern on a five-point Likert Scale in terms of ease of use as well as in terms of usability (Appendix A & B). After completing the task for all five aim patterns on a given day, subjects were then instructed to rank the scanners in order of preference, by physically putting the scanners in order from best to worst. If it was the fifth or tenth day, the Time Stress-Paced Task was then completed and the aim patterns were rated and ranked identical to the process in the Self-Paced Task. Ranking the aim patterns (For Self-Paced Task on days 1-4/6-9; For Time Stress-Paced Task on days 5/10) concluded the day for the experiment and instrumentation was then detached from the subject.

3.7 Data Analysis

Raw data were collected for task completion time and wrist and forearm deviation in the pronation/supination, flexion/extension and radial/ulnar movement planes. Wrist and forearm deviation data were converted to degrees of movement from neutral according to the Biometrics provided conversion found in the user's manual. A macro specific to the experiment set-up was written in Microsoft Excel using Visual Basic in order to separate the data by event marker. All data were then compiled into a single spreadsheet that was formatted for the MiniTab statistical software package.

A multi-factor analysis of variance (ANOVA) for repeated measures was performed on each dependent variable. Analysis was completed for the Self-Paced Task on the scan time dependent variable as well as all wrist deviation dependent variables and both subjective rating dependent variables listed in Section 3.5 using the independent variables Subject, Group, Day, Aim Pattern and Target Type. An ANOVA for repeated measures was completed with Subject as a nested factor within Group. Significant Main effects and Interaction effects were then individually analyzed using two-factor analysis of variance for repeated measures. This analysis was then repeated for the Self-Paced and Time Stress-Paced Task data from Day 5 and Day 10 for the same dependent variables using the independent variables Subject, Group, Task, Day, Aim Pattern and Target Type. Only the Task main effect and its interaction effects were of concern. Further information on data analysis can be found in Section 4. All analysis was completed using the MiniTab 15 statistical software package.

Section 4

Results

Analysis of variance for repeated measures was completed for both the Self-Paced and Time Stress-Paced Tasks. The independent variables Group, Subject, Aim Pattern, Target Type, Day and Task were used with the dependent variables for Supination, Pronation, Flexion, Extension, Ulnar Deviation, Scan Time, Perceived Comfort and Perceived Usability.

4.1 Self-Paced Task

During the self-paced task, participants were instructed to complete the scanning task at a normal, comfortable pace as if the task were their full-time job. An ANOVA for repeated measures was completed on wrist deviations and scan time to assess ergonomics and efficiency. Table 4.1.1 depicts a summary of the ANOVA results.

For each dependent variable, the statistically significant highest order interactions were fully analyzed. Effects were considered statistically significant for a .05 alpha level. For example, for Supination the Group*Day*Target Type interaction is statistically significant and was fully analyzed. Any two-way interaction or main effect not included in this three-way interaction that was statistically significant was also fully analyzed. Table 4.1.2 depicts a summary of which main effects and interaction effects were fully analyzed. Further analysis was completed using AVOVA for repeated measures and Tukey's HSD Post Hoc Tests.

	Subject (Group)	Group	Day	Aim Pattern	Target Type	Group* Day	Group* Aim Pattern	Group* Target Type	Day*Aim Pattern	Day* Target Type	Aim Pattern* Target Type	Group* Day* Aim Pattern	Group* Day* Target Type	Group*Aim Pattern* Target Type	Day*Aim Pattern* Target Type
Supination	0.000*	0.143	0.000*	0.000*	0.000*	0.000*	0.397	0.000*	0.148	0.000*	0.000*	0.685	0.000*	0.944	0.998
Pronation	0.000*	0.050*	0.000*	0.364	0.000*	0.000*	0.044*	0.012*	0.035*	0.000*	0.938	0.004*	0.061	0.972	0.999
Flexion	0.000*	0.568	0.000*	0.000*	0.000*	0.000*	0.000*	0.000*	0.612	0.000*	0.000*	0.567	0.051	0.000*	0.991
Extension	0.000*	0.680	0.000*	0.054	0.000*	0.000*	0.002*	0.005*	0.480	0.011*	0.662	0.702	0.005*	0.691	1.000
Ulnar	0.000*	0.430	0.000*	0.629	0.000*	0.000*	0.236	0.000*	0.965	0.361	0.250	0.277	0.742	0.699	1.000
Time	0.000*	0.301	0.000*	0.000*	0.000*	0.041*	0.101	0.000*	0.294	0.000*	0.000*	0.826	0.892	0.002*	0.175

*Significant at .05 alpha level

Table 4.1.1: Self-Paced Task Ergonomics and Efficiency ANOVA Results 1

	Subject (Group)	Group	Day	Aim Pattern	Target Type	Group* Day	Group* Aim Pattern	Group* Target Type	Day*Aim Pattern	Day* Target Type	Aim Pattern* Target Type	Group* Day* Aim Pattern	Group* Day* Target Type	Group*Aim Pattern* Target Type	Day*Aim Pattern* Target Type
Supination	0.000*		0.000*	0.000*	0.000*	0.000*		0.000*		0.000*	0.000*		0.000*		
Pronation	0.000*	0.050*	0.000*		0.000*	0.000*	0.044*	0.012*	0.035*	0.000*		0.004*			
Flexion	0.000*		0.000*	0.000*	0.000*	0.000*	0.000*	0.000*		0.000*	0.000*			0.000*	
Extension	0.000*		0.000*		0.000*	0.000*	0.002*	0.005*		0.011*			0.005*		
Ulnar	0.000*		0.000*		0.000*	0.000*		0.000*							
Time	0.000*		0.000*	0.000*	0.000*	0.041*		0.000*		0.000*	0.000*			0.002*	

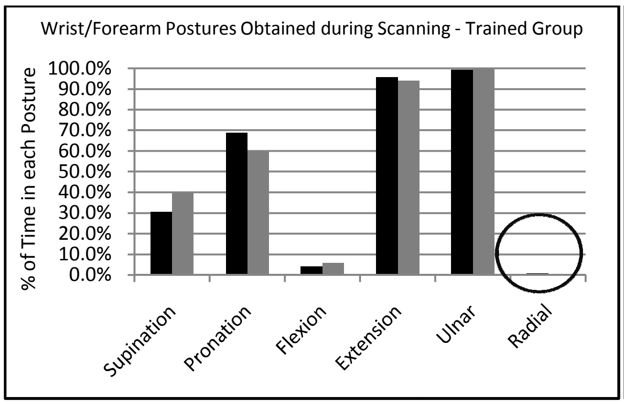
*Significant at .05 alpha level   Fully Analyzed

Table 4.1.2: Self-Paced Task Ergonomics and Efficiency ANOVA Results 2

4.1.1 Ergonomics

4.1.1.1 Radial Deviation

Radial Deviation is not included in further analysis since this wrist posture is not prominently used in handheld scanning. Figure 4.1.1 and 4.1.2 below display a snapshot of the percentage of time during each task that two subjects from each Group were in each wrist and forearm posture obtained during scanning. Additionally, average Radial and Ulnar Deviation for each Target Type is shown in Figure 4.1.3. Based on the small amount of Radial Deviation present, it is concluded that further Radial Deviation analysis is not necessary or applicable to this study.



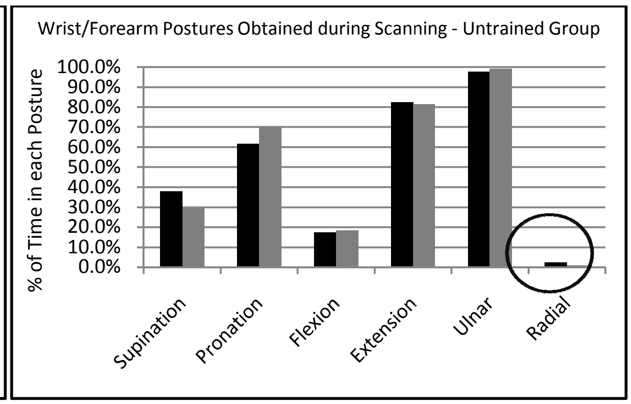


Figure 4.1.1 and 4.1.2: Wrist/Forearm Postures Obtained during Scanning – The Figure on the left depicts percentage in each wrist deviation for two subjects in the Trained Group. The figure on the right depicts percentage in each wrist deviation for two subjects in the Untrained Group. The black bars correspond to the self-paced task and the gray bars correspond to the time-stress task. Circled is the percentage of Radial Deviation.

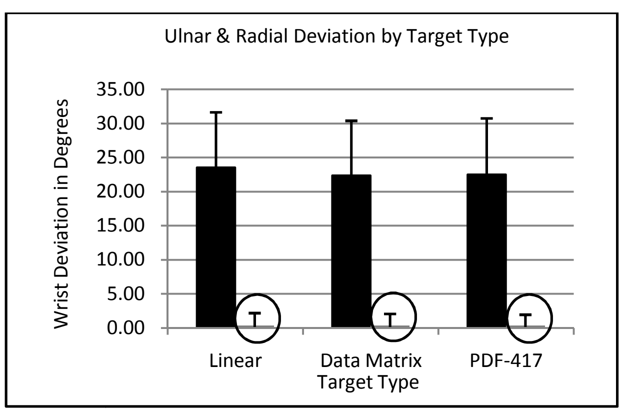


Figure 4.1.3: Ulnar & Radial Deviation by Target Type – Depiction of average radial and ulnar deviation for both Groups during the self-paced task broken down by Target Type. The black bars correspond to Ulnar Deviation. The grey bars correspond to Radial Deviation. Circled is average radial deviation.

4.1.1.2 Supination

All Minitab results for Supination in the Self-Paced Task can be found in Appendix D.

*4.1.1.2.1 Group*Day*Target Type*

Data were separated by Group (Trained and Untrained). Within each Group, data were then separated by Target Type to analyze the effect of Day. Interaction plots for the Group*Day*Target Type three-way interaction are depicted below in Figures 4.1.4 and 4.1.5.

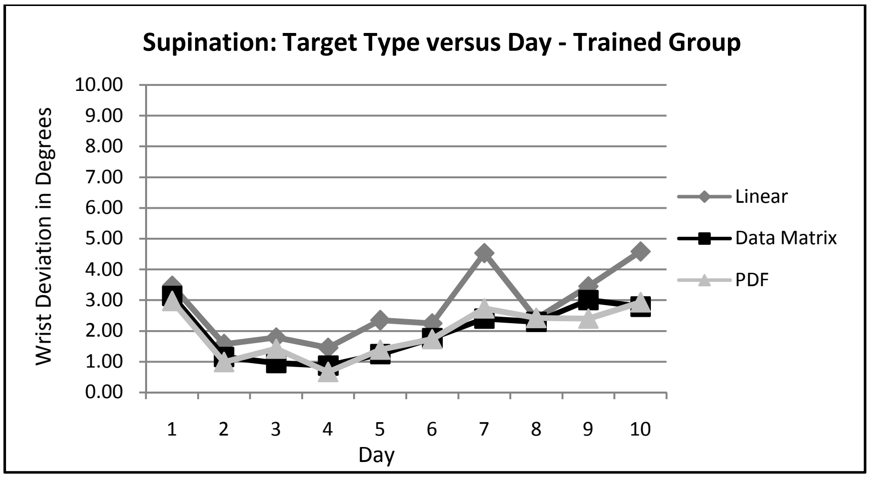


Figure 4.1.4: Supination: Target Type versus Day – Trained Group, Interaction Plot

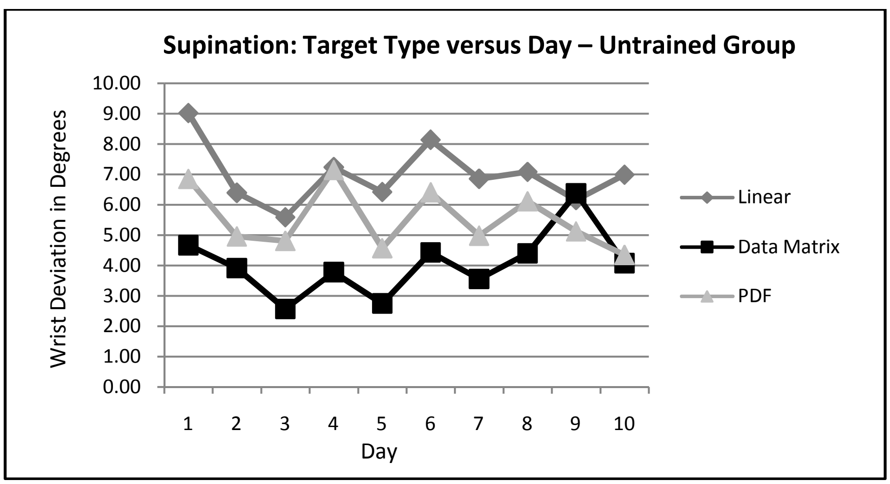


Figure 4.1.5: Supination: Target Type versus Day – Untrained Group, Interaction Plot

For each Target Type within each Group, Tukey's HSD Post Hoc Test was completed for Day to determine statistically significant differences between Days. For the Linear Target Type and the Trained Group, Day is statistically significant ($F_{9,\ 1520}$=3.21, P=0.003). Day 4 is

significantly different from both Day 7 (P=0.0401) and Day 10 (P=0.0345). There are no other statistically significant differences between days at a .05 or .10 alpha level. For the Linear Target Type and the Untrained Group, Day is not statistically significant ($F_{9,\ 1520}$=0.93, P=0.505). There are no statistically significant differences between Days at a .05 or .10 alpha level. Figure 4.1.6 and 4.1.7 below depict average Supination for the Linear Target Type for both Groups.

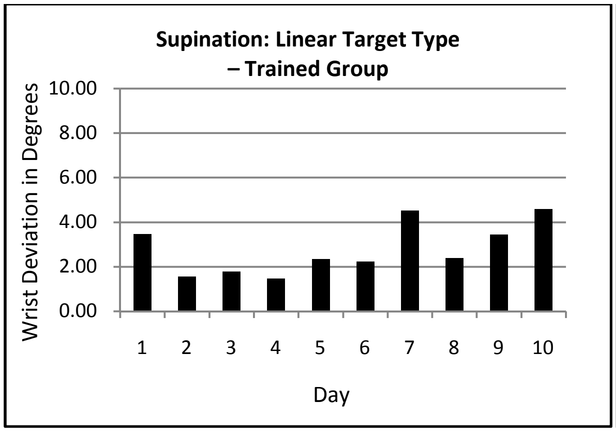


Figure 4.1.6: Supination: Linear Target Type – Trained Group

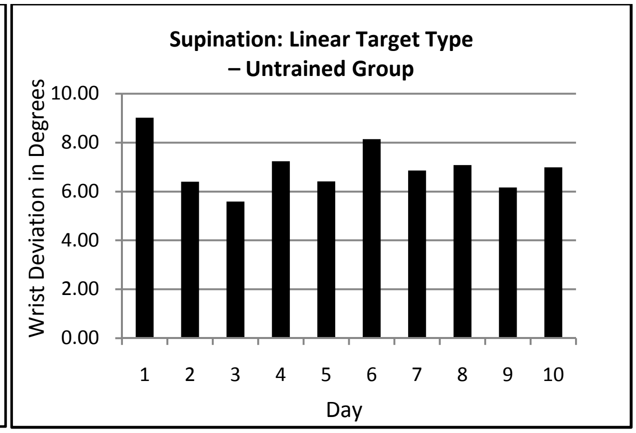


Figure 4.1.7: Supination: Linear Target Type – Untrained Group

For the Data Matrix Target Type and the Trained Group, Day is statistically significant ($F_{9,\ 1520}$=2.26, P=0.029). However, there are no statistically significant differences between Days at a .05 or .10 alpha level. For the Data Matrix Target Type and Untrained Group, Day is not statistically significant ($F_{9,\ 1520}$=1.53, P=0.158). There are no statistically significant differences between Days at a .05 or .10 alpha level. Figures 4.1.8 and 4.1.9 below depict average Supination deviation for the Data Matrix Target Type for both Groups.

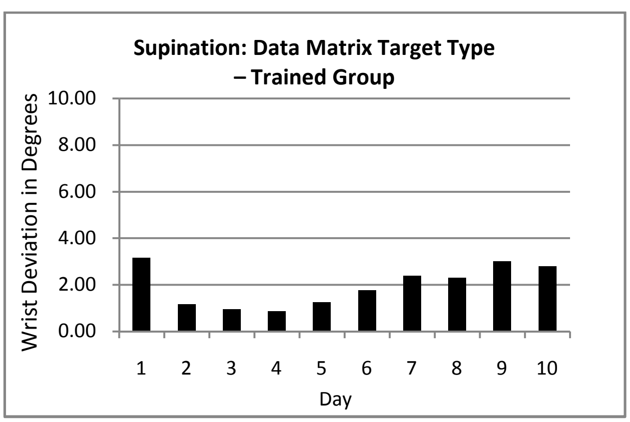


Figure 4.1.8: Supination: Data Matrix Target Type – Trained Group

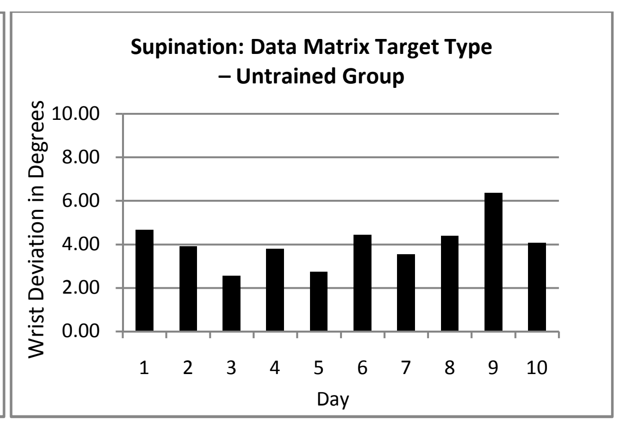


Figure 4.1.9: Supination: Data Matrix Target Type – Untrained Group

For the PDF Target Type and the Trained Group, Day is not statistically significant ($F_{9, 1520}$=1.77, P=0.092). There are no statistically significant differences between days at a .05 or .10 alpha level. For the Data Matrix Target Type and Untrained Group, Day is not statistically significant ($F_{9, 1520}$=0.76, P=0.654). There are no statistically significant differences between Days at a .05 or .10 alpha level. Figure 4.1.10 and 4.1.11 below depict average Supination deviation for the PDF Target Type for both Groups.

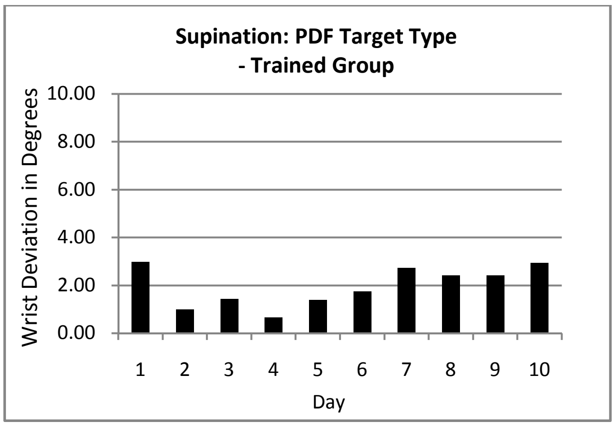


Figure 4.1.10: Supination: PDF Target Type – Trained Group

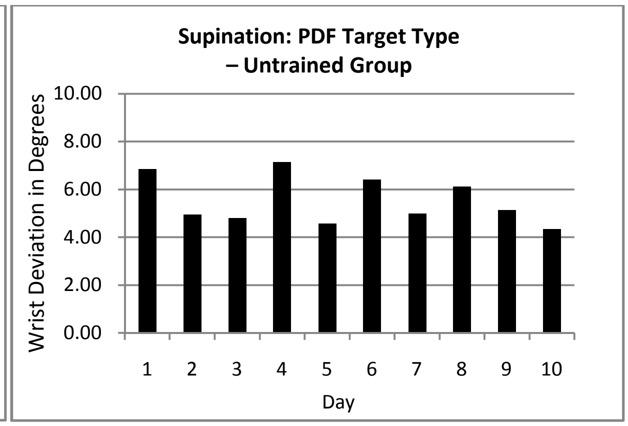


Figure 4.1.11: Supination: PDF Target Type – Untrained Group

For the Linear Target Type, Day was statistically significant for both Groups. However, there were statistically significant differences for Day in the Trained Group, but not in the Untrained Group. Although Day was statistically significant for the Data Matrix Target Type in the Trained Group, no pair-wise difference between Days were statistically significant. In general, the Untrained Group had greater average supination than the Trained Group across all Target Types and Days. Although there are statistically significant differences between Days, no obvious trends emerge for either Group, for any Target Type.

*4.1.1.2.2 Group*Target Type (Target Type Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the Target Type Main Effect within each Group. An interaction plot for the Group*Target Type two-way interaction is depicted below in Figure 4.1.12.

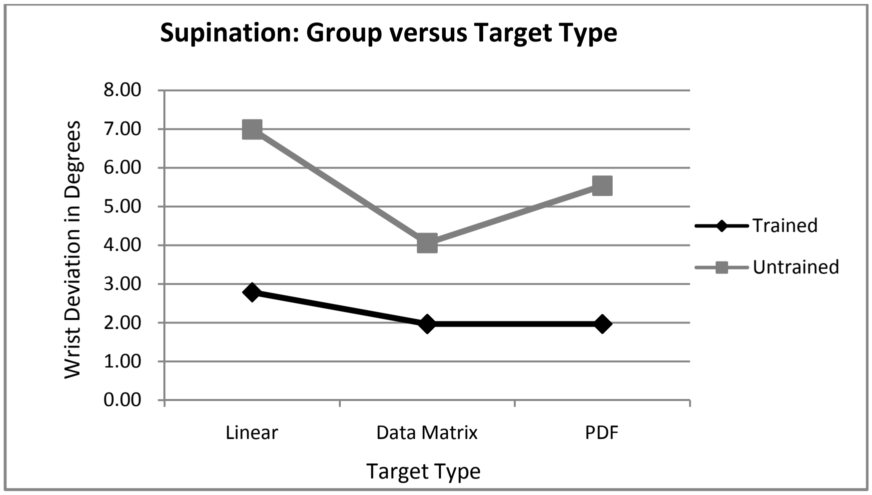


Figure 4.1.12: Supination: Target Type Main Effect by Group – Interaction Plot

For each Group, Tukey's HSD Post Hoc Test was completed for Target Type to determine statistically significant differences between Target Types. For the Trained Group, Target Type is statistically significant ($F_{2,\ 4776}$=7.11, P=0.007). The Linear Target Type is statistically different from the Data Matrix and PDF Target Types (P-value= 0.0146 for both pair-wise comparisons). For the Untrained Group, Target Type is statistically significant ($F_{2,\ 4776}$=5.68, P=0.016). The Linear Target Type is statistically different from the Data Matrix Target Type (P-value=0.0119). There are no other statistically significant differences between Target Types at a .05 or .10 alpha level in either Group.

Within the Linear Target Type there is no statistically significant difference between Groups ($F_{1,\ 3184}$=3.73, P=0.095). Within the Data Matrix Target Type there is no statistically significant difference between Groups ($F_{1,\ 3184}$=0.85, P=0.386). Within the PDF Target Type there is no statistically significant difference between Groups ($F_{1,\ 3184}$=2.39, P=0.166). Although the Untrained Group has higher average Supination for all Target Types it is not statistically significant at a .05 alpha level. For the Linear Target Type, there is a difference between Groups at a .10 alpha level with the Untrained Group averaging 4.21 degrees greater Supination than the Untrained Group. Figure 4.1.13 depicts the average Supination for each Group by Target Type.

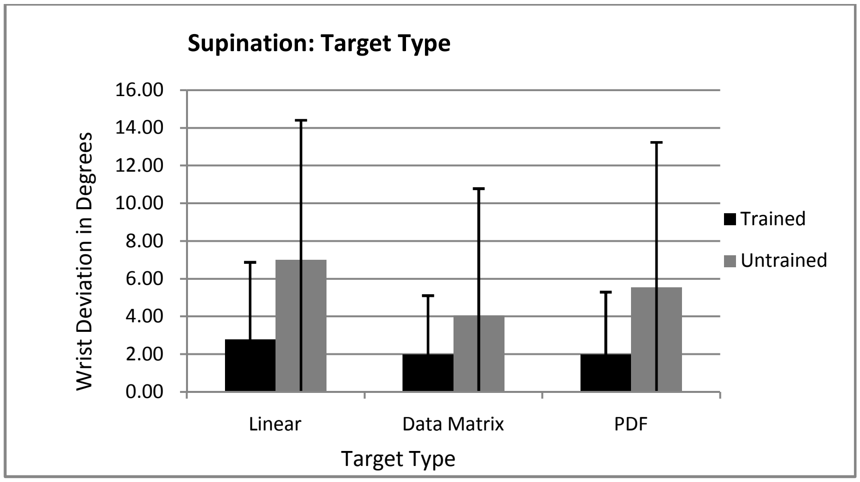


Figure 4.1.13: Supination: Target Type Main Effect by Group

*4.1.1.2.3 Aim Pattern*Target Type*

Data were separated by Target Type to analyze the effect of Aim Pattern within each Target Type. An interaction plot for the Target Type*Aim Pattern two-way interaction is depicted below in Figure 4.1.14.

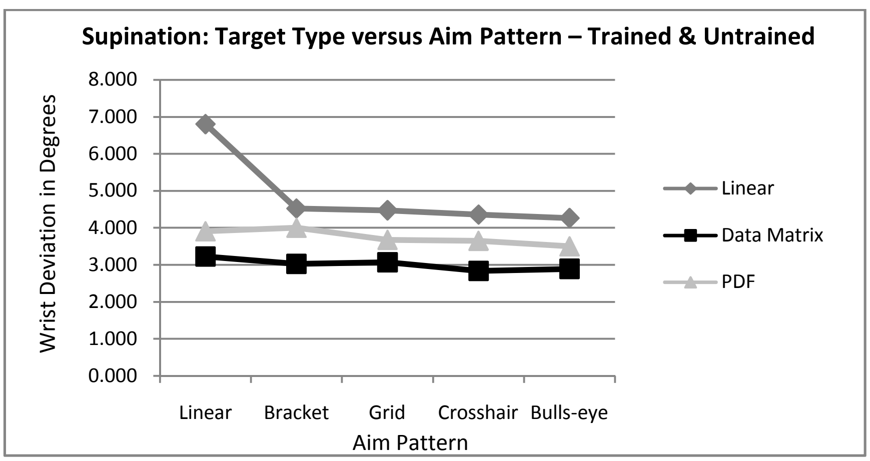


Figure 4.1.14: Supination: Target Type versus Aim Pattern – Interaction Plot

For each Target Type, Tukey's HSD Post Hoc Test was completed for Aim Pattern to determine statistically significant differences between Aim Patterns. When the Trained Group scans the Linear Target Type, Aim Pattern is statistically significant ($F_{4, 1560}$=11.10, P=0.000). The LED Aim Pattern is significantly different from the Bracket, Grid, Crosshair and Bulls-eye Aim

Patterns (P=0.0001, 0.0005, 0.0001, and 0.0001 respectively). The LED Aim Pattern results in an average 2.33 degrees greater Supination than the other Aim Patterns.

When the Untrained Group scans the Linear Target Type, Aim Pattern is statistically significant ($F_{4,\ 1560}$=6.46, P=0.001). The LED Aim Pattern is significantly different from the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns (P=0.0135, 0.0031, 0.0032, and 0.0017 respectively). The LED Aim Pattern results in an average 2.45 degrees greater Supination than the other Aim Patterns.

There are no statistically significant differences (at .05 or .10 level) between the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when scanning the Linear Target Type for either Group.

For the LED and Bracket Aim Patterns, Group is not statistically significant at a .05 level, but is at a .10 alpha level (LED: $F_{1,\ 624}$=4.78, P=0.065; Bracket: $F_{1,\ 624}$=4.45, P=0.073). When the Untrained Group scans the Linear Target Type with the LED or Bracket Aim Pattern, the average Supination is an average 4.43 degrees greater than for the Trained Group. Group is not statistically significant at a .05 or .10 level for the Grid, Crosshair or Bulls-eye Aim Patterns. Figure 4.1.15 depicts the average Supination for the Linear Target Type by Aim Pattern, broken into Group.

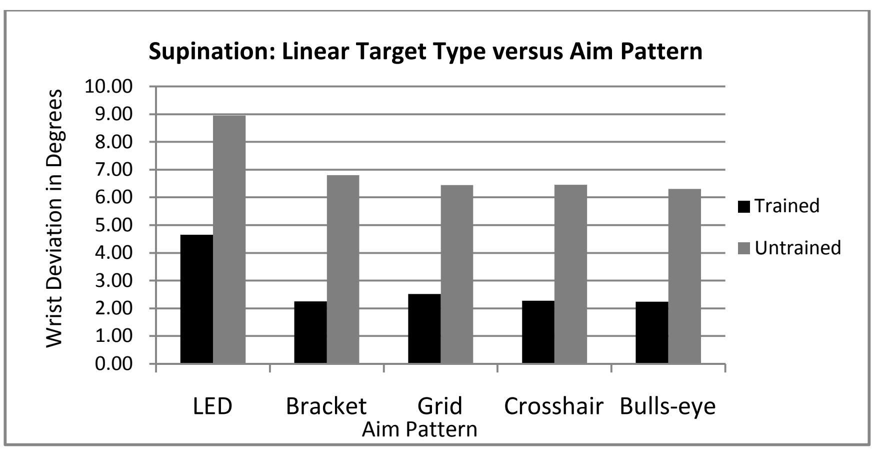


Figure 4.1.15: Supination: Linear Target Type versus Aim Pattern

When the Trained Group scans the Data Matrix Target Type, Aim Pattern is not statistically significant ($F_{4,\ 1560}$=1.09, P=0.381). When the Untrained Group scans the Data Matrix Target Type, Aim Pattern is not statistically significant ($F_{4,\ 1560}$=0.72, P=0.583). There are no

statistically significant differences (at .05 or .10 level) between the LED, Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when scanning the Data Matrix Target Type. Group is not statistically significant at a .05 or .10 level for any Aim Pattern when scanning the Data Matrix Target Type. Figure 4.1.16 depicts the average Supination for the Data Matrix Target Type by Aim Pattern, broken into Group.

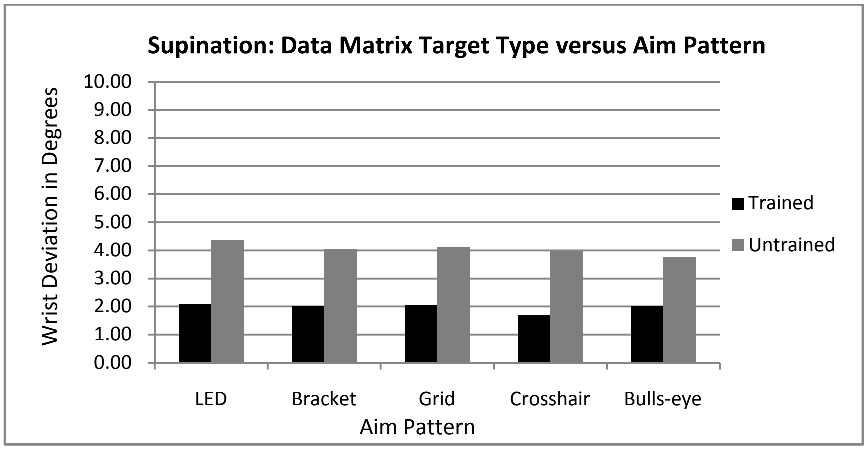


Figure 4.1.16: Supination: Data Matrix Target Type versus Aim Pattern

When the Trained Group scans the PDF Target Type, Aim Pattern is not statistically significant ($F_{4,\ 1560}$=1.82, P=0.152). When the Untrained Group scans the PDF Target Type, Aim Pattern is not statistically significant ($F_{4,\ 1560}$=1.50, P=0.230). There are no statistically significant differences (at .05 or .10 level) between the LED, Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when scanning the PDF Target Type. Group is not statistically significant at a .05 or .10 level for any Aim Pattern when scanning the PDF Target Type. Figure 4.1.17 depicts the average Supination for the PDF Target Type by Aim Pattern, broken into Group.

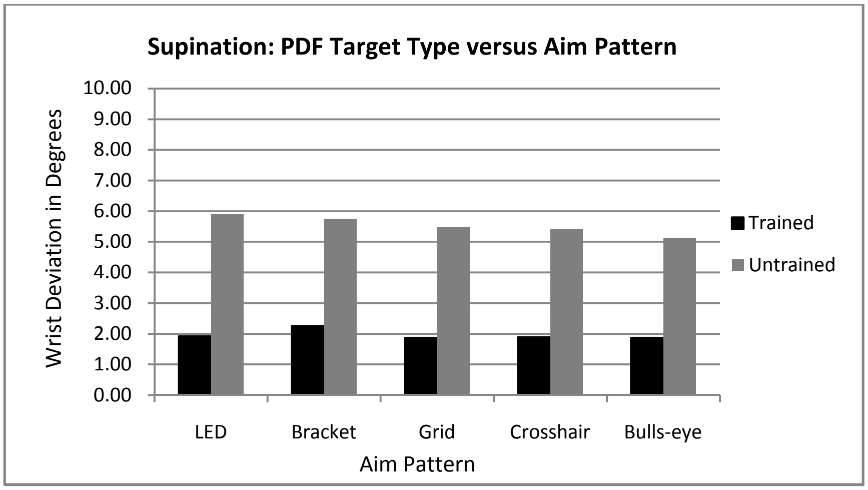


Figure 4.1.17: Supination: PDF Target Type versus Aim Pattern

There is a statistically significant difference between the LED Aim Pattern and the other four Aim Patterns when scanning the Linear Target Type. The LED Aim Pattern results in greater Supination by an average 2.33 degrees. There were no statistically significant differences between Aim Patterns when scanning the Data Matrix or PDF Target Types.

4.1.1.3 Pronation

All Minitab results for Pronation in the Self-Paced Task can be found in Appendix E.

*4.1.1.3.1 Group*Day*Aim Pattern*

Data were separated by Group (Trained and Untrained). Within each Group, data were then separated by Aim Pattern to analyze the effect of Day. Interaction plots for the Group*Day*Target Type three-way interaction are depicted below in Figures 4.1.18 and 4.1.19.

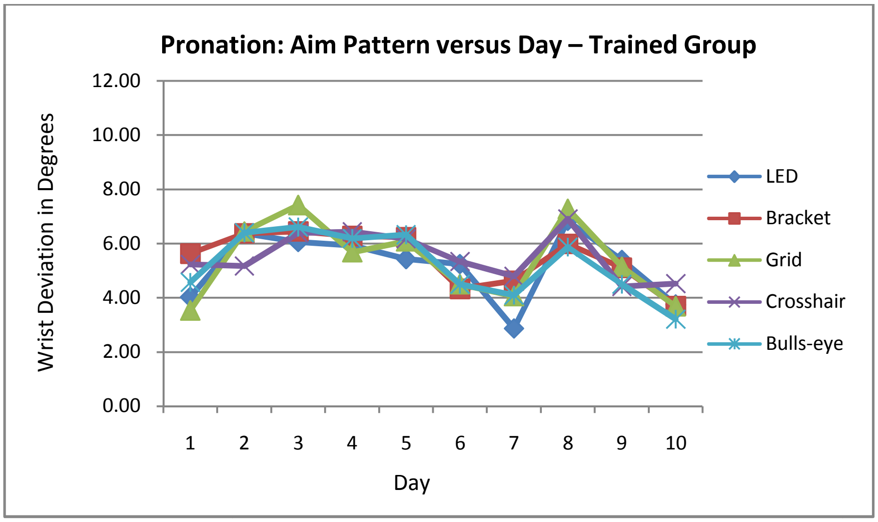


Figure 4.1.18: Pronation: Aim Pattern versus Day – Trained Group, Interaction Plot

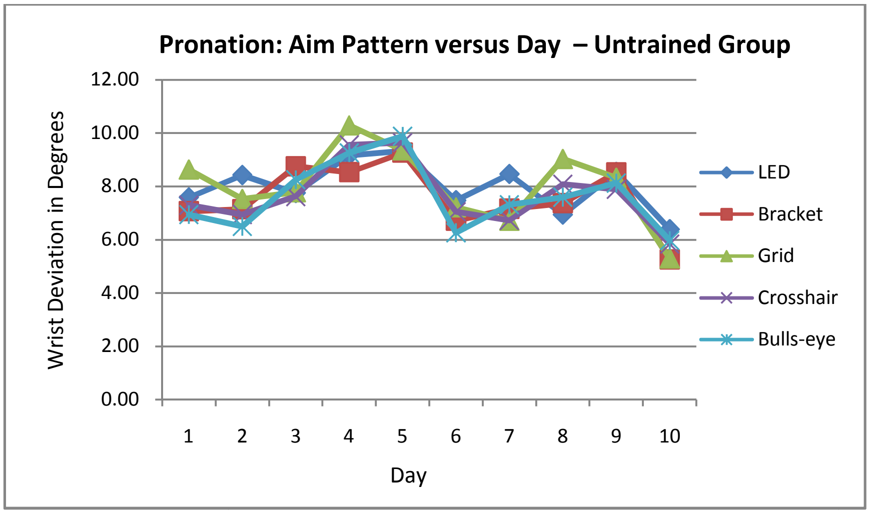


Figure 4.1.19: Pronation: Aim Pattern versus Day – Untrained Group, Interaction Plot

For each Aim Pattern within each Group, Tukey's HSD Post Hoc Test was completed for Day to determine statistically significant differences between Days. When the Trained Group scans using the LED Aim Pattern, Day is not statistically significant ($F_{9, 880}$=1.08, P=0.387). When the Untrained Group scans using the LED Aim Pattern, Day is not statistically significant ($F_{9, 880}$=1.26, P=0.278). Figures 4.1.20 and 4.1.21 depict the average Pronation for the LED Aim Pattern for each Group.

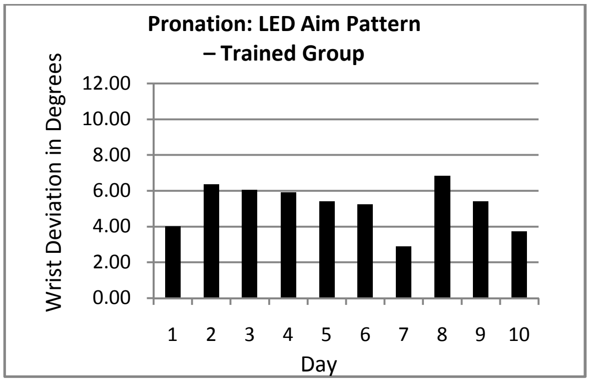


Figure 4.1.20: Pronation: LED Aim Pattern – Trained Group

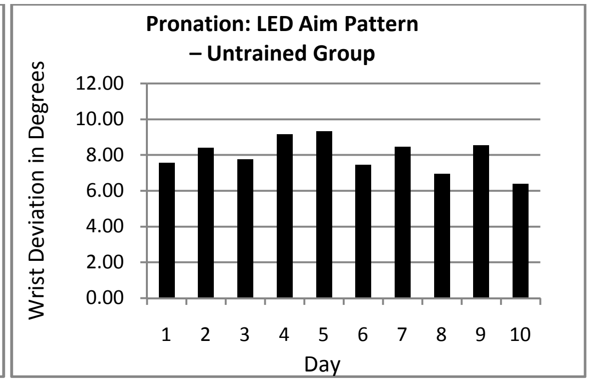


Figure 4.1.21: Pronation: LED Aim Pattern – Untrained Group

When the Trained Group scans using the Bracket Aim Pattern, Day is not statistically significant ($F_{9,\ 880}$=0.60, P=0.791). When the Untrained Group scans using the Bracket Aim Pattern, Day is not statistically significant ($F_{9,\ 880}$=1.24, P=0.289). Figures 4.1.22 and 4.1.23 depict the average Pronation for the Bracket Aim Pattern for each Group.

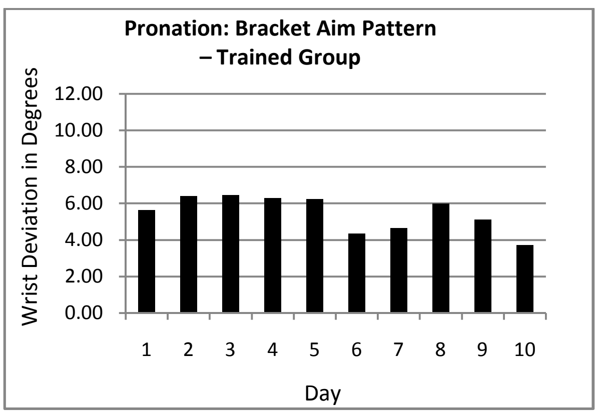


Figure 4.1.22: Pronation: Bracket Aim Pattern – Trained Group

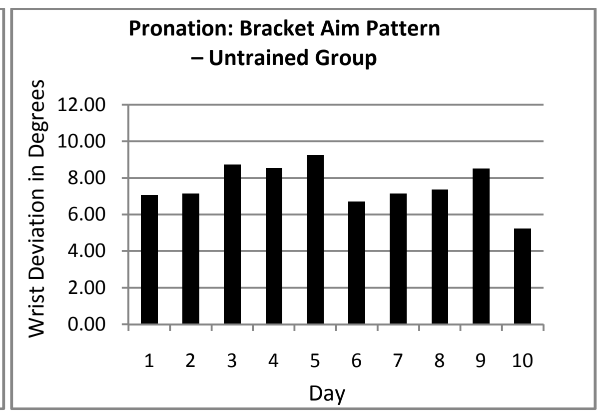


Figure 4.1.23: Pronation: Bracket Aim Pattern – Untrained Group

When the Trained Group scans using the Grid Aim Pattern, Day is not statistically significant ($F_{9,\ 880}$=1.40, P=0.209). When the Untrained Group scans using the Grid Aim Pattern, Day is statistically significant at a .10 alpha level ($F_{9,\ 880}$=1.97, P=0.058). Day 4 is significantly different from Day 10 at a .05 level (P=0.0311). Day 4 has greater Pronation than Day 10 by an average 4.993 degrees. Figures 4.1.24 and 4.1.25 depict the average Pronation for the Grid Aim Pattern for each Group.

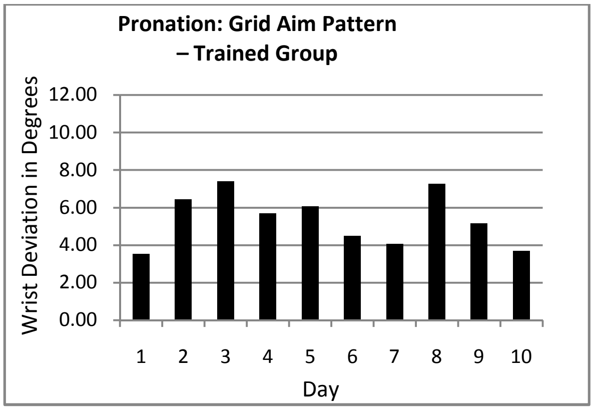


Figure 4.1.24: Pronation: Grid Aim Pattern – Trained Group

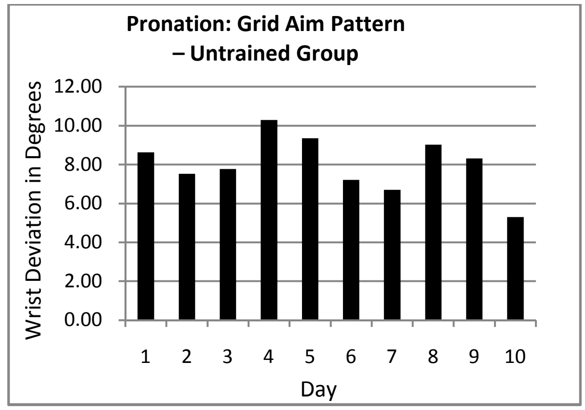


Figure 4.1.25: Pronation: Grid Aim Pattern – Untrained Group

When the Trained Group scans using the Crosshair Aim Pattern, Day is not statistically significant ($F_{9,\ 880}$=0.61, P=0.781). When the Untrained Group scans using the Crosshair Aim Pattern, Day is not statistically significant ($F_{9,\ 880}$=1.52, P=0.160). Figures 4.1.26 and 4.1.27 depict the average Pronation for the Crosshair Aim Pattern for each Group.

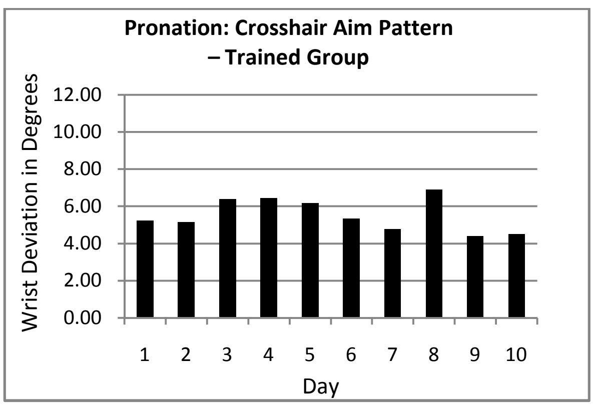


Figure4.1.26: Pronation: Crosshair Aim Pattern
– Trained Group

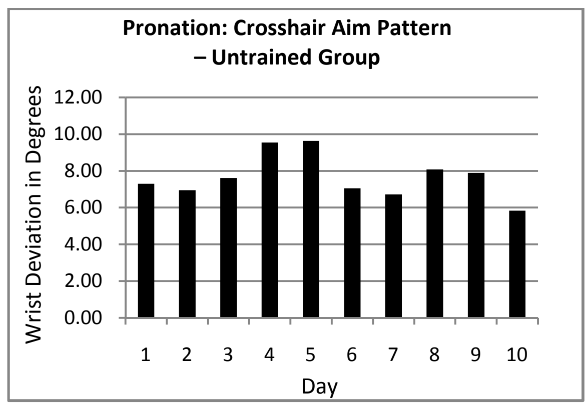


Figure 4.1.27: Pronation: Crosshair Aim Pattern
– Untrained Group

When the Trained Group scans using the Bulls-eye Aim Pattern, Day is not statistically significant ($F_{9,\ 880}$=1.11, P=0.372). When the Untrained Group scans using the Bulls-eye Aim Pattern, Day is statistically significant at a .05 alpha level ($F_{9,\ 880}$=2.70, P=0.010). Day 5 is significantly different from Day 10 at a .05 level (P=0.0244). Day 5 is significantly different from Day 6 at a .10 level (P=0.0502). Day 2 is significantly different from Day 5 at a .10 level (P=0.0862). Figures 4.1.28 and 4.1.29 depict the average Pronation for the Bulls-eye Aim Pattern for each Group.

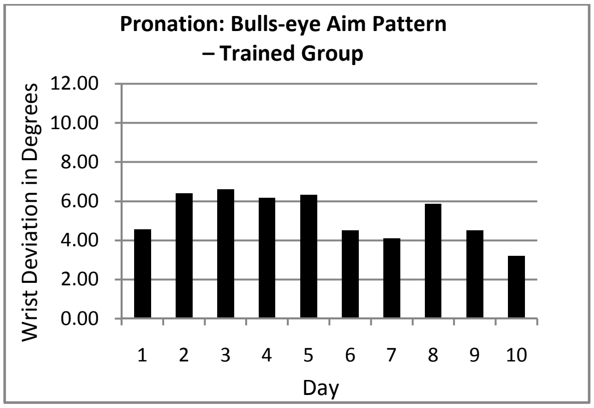


Figure 4.1.28: Pronation: Bulls-eye Aim Pattern – Trained Group

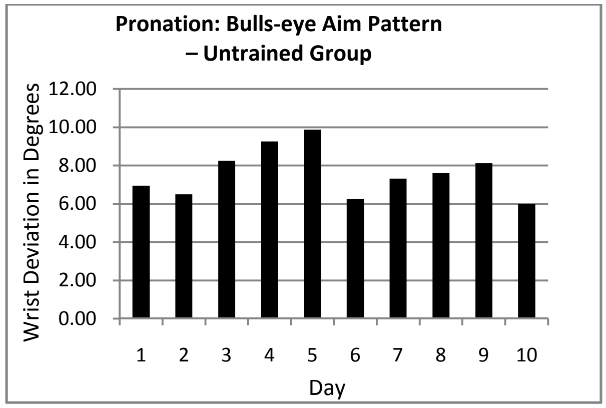


Figure 4.1.29: Pronation: Bulls-eye Aim Pattern – Untrained Group

There are no statistically significant differences (at .05 or .10 level) between Days for the Trained Group using any Aim Pattern. For the Untrained Group, statistical differences between Days are present for the Grid and Bulls-eye Aim Patterns. Although there are statistically significant differences between Days, no obvious trends emerge for either Group for any Aim Pattern.

*4.1.1.3.2 Group*Aim Pattern (Aim Pattern Main Effect by Group)*

Data were separated by Group (Trained and Untrained) to analyze the Aim Pattern Main Effect within each Group. An interaction plot for the Group*Aim Pattern two-way interaction is depicted below in Figure 4.1.30.

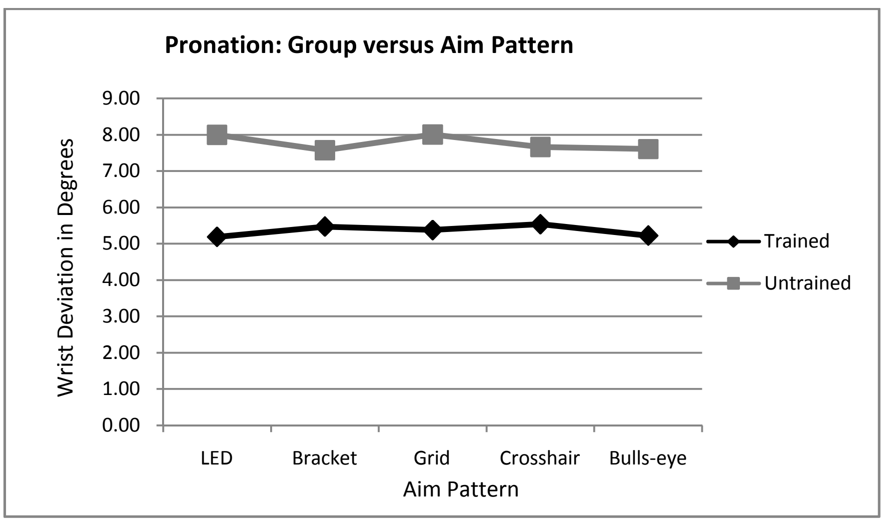


Figure 4.1.30: Pronation: Aim Pattern Main Effect by Group – Interaction Plot

For each Group, Tukey's HSD Post Hoc Test was completed for Aim Pattern to determine statistically significant differences between Aim Patterns. For the Trained Group, Aim Pattern is not statistically significant ($F_{4, 4760}$ =0. 76, P-value=0.561). For the Untrained Group, Aim Pattern is not statistically significant ($F_{4, 4760}$ =1. 27, P-value=0.304). There are no statistically significant differences (at .05 or .10 level) between Aim Patterns for either Group.

Group is statistically significant at a .05 alpha level for the LED and Grid Aim Patterns (LED: $F_{1, 1904}$ =5.40, P-value=0.036; Grid: $F_{1, 1904}$ =5.10, P-value=0.040). Group is statistically significant at a .10 level for the Bracket, Crosshair and Bulls-eye Aim Patterns (Bracket: $F_{1, 1904}$ =3.77, P=0.073; Crosshair: $F_{1, 1904}$=3.89, P-value=0.069; Bulls-eye: $F_{1, 1904}$ =3.99, P-value=0.065). Pronation for the Trained Group is less than for the Untrained Group across all Aim Patterns and this difference is statistically significant with at least a .10 level. Figure 4.1.31 depicts the average Pronation for each Group by Aim Pattern.

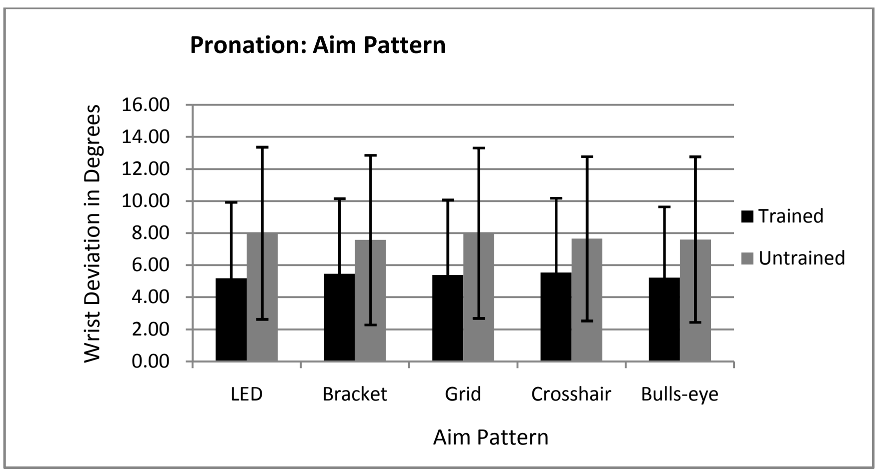


Figure 4.1.31: Pronation: Aim Pattern Main Effect by Group

*4.1.1.3.3 Day*Target Type*

Data were separated by Target Type to analyze the effect of Day. An interaction plot for the Day*Target Type two-way interaction is depicted below in Figure 4.1.32.

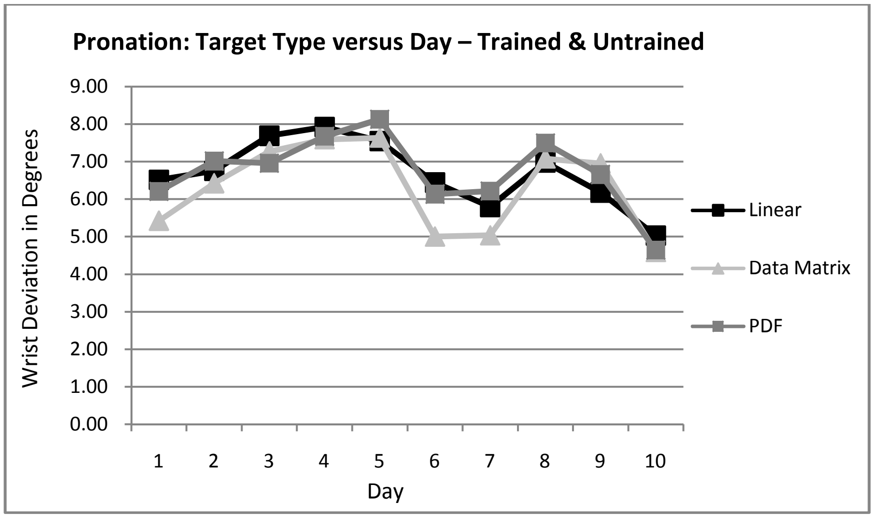


Figure 4.1.32: Pronation: Target Type versus Day – Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Target Type to determine statistically significant differences between Days. For the Linear Target Type, Day is statistically significant at a .05 alpha level ($F_{9, 3175}$=13.89, P=0.000). Day 1 is different from Days 3, 4, and 10 at a .05 level (P=0.0199, 0.0015 and 0.0006 respectively). Day 1 is different from Day 5 at a .10 level (P=0.0740). Day 2 is different from Days 4 and 10 at a .05 level (P=0.0212 and 0.0000 respectively). Day 3 is different from Days 6, 7, 9 and 10 at a .05 level (P=0.0095, 0.0000, 0.0004 and 0.0000 respectively). Day 4 is different from Days 6, 7, 9 and 10 at a .05 level (P=0.0006, 0.0000, 0.0000 and 0.0000 respectively). Day 5 is different from Days 6, 7, 9 and 10 at a .05 level (P=0.0395, 0.0000, 0.0024 and 0.0000 respectively). Day 6 is different from Day 10 at a .05 level (P=0.0014). Day 7 is different from Day 8 at a .05 level (P=0.0174). Day 8 is different from Day 10 at a .05 level (P=0.0000). Day 9 is different from Day 10 at a .05 level (P=0.0266). There are no other statistically significant differences (at a .05 or .10 level) between Days. Figure 4.1.33 depicts the average Pronation for the Linear Target Type by Day.

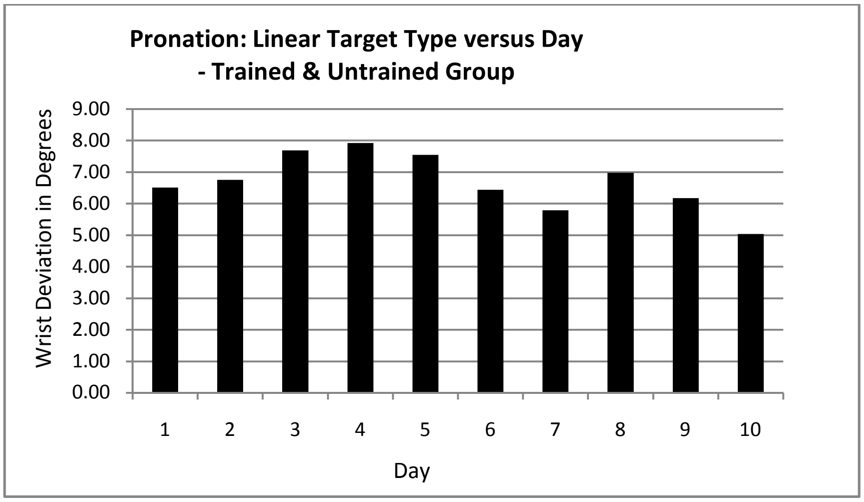


Figure 4.1.33: Pronation: Linear Target Type versus Day

For the Data Matrix Target Type, Day is statistically significant ($F_{9,\ 3175}$=25.28, P=0.000). Day 1 is different from Days 3, 4, 5, 8 and 9 at a .05 level (P=0.0000, 0.0000, 0.0000, 0.0000 and 0.0002 respectively). Day 1 is different from Day 2 at a .10 level (P=0.0748). Day 2 is different from Days 4, 5, 6, 7 and 10 at a .05 level (P=0.0141, 0.0091, 0.0007, 0.0011 and 0.0000 respectively). Day 3 is different from Days 6, 7 and 10 at a .05 level (P=0.0000, 0.0000 and 0.0000 respectively). Day 4 is different from Days 6, 7 and 10 at a .05 level (P=0.0000, 0.0000 and 0.0000 respectively). Day 5 is different from Days 6, 7 and 10 at a .05 level (P=0.0000, 0.0000 and 0.0000 respectively). Day 6 is different from Days 8 and 9 at a .05 level (P=0.0000 and 0.0000 respectively). Day 7 is different from Days 8 and 9 at a .05 level (P=0.0000 and 0.0000 respectively). Day 8 is different from Day 10 at a .05 level (P=0.0000). Day 9 is different from Day 10 at a .05 level (P=00000). There are no other statistically significant differences (at a .05 or .10 level) between Days. Figure 4.1.34 depicts the average Pronation for the Data Matrix Target Type by Day.

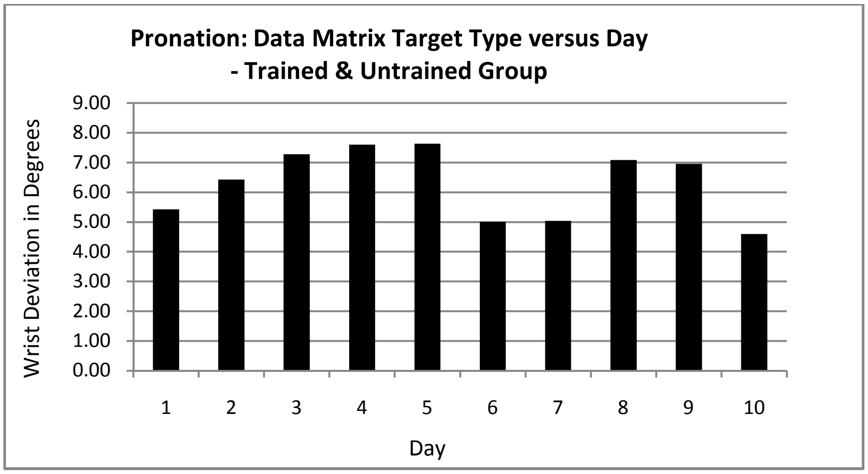


Figure 4.1.34: Pronation: Data Matrix Target Type versus Day

For the PDF Target Type, Day is statistically significant ($F_{9,\ 3175}$=15.87, P=0.000). Day 1 is different from Days 4, 5, 8 and 10 at a .05 level (P=0.0012, 0.0000, 0.0089 and 0.0004 respectively). Day 2 is different from Days 5 and 10 at a .05 level (P=0.0496 and 0.0000 respectively). Day 3 is different from Days 5 and 10 at a .05 level (P=0.0297 and 0.0000 respectively). Day 4 is different from Days 6, 7 and 10 at a .05 level (P=0.0005, 0.0014 and 0.0000 respectively). Day 5 is different from Days 6, 7, 9 and 10 at a .05 level (P=0.0000, 0.0000, 0.0012 and 0.0000 respectively). Day 6 is different from Days 8 and 10 at a .05 level (P=0.0041 and 0.0010 respectively). Day 7 is different from Days 8 and 10 at a .05 level (P=0.0096 and 0.0004 respectively). Day 8 is different from Day 10 at a .05 level (P=0.0000). Day 9 is different from Day 10 at a .05 level (P=0.0000). There are no other differences (at a .05 or .10 level) between Days. Figure 4.1.35 depicts the average Pronation for the PDF Target Type by Day.

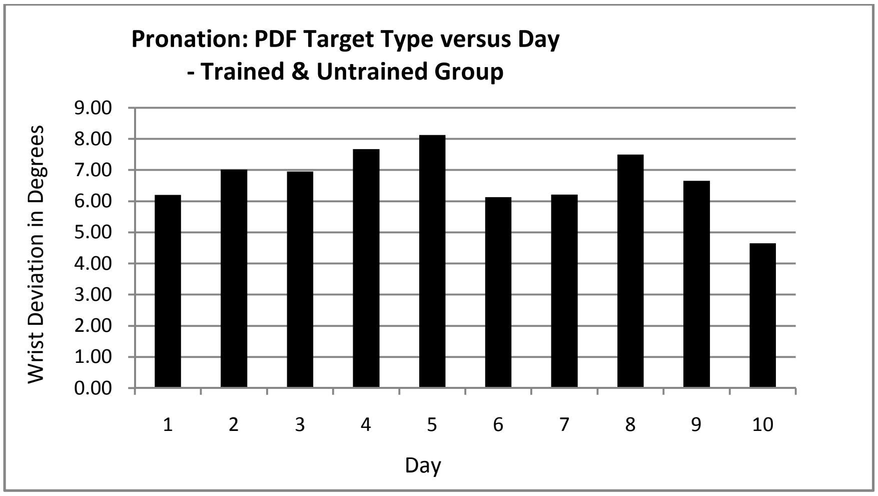


Figure 4.1.35: Pronation: PDF Target Type versus Day

For the Linear, Data Matrix and PDF Target Types, there are pair-wise differences between Days that are statistically significant at the .05 alpha level. No trends are apparent across Days for any Target Type.

*4.1.1.3.4 Group*Target Type (Target Type Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the effect of Target Type. An interaction plot for the Group*Target Type two-way interaction is depicted below in Figure 4.1.36.

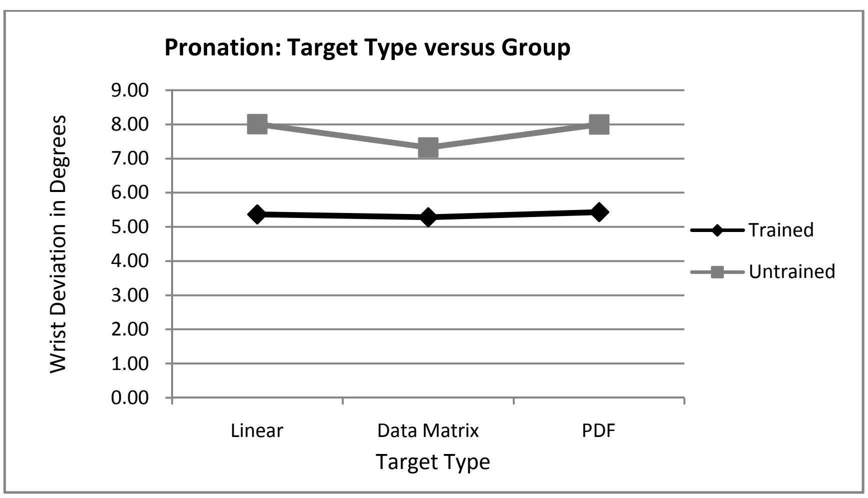


Figure 4.1.36: Pronation: Target Type Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Target Type. For the Trained Group, Target Type is not statistically significant ($F_{2,\ 4776}$=0.12, p=0.889). For the Untrained Group, Target Type is not statistically significant ($F_{2,\ 4776}$=0.57, p=0.578).

For the Linear Target Type, there is no statistically significant difference between Groups at a .05 alpha level, but there is at a .10 level ($F_{1,\ 3184}$=4.32, p=.076). For the Data Matrix Target Type, there is no statistically significant difference between Groups ($F_{1,\ 3184}$=3.22, p=0.116). For the PDF Target Type, there is no statistically significant difference between Groups ($F_{1,\ 3184}$=3.35, p=0.110).

At an alpha level of .10, there is a difference between Groups for the Linear Target Type. The Trained Group has less Pronation than the Untrained Group by an average of 2.63 degrees. Although the Trained Group has lower average pronation for the Data Matrix and PDF Target Types it is not statistically significant. Figure 4.1.37 depicts the average Pronation for each Group by Target Type.

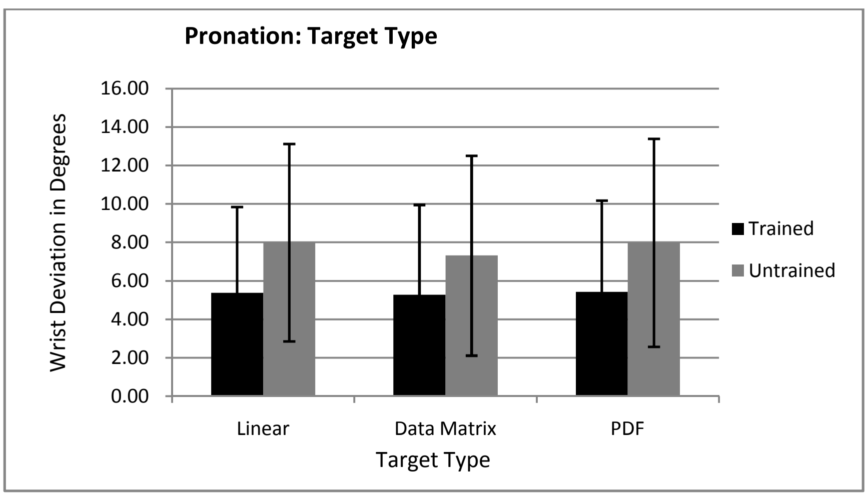


Figure 4.1.37: Pronation: Target Type Main Effect by Group

4.1.1.4 Flexion

All Minitab results for Flexion in the Self-Paced Task can be found in Appendix F.

*4.1.1.4.1 Group*Target Type*Aim Pattern*

Data were separated by Group (Trained and Untrained). Data were then separated by Target Type within each Group to analyze the effect of Aim Pattern. Interaction plots for the

Group*Aim Pattern*Target Type three-way interaction are depicted below in Figure 4.1.38 and 4.1.39.

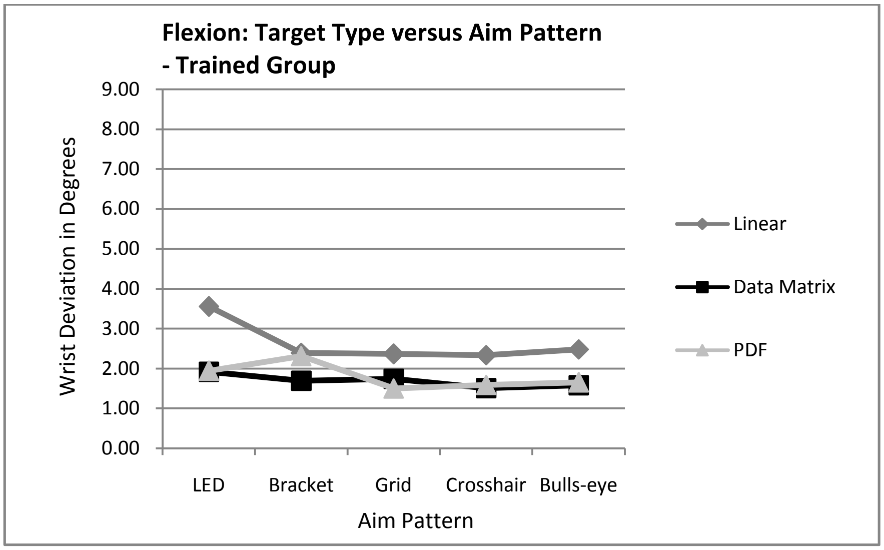


Figure 4.1.38: Flexion: Target Type versus Aim Pattern – Trained Group, Interaction Plot

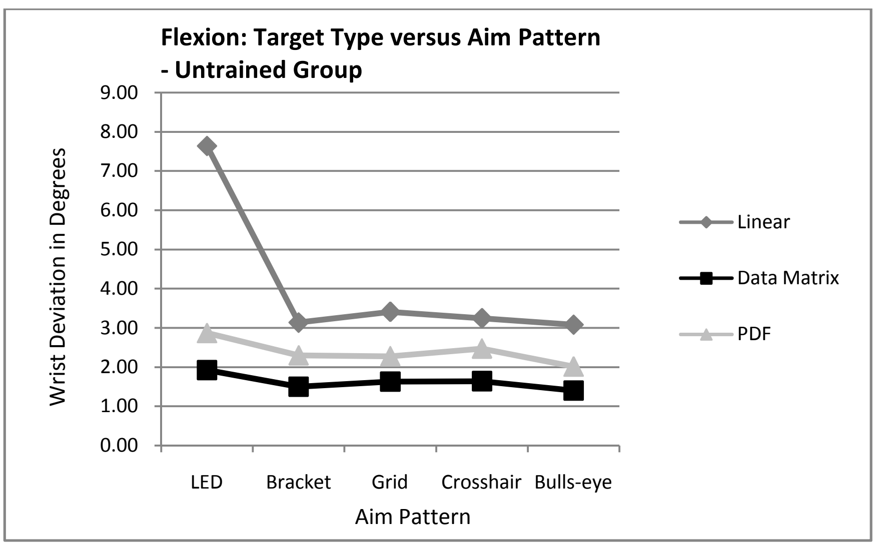


Figure 4.1.39: Flexion: Target Type versus Aim Pattern – Untrained Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group, for each Target Type to determine statistically significant differences between Aim Patterns. For the Linear Target Type, Group is not statistically significant (LED: $F_{1,\ 624}$=2.52, P=0.156; Bracket: $F_{1,\ 624}$=0.23, P=0.644; Grid: $F_{1,\ 624}$=0.50, P=0.503; Crosshair: $F_{1,\ 624}$=0.36, P=0.568; Bulls-eye: $F_{1,\ 624}$=0.19, P=0.679). There is no difference between the Trained and Untrained Group when scanning the Linear Target Type with any of the Aim Patterns.

For the Linear Target Type and the Trained Group, Aim Pattern is statistically significant ($F_{4, 1560}$=5.05, P=0.003). There is a statistically significant difference between the LED Aim Pattern and the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns (P=0.0114, 0.0093, 0.0077, and 0.0220 respectively). The LED Aim Pattern results in an average 1.16 degrees greater Flexion than the other Aim Patterns. There is no statistically significant difference (at a .05 or .10 level) between the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when the Trained Group scans the Linear Target Type.

For the Linear Target Type and the Untrained Group, Aim Pattern is statistically significant ($F_{4, 1560}$=6.88, P=0.001). There is a statistically significant difference between the LED Aim Pattern and the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns (P=0.0020, 0.0040, 0.0027, and 0.0018 respectively). The LED Aim Pattern results in an average 4.42 degrees greater Flexion than the other Aim Patterns. There is no statistically significant difference (at a .05 or .10 level) between the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when the Untrained Group scans the Linear Target Type. Figure 4.1.40 depicts the average Flexion for the Linear Target Type by Aim Pattern for each Group.

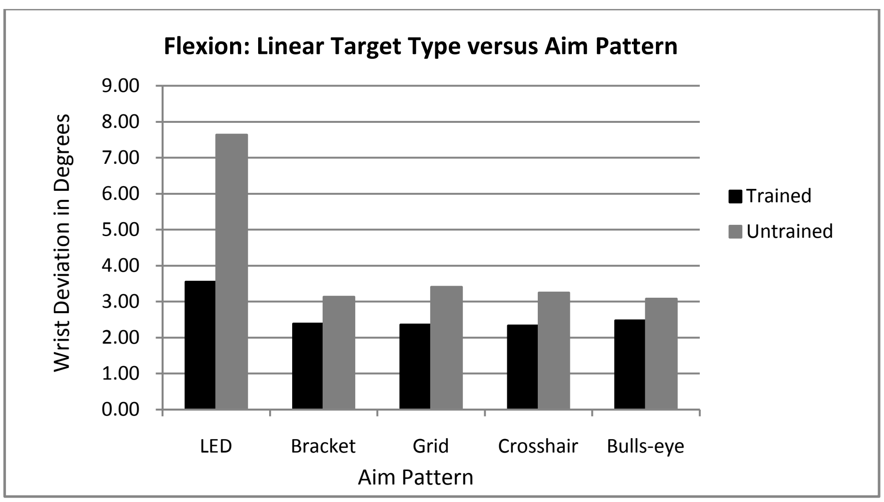


Figure 4.1.40: Flexion: Linear Target Type versus Aim Pattern

For the Data Matrix Target Type, Group is not statistically significant (LED: $F_{1, 624}$=0.00, P=0.995; Bracket: $F_{1, 624}$=0.05, P=0.837; Grid: $F_{1, 624}$=0.01, P=0.907; Crosshair: $F_{1, 624}$=0.02, P=0.900; Bulls-eye: $F_{1, 624}$=0.03, P=0.864). There is no difference between the Trained and Untrained Group when scanning the Data Matrix Target Type with any of the Aim Patterns.

For the Data Matrix Target Type and the Trained Group, Aim Pattern is not statistically significant ($F_{4, 1560}$=0.85, P=0.505). There is no statistically significant difference (at a .05 or .10 level) between the Led, Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when the Trained Group scans the Data Matrix Target Type.

For the Linear Target Type and the Untrained Group, Aim Pattern is not statistically significant ($F_{4, 1560}$=1.10, P=0.374). There is no statistically significant difference (at a .05 or .10 level) between the LED, Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when the Untrained Group scans the Data Matrix Target Type. Figure 4.1.41 depicts the average Flexion for the Data Matrix Target Type by Aim Pattern for each Group.

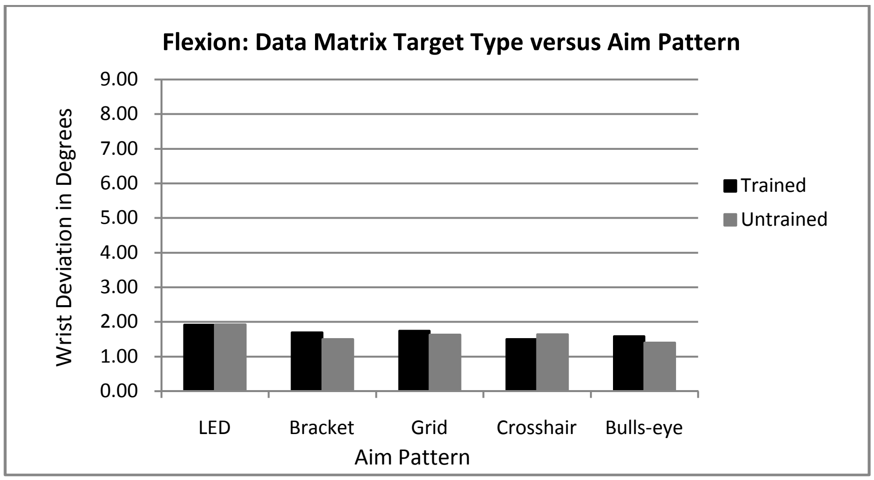


Figure 4.1.41: Flexion: Data Matrix Target Type versus Aim Pattern

For the PDF Target Type, Group is not statistically significant (LED: $F_{1, 624}$=0.32, P=0.591; Bracket: $F_{1, 624}$=0.00, P=0.996; Grid: $F_{1, 624}$=0.26, P=0.629; Crosshair: $F_{1, 624}$=0.34, P=0.579; Bulls-eye: $F_{1, 624}$=0.06, P=0.810). There is no difference between the Trained and Untrained Group when scanning the PDF Target Type with any of the Aim Patterns.

For the PDF Target Type and the Trained Group, Aim Pattern is statistically significant ($F_{4, 1560}$=3.44, P=0.021). There is a statistically significant difference between the Bracket Aim Pattern and the Grid Aim Pattern at a .05 level (P=0.0254). The Bracket Aim Pattern results in an average of 0.81 degrees greater Flexion than the Grid Aim Pattern. There is a statistically significant difference between the Bracket Aim Pattern and the Crosshair and Bulls-eye Aim Patterns at a .10 level (P=0.0552 and 0.0936 respectively). The Bracket Aim Pattern results in average Flexion 0.69 degrees greater than for the Crosshair and Bulls-eye Aim Patterns. There

are no other statistically significant differences (at a .05 or .10 level) between Aim Patterns when scanning the PDF Target Type.

For the PDF Target Type and the Untrained Group, Aim Pattern is not statistically significant at a .05 level, but is significant at a .10 level ($F_{4,\ 1560}$=2.33, P=0.081). There is a statistically significant difference between the LED Aim Pattern and the Bulls-eye Aim Pattern (P=0.0488). The LED Aim Pattern results in an average 0.85 degrees greater Flexion than the Bulls-eye Aim Pattern. There are no other statistically significant differences (at a .05 or .10 level) between Aim Patterns when the Untrained Group scans the PDF Target Type. Figure 4.1.42 depicts the average Flexion for the PDF Target Type by Aim Pattern for each Group.

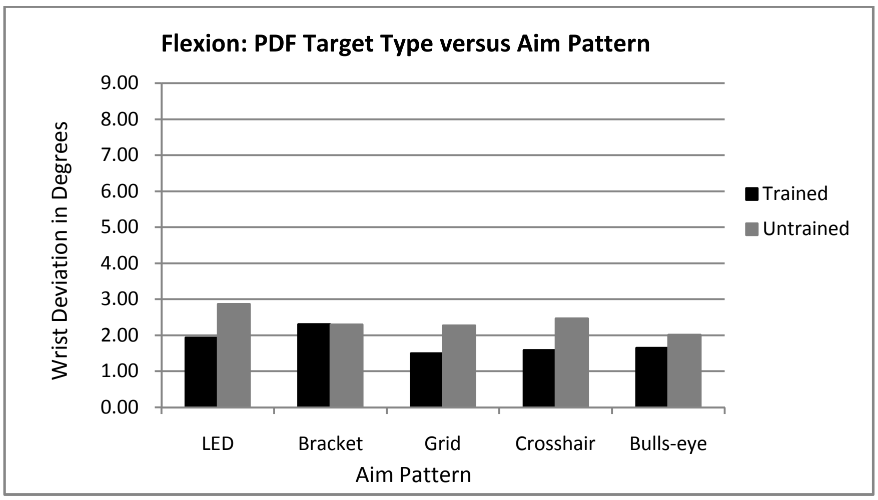


Figure 4.1.42: Flexion: PDF Target Type versus Aim Pattern

For both Groups, there is a statistically significant difference between the LED Aim Pattern and the other four Aim Patterns when scanning the Linear Target Type. The LED Aim Pattern resulted in greater Flexion (Trained: 1.16 degrees, Untrained: 4.42 degrees). There is no significant difference between Aim Patterns when scanning the Data Matrix Target Type for either Group. For the Trained Group, the PDF Target Type is significant at a .05 level. The Bracket Aim Pattern results in 0.81 degrees greater Flexion than for the Grid Aim Pattern at a .05 alpha level. The Bracket Aim Pattern results in 0.69 degrees greater Flexion than for the Crosshair and Bulls-eye Aim Patterns at a .10 alpha level. For the Untrained Group, the PDF Target Type is significant at a .10 level. The LED Aim Pattern results in 0.85 degrees greater

Flexion than the Bulls-eye Aim Pattern at a .05 level. Group is not statistically significant for any Aim Pattern, for any Target Type.

*4.1.1.4.2 Target Type*Day*

Data were separated by Target Type to analyze the effect of Day. An interaction plot for the Target Type*Day two-way interaction is depicted below in Figure 4.1.43.

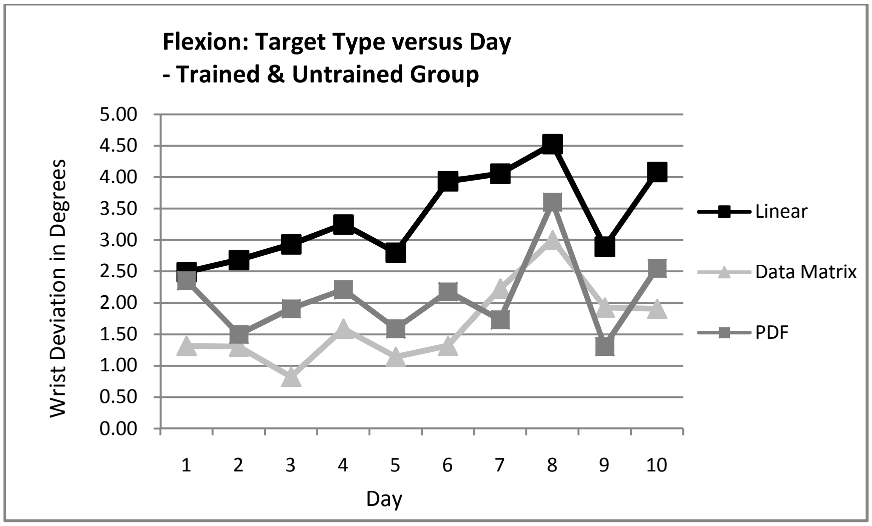


Figure 4.1.43: Flexion: Target Type versus Day, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Target Type to determine statistically significant differences between Days. For the Linear Target Type, Day is statistically significant ($F_{9,\ 3175}$=6.69, P=0.000). Day 1 is different from Days 6, 7, 8 and 10 at a .05 level (P=0.0088, 0.0027, 0.0000 and 0.0020 respectively). Day 2 is different from Days 6, 7, 8 and 10 at a .05 level (P=0.0463, 0.0170, 0.0001 and 0.0134 respectively). Day 3 is different at Day 8 at a .05 level (P=0.0020). Day 3 is different from Day 10 at a .10 level (P=0.0962). Day 4 is different from Day 8 at a .05 level (P=0.0377). Day 5 is different from Days 7, 8 and 10 at a .05 level (P=0.0447, 0.0005 and 0.0361 respectively). Day 7 is different from Day 10 at a .10 level (P=0.0901). Day 8 is different from Day 9 at a .05 level (P=0.0014). Day 9 is different from Day 10 at a .10 level (P=0.0744). There are no other statistically significant differences (at a .05 or .10 level) between Days. Figure 4.1.44 depicts the average Flexion for the Linear Target Type by Day.

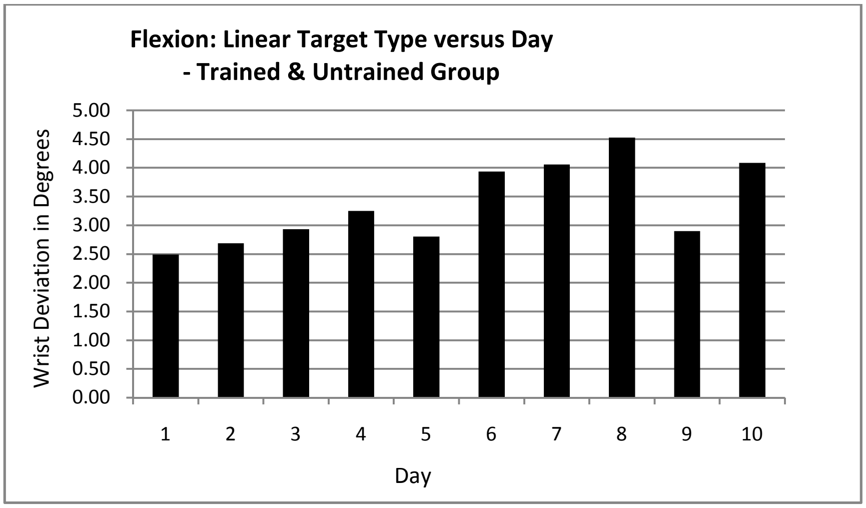


Figure 4.1.44: Flexion: Linear Target Type versus Day

For the Data Matrix Target Type, Day is statistically significant ($F_{9,\ 3175}$=10.13, P=0.000). Day 1 is different from Days 7 and 8 at a .05 level (P=0.0381 and 0.0000 respectively). Day 2 is different from Days 7 and 8 at a .05 level (P=0.0338 and 0.0000 respectively). Day 3 is different from Days 7, 8, 9 and 10 at a .05 level (P=0.0000, 0.0000, 0.0034 and 0.0047 respectively). Day 4 is different from Day 8 at a .05 level (P=0.0000). Day 5 is different from Days 7 and 8 at a .05 level (P=0.0043 and 0.0000 respectively). Day 6 is different from Days 7 and 8 at a .05 level (P=0.0395 and 0.0000 respectively). Day 8 is different from Days 9 and 10 at a .05 level (P=0.0050 and 0.0037 respectively). There are no other statistically significant differences (at a .05 or .10 level) between Days. Figure 4.1.45 depicts the average Flexion for the Data Matrix Target Type by Day.

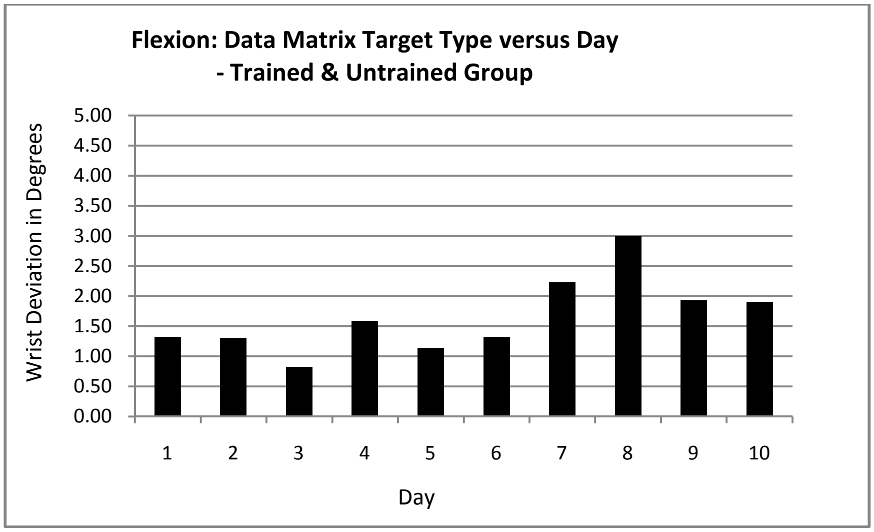


Figure 4.1.45: Flexion: Data Matrix Target Type versus Day

For the PDF Target Type, Day is statistically significant ($F_{9,\ 3175}$=8.55, P=0.000). Day 1 is different from Days 8 and 9 at a .05 level (P=0.0039, 0.0376). Day 2 is different from Day 8 at a .05 level (P=0.0000). Day 3 is different from Day 8 at a .05 level (P=0.0000). Day 4 is different from Day 8 at a .05 level (P=0.0006). Day 5 is different from Day 8 at a .05 level (P=0.0000). Day 5 is different from Day 10 at a .10 level (P=0.0814). Day 6 is different from Day 8 at a .05 level (P=0.0004). Day 7 is different from Day 8 at a .05 level (0.0000). Day 8 is different from Day 9 and 10 at a .05 level (P=0.0000 and 0.0352 respectively). Day 9 is different from Day 10 at a .05 level (P=0.0043). There are no other statistically significant differences (at a .05 or .10 level) between Days. Figure 4.1.46 depicts the average Flexion for the PDF Target Type by Day.

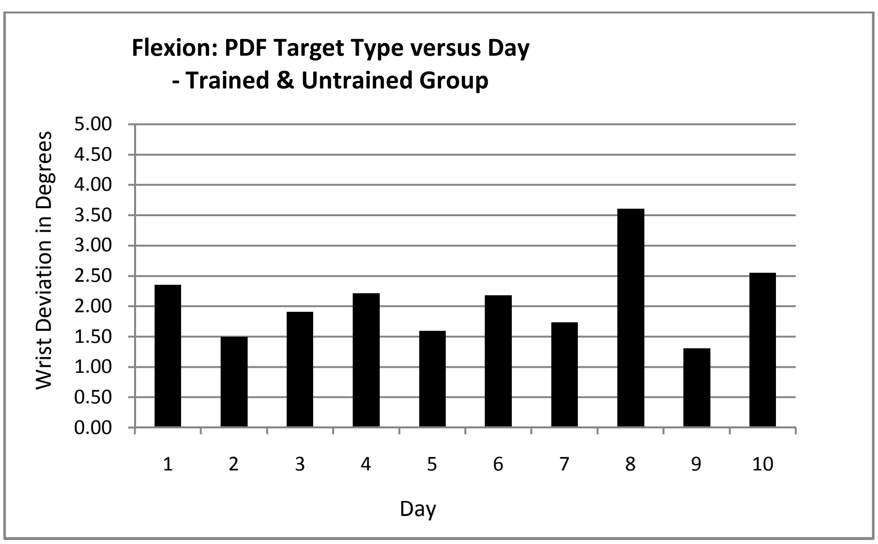


Figure 4.1.46: Flexion: PDF Target Type versus Day

For the Linear, Data Matrix and PDF Target Types, there are pair-wise differences between Days that are statistically significant at the .05 alpha level. No trends are apparent across Days for any Target Type.

*4.1.1.4.3 Group*Target Type (Target Type Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the effect of Target Type. An interaction plot for the Group*Target Type two-way interaction is depicted below in Figure 4.1.47.

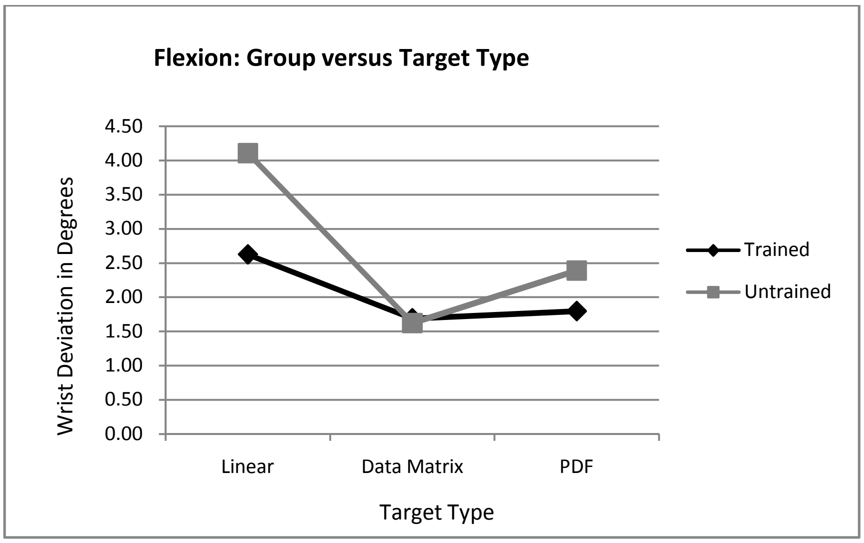


Figure 4.1.47: Flexion: Target Type Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Target Types. For the Trained Group, Target Type is statistically significant ($F_{2,\ 4776}$=6.45, P=0.010). The Linear Target Type is different from the Data Matrix and PDF Target Types (P=.0141 and P=.0293 respectively). The Data Matrix and PDF Target Types are not significantly different at a .05 or .10 level.

For the Untrained Group, Target Type is statistically significant ($F_{2,\ 4776}$=7.16, P=0.007). The Linear Target Type is different from the Data Matrix Target Type at a .05 alpha level (P=0.0064). The Linear Target Type is different from the PDF Target Type at a .10 alpha level (P=0.0563). The Data Matrix and PDF Target Types are not significantly different at a .05 or .10 level.

When the Trained Group scans the Linear Target Type, it results in a significantly greater average of 0.89 degrees Flexion compared to the other Target Types. When the Untrained Group scans the Linear Target Type, it results in a significantly greater average of 2.11 degrees Flexion compared to the other Target Types.

For the Linear Target Type, Group is not statistically significant ($F_{1,\ 3184}$=0.87, P=0.382). For the Data Matrix Target Type, Group is not statistically significant ($F_{1,\ 3184}$=0.00, P=0.947). For the PDF Target Type, Group is not statistically significant ($F_{1,\ 3184}$=0.15, P=0.710). Although The Trained Group has lower average Flexion for the Linear and PDF Target Types, it is not statistically significant. Figure 4.1.48 depicts the average Flexion for each Group by Target Type.

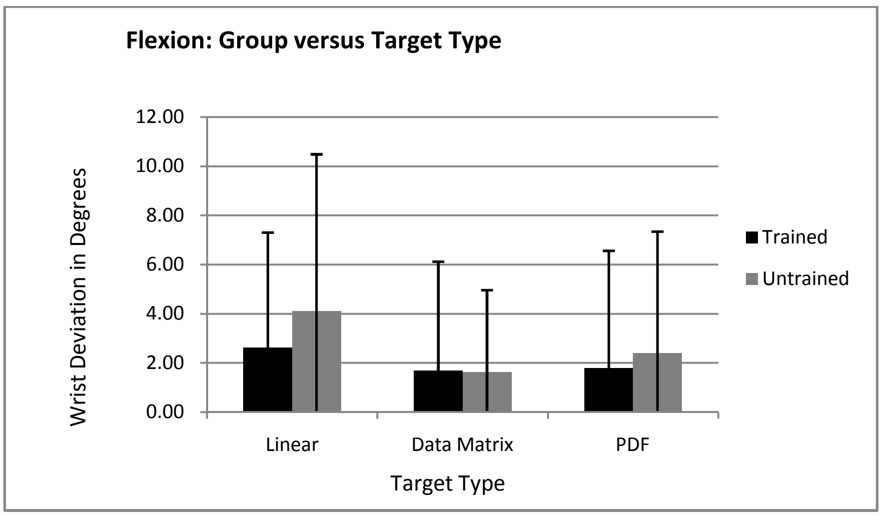


Figure 4.1.48: Flexion: Target Type Main Effect by Group

*4.1.1.4.4 Group*Aim Pattern (Aim Pattern Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the effect of Aim Pattern. An interaction plot for the Group*Aim Pattern two-way interaction is depicted below in Figure 4.1.49.

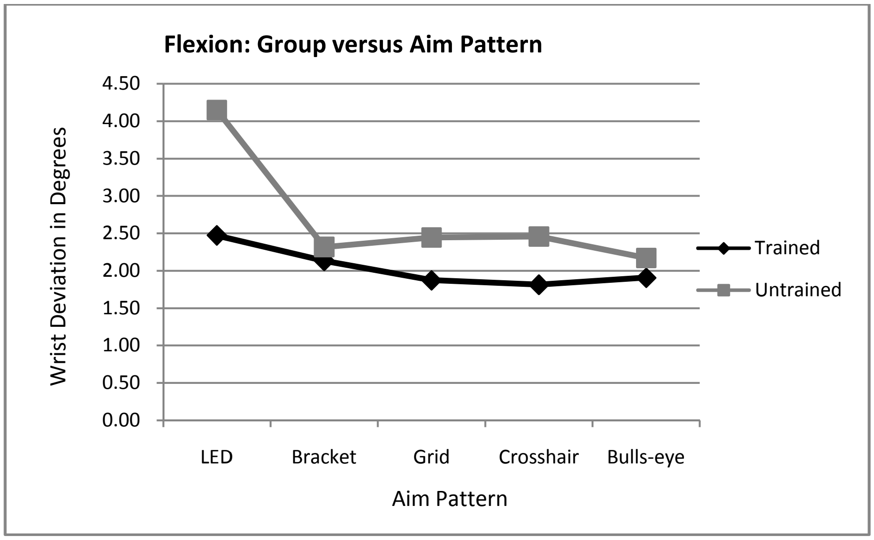


Figure 4.1.49: Flexion: Aim Pattern Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Aim Patterns. For the Trained Group, Aim Pattern is statistically significant ($F_{4, 4760}$=5.38, P=0.002). The LED Aim Pattern is different from the Grid, Crosshair and Bulls-eye Aim Patterns at a .05 alpha level (P=0.0090, 0.0036 and 0.0150 respectively). The LED Aim Pattern results in average Flexion 0.61 degrees greater than these other Aim Patterns. No other pair-wise comparisons are significantly different at a .05 or .10 level.

For the Untrained Group, Aim Pattern is statistically significant ($F_{4, 4760}$=7.61, P=0.000). The LED Aim Pattern is different from the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns at a .05 alpha level (P=0.0013, 0.0028, 0.0031 and 0.0005 respectively). The LED Aim Pattern results in average Flexion 1.80 degrees greater than the other Aim Patterns. No other pair-wise comparisons are significantly different at a .05 or .10 level.

Group is not statistically significant for any Aim Pattern (LED: $F_{1, 1904}$=1.56, P=0.232; Bracket: $F_{1, 1904}$=0.03, P=0.871; Grid: $F_{1, 1904}$=0.26, P=0.619; Crosshair: $F_{1, 1904}$=0.28, P=0.604; Bulls-eye: $F_{1, 1904}$=0.06, P=0.811). Figure 4.1.50 depicts the average Flexion for each Group by Aim Pattern.

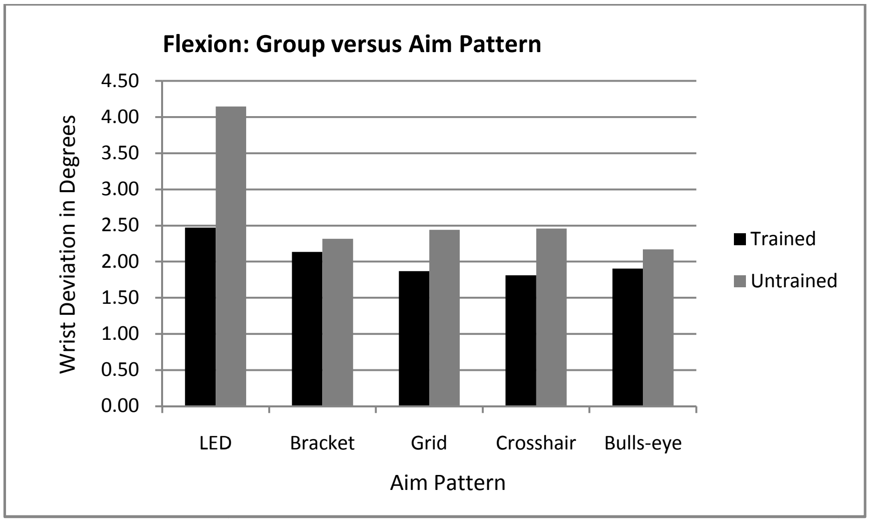


Figure 4.1.50: Flexion: Aim Pattern Main Effect by Group

Aim Pattern is significant for both Groups at a .05 alpha level. The LED Aim Pattern is different from the Grid, Crosshair and Bulls-eye Aim Patterns in both Groups and is different from the Bracket Aim Pattern in the Untrained Group.

*4.1.1.4.5 Group*Day (Day Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the effect of Day. An interaction plot for the Group*Day two-way interaction is depicted below in Figure 4.1.51.

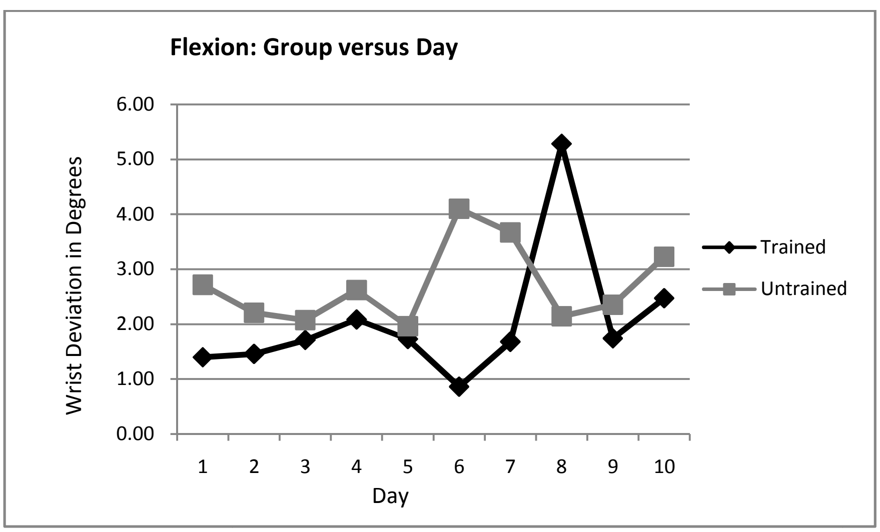


Figure 4.1.51: Flexion: Day Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Days. For the Trained Group, Day is not statistically significant ($F_{9,\ 4720}$=1.41, P=0.203). There is no significant difference between Days at a .05 level. Day 6 is different from Day 8 at a .10 alpha level (P=0.0882). No other pair-wise comparisons are significantly different at a .05 or .10 alpha level.

For the Untrained Group, Day is not statistically significant ($F_{9,\ 4720}$=1.43, P=0.193). There is no significant difference between Days at a .05 or .10 level. Figure 4.1.52 and 4.1.53 depict the average Flexion for each Group by Day.

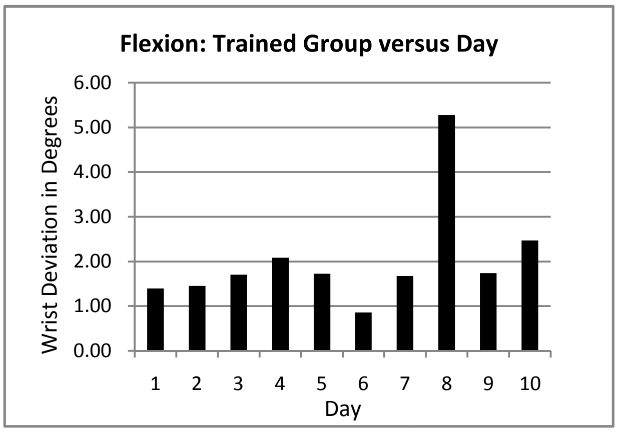


Figure 4.1.52: Flexion: Trained Group versus Day

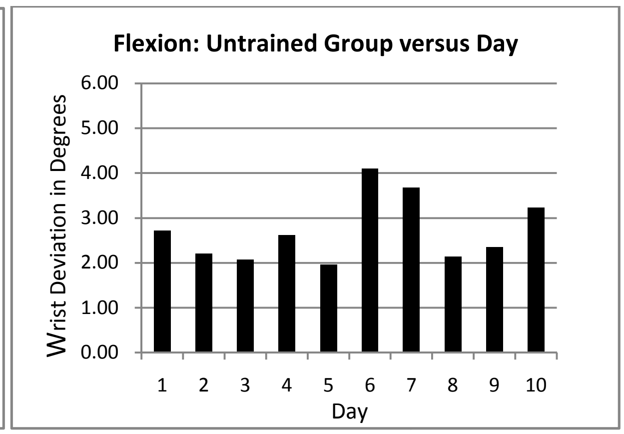


Figure 4.1.53: Flexion: Untrained Group versus Day

Day is not statistically significant in either Group however in the Trained Group there is a significant pair-wise difference between Day 6 and 8 at a .10 level. The Untrained Group has higher wrist Flexion every Day except Day 8, but all differences are by less than 4 degrees. There are no apparent trends across Days in either Group. It should be noted however, that there is an obvious increase in Flexion for the Trained Group on Day 8 compared to the other Days, but there is no assignable cause for this spike in Flexion.

4.1.1.5 Extension

All Minitab results for Extension in the Self-Paced Task can be found in Appendix G.

*4.1.1.5.1 Group*Day*Target Type*

Data were separated by Group (Trained and Untrained). Within each Group, data were then separated by Target Type to analyze the effect of Day. Interaction plots for the Group*Day*Target Type three-way interaction is depicted below in Figure 4.1.54 and 4.1.55.

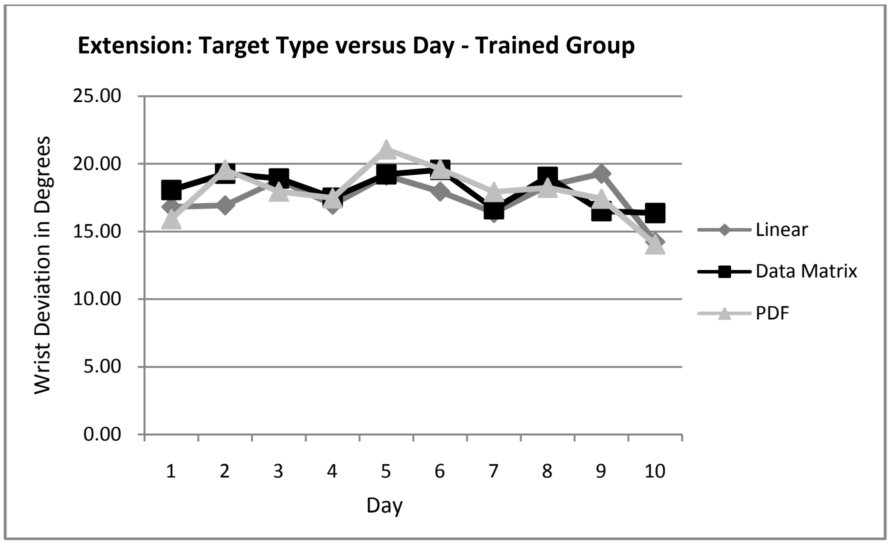


Figure 4.1.54: Extension: Target Type versus Day – Trained Group, Interaction Plot

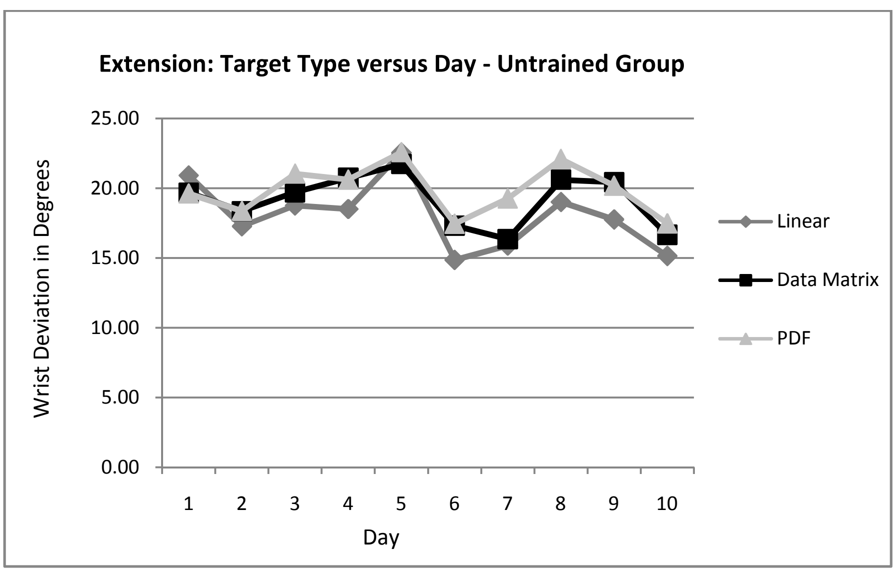


Figure 4.1.55: Extension: Target Type versus Day – Trained Group, Interaction Plot

Within each Group, Tukey's HSD Post Hoc Test was completed for each Day to determine statistically significant differences between Days. For the Trained Group, Day is not statistically significant for the Linear Target Type ($F_{9,\ 1520}$=0.45, P=0.902). There is no significant difference (at a .05 or .10 level) between Days when the Trained Group scans the Linear Target Type. For the Untrained Group, Day is not statistically significant for the Linear Target Type ($F_{9,1520}$=1.44, P=0.189). There is no significant difference (at a .05 or .10 level) between Days when the Untrained Group scans the Linear Target Type. Figure 4.1.56 and 4.1.57 depict the average Extension for each Group by Day for the Linear Target Type.

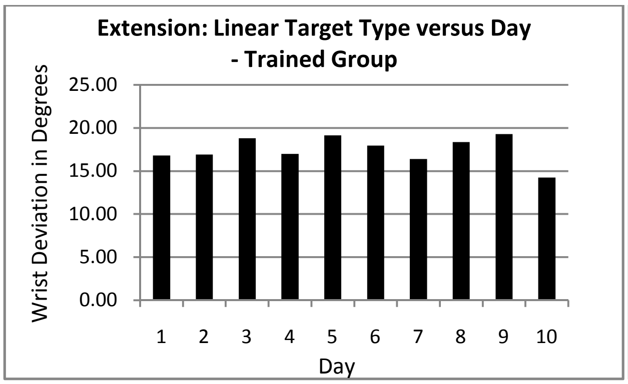


Figure 4.1.56: Extension: Linear Target Type versus Day - Trained Group

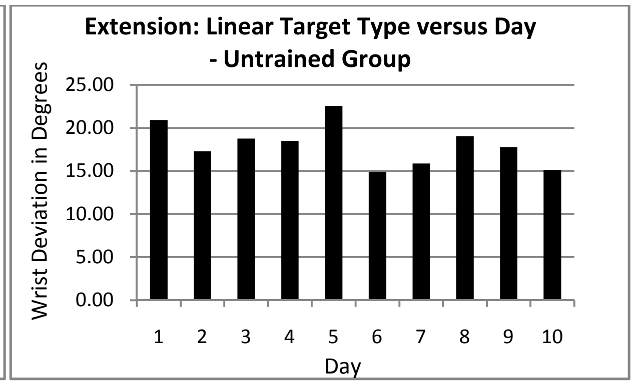
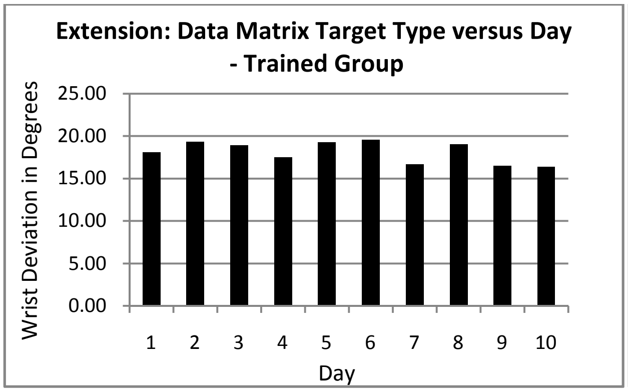


Figure 4.1.57: Extension: Linear Target Type versus Day - Untrained Group

For the Trained Group, Day is not statistically significant for the Data Matrix Target Type ($F_{9,\ 1520}$=0.23, P=0.989). There is no significant difference (at a .05 or .10 level) between Days when the Trained Group scans the Data Matrix Target Type. For the Untrained Group, Day is not statistically significant for the Data Matrix Target Type ($F_{9,\ 1520}$=0.81, P=0.607). There is no significant difference (at a .05 or .10 level) between Days when the Untrained Group scans the Data Matrix Target Type. Figure 4.1.58 and 4.1.59 depict the average Extension for each Group by Day for the Data Matrix Target Type.



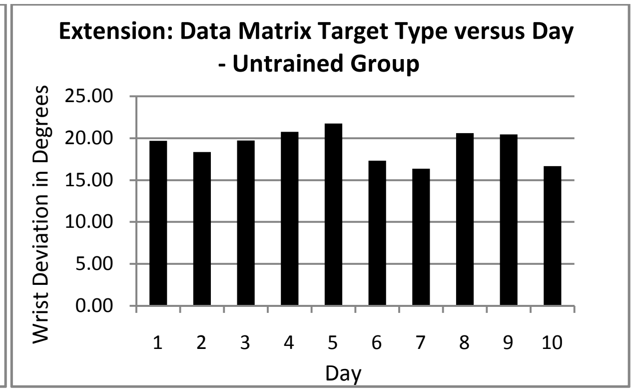
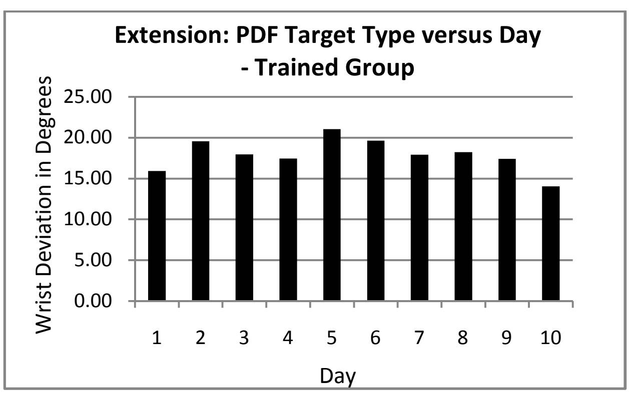


Figure 4.1.58: Extension: Data Matrix Target Type versus Day - Trained Group

Figure 4.1.59: Extension: Data Matrix Target Type versus Day - Untrained Group

For the Trained Group, Day is not statistically significant for the PDF Target Type ($F_{9, 1520}$=0.71, P=0.700). There is no significant difference (at a .05 or .10 level) between Days when the Trained Group scans the PDF Target Type. For the Untrained Group, Day is not statistically significant for the PDF Target Type ($F_{9, 1520}$=0.71, P=0.699). There is no significant difference (at a .05 or .10 level) between Days when the Untrained Group scans the PDF Target Type. Figure 4.1.60 and 4.1.61 depict the average Extension for each Group by Day for the PDF Target Type.



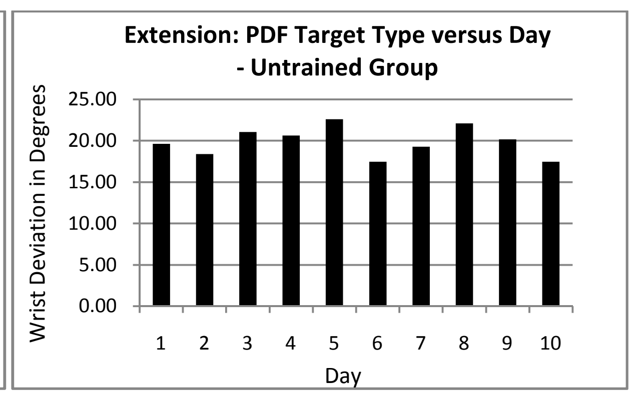


Figure 4.1.60: Extension: PDF Target Type versus Day - Trained Group

Figure 4.1.61: Extension: PDF Target Type versus Day - Untrained Group

Day was not significant for any Target Type, for either Group. Additionally, there were no significant differences between Days for any Target Type. However, for the Linear Target Type, Day was much closer to being statistically significant for the Untrained Group than for the

Trained Group. Although there are statistically significant differences between Days, no obvious trends emerge.

*4.1.1.5.2 Group*Target Type (Target Type Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the effect of Target Type. An interaction plot for the Group*Target Type two-way interaction is depicted below in Figure 4.1.62.

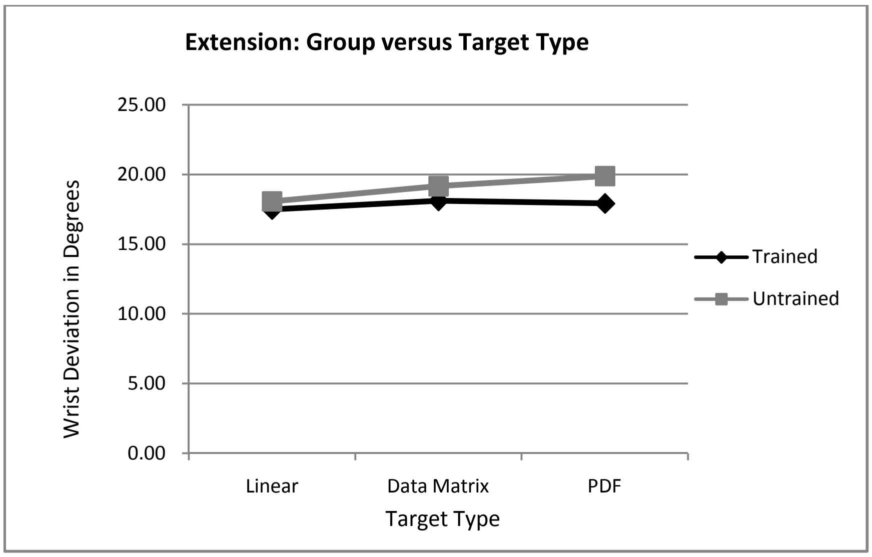


Figure 4.1.62: Extension: Target Type Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Target Types. For the Trained Group, Target Type is not statistically significant ($F_{2,\ 4776}$=0.91, P=0.426). There is no difference between Target Types at a .05 or .10 level. For the Untrained Group, Target Type is statistically significant ($F_{2,\ 4776}$=4.02, P=0.042). The Linear Target Type is different from PDF Target Type (P=0.0344). When the Untrained Group scans the Linear Target Type there is an average of 1.81 degrees less Extension than for the PDF Target Type. No other pair-wise comparisons are significantly different at .05 or .10 level.

For the Linear Target Type, Group is not statistically significant ($F_{1,\ 3184}$=0.87, P=0.382). For the Data Matrix Target Type, Group is not statistically significant ($F_{1,\ 3184}$=0.00, P=0.947). For the PDF Target Type, Group is not statistically significant ($F_{1,\ 3184}$=0.15, P=0.710). Although the

Trained Group has lower Extension for all Target Types, it is not statistically significant. Figure 4.1.63 depicts the average Extension for each Target Type, by Group.

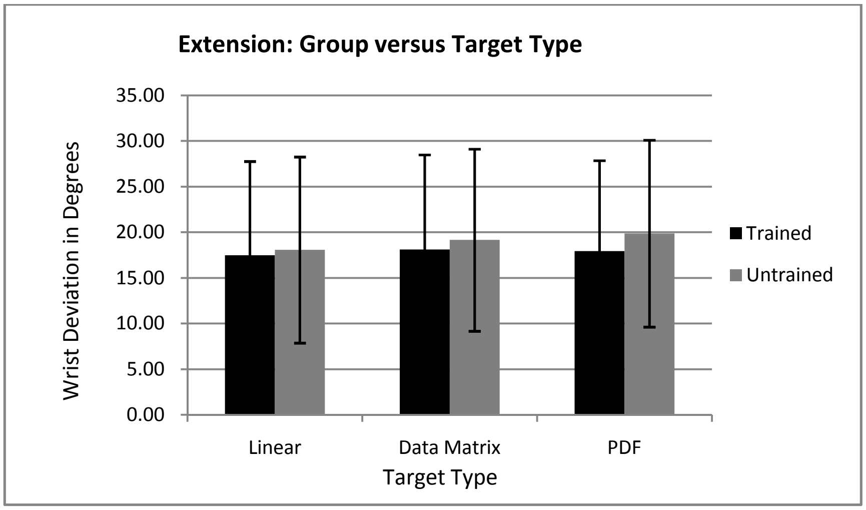


Figure 4.1.63: Extension: Target Type Main Effect by Group

*4.1.1.5.3 Group*Aim Pattern (Aim Pattern Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the effect of Aim Pattern. An interaction plot for the Group*Aim Pattern two-way interaction is depicted below in Figure 4.1.64.

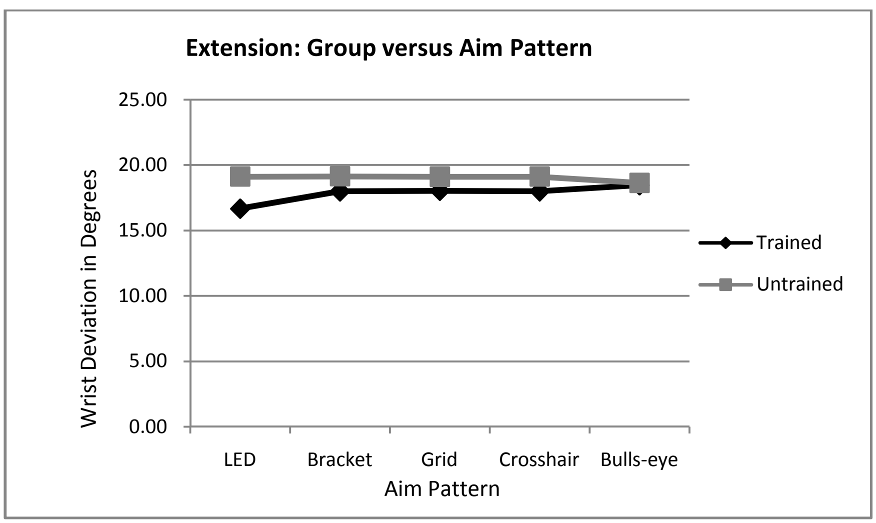


Figure 4.1.64: Extension: Aim Pattern Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Aim Patterns. For the Trained Group, Aim Pattern is statistically significant ($F_{4, 4760}$=3.22, P=0.027). The LED Aim Pattern is significantly different from the Bulls-eye Aim Pattern (P=0.0179). There are no other significantly different pair-wise comparisons at a .05 or .10 alpha level. For the Untrained Group, Aim Pattern is not statistically significant ($F_{4, 4760}$=0.80, P=0.537).

Group is not statistically significant for any Aim Pattern (LED: $F_{1, 1904}$ =0.83, P=0.377; Bracket: $F_{1, 1904}$ =0.15, P=0.708; Grid: $F_{1, 1904}$ =0.14, P=0.712; Crosshair: $F_{1, 1904}$ =0.16, P=0.697; Bulls-eye: $F_{1, 1904}$ =0.00, P=0.954). Although the Trained Group has less average Extension for all Aim Patterns, it is not statistically significant. Figure 4.1.65 depicts the average Extension for each Aim Pattern, by Group.

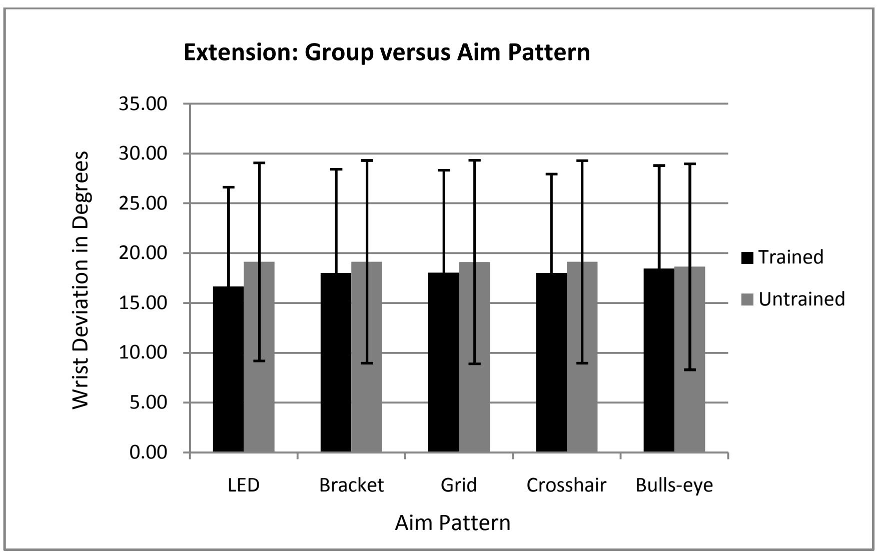


Figure 4.1.65: Extension: Aim Pattern Main Effect by Group

4.1.1.6 Ulnar Deviation

All Minitab results for Ulnar Deviation in the Self-Paced Task can be found in Appendix H.

*4.1.1.6.1 Group*Target Type*

Data were separated by Group (Trained and Untrained) to analyze the effect of Target Type. An interaction plot for the Group*Target Type two-way interaction is depicted below in Figure 4.1.66.

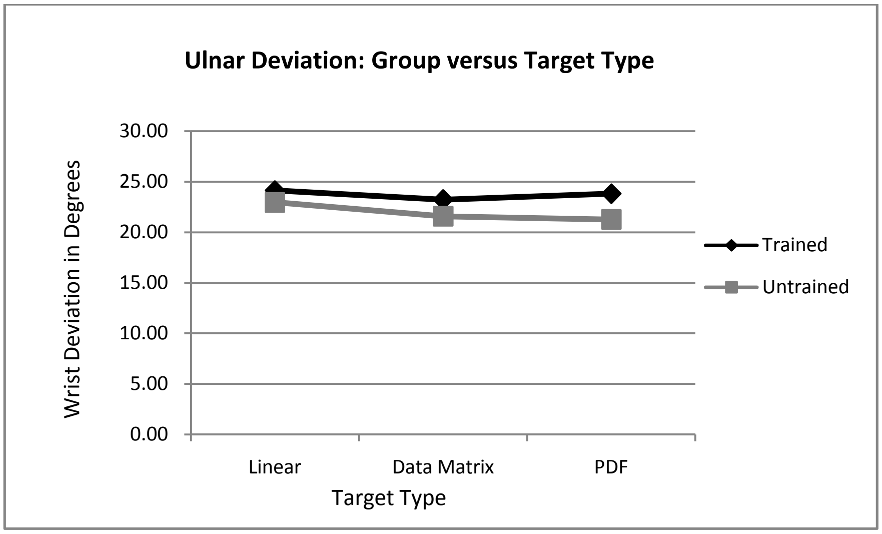


Figure 4.1.66: Ulnar Deviation: Target Type Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Target Types. For the Trained Group, Target Type is not statistically significant ($F_{2, 4776}$=1.47, P=0.263). There is no significant difference (at a .05 or .10 level) between Target Types for the Trained Group. For the Untrained Group, Target Type is statistically significant ($F_{2, 4776}$=9.64, P=0.002). The Linear Target Type is significantly different from the Data Matrix and PDF Target Types (P=0.0121 and P=0.0028 respectively). When the Untrained Group scans the Linear Target Type, the average Ulnar Deviation is 1.54 degrees greater than for the other two Target Types. The Data Matrix and PDF Target Types are not significantly different at a .05 or .10 level.

For the Linear Target Type, Group is not statistically significant ($F_{1, 3184}$=0.27, P=0.622). For the Data Matrix Target Type, Group is not statistically significant ($F_{1, 3184}$=0.43, P=0.532). For the PDF Target Type, Group is not statistically significant ($F_{1, 3184}$=0.93, P=0.366). Although the Untrained Group has lower average Ulnar Deviation for all Target Types it is not statistically significant. Figure 4.1.67 depicts the average Ulnar Deviation for each Target Type, by Group.

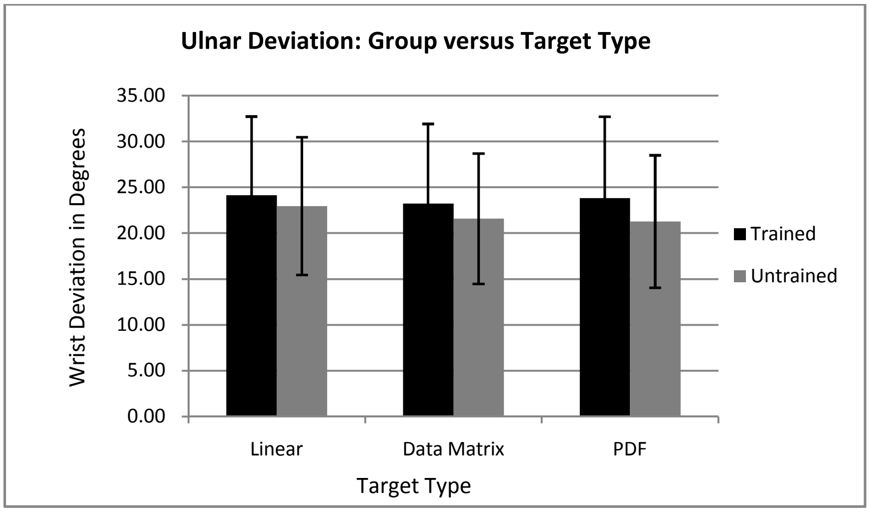


Figure 4.1.67: Ulnar Deviation: Target Type Main Effect by Group

*4.1.1.6.2 Group*Day (Day Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the effect of Day. An interaction plot for the Group*Day two-way interaction is depicted below in Figure 4.1.68.

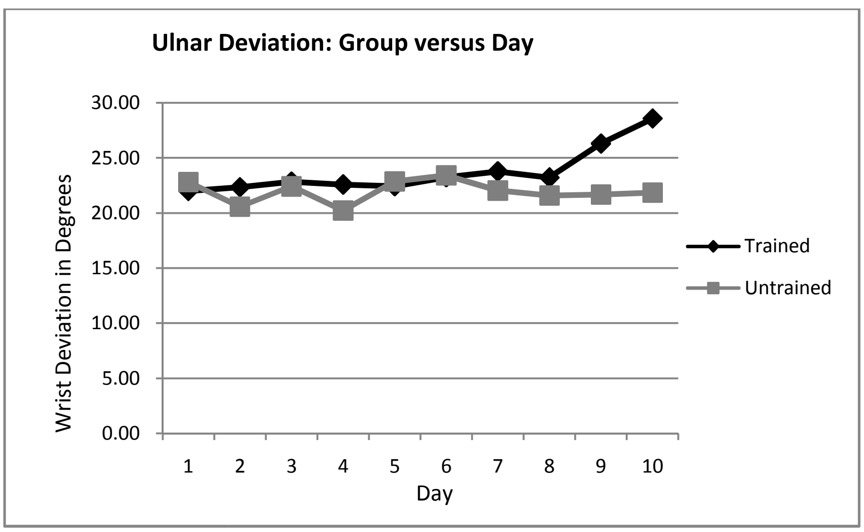


Figure 4.1.68: Ulnar Deviation: Day Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Days. For the Trained Group, Day is not statistically significant ($F_{9, 4720}$=1.10, P=0.376). There is no significant difference (at a .05 or .10 level) between Days for the Trained Group. For the Untrained Group, Day is not statistically significant ($F_{9, 4720}$=0.51,

P=0.865). There is no significant difference (at a .05 or .10 level) between Days for the Untrained Group. Figure 4.1.69 and 4.4.70 depict the average Ulnar Deviation for each Day, by Group.

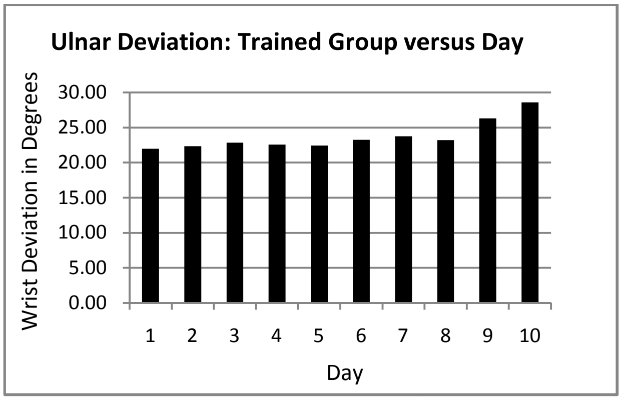


Figure 4.1.69: Ulnar Deviation: Day Main Effect by Group - Trained Group

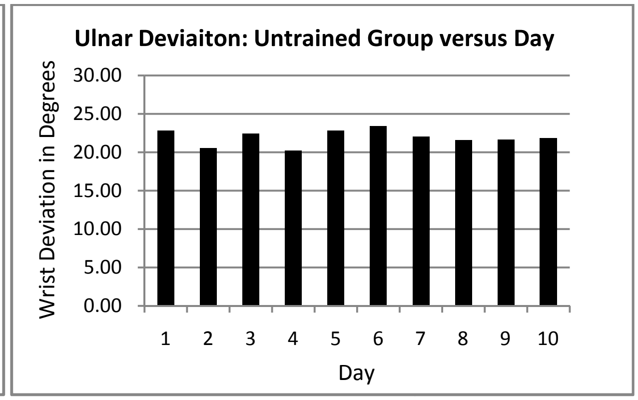


Figure 4.1.70: Ulnar Deviation: Day Main Effect by Group - Untrained Group

Day was not statistically significant for either Group. There was no significant difference between Days for either Group at a .05 or .10 alpha level. Trained Group Ulnar Deviation started to increase from Day 8 to Day 10, however there were no significant differences between any Days. Day was closer to being statistically statistical significant for the Trained Group than for the Untrained Group.

4.1.2 Efficiency: Scan Time

All Minitab results for Scan Time in the Self-Paced Task can be found in Appendix I.

4.1.2.1 Group*Aim Pattern*Target Type

Data were separated by Group (Trained and Untrained). Within each Group, data were separated by Target Type to analyze the effect of Aim Pattern. Interaction plots for the Group*Aim Pattern*Target Type three-way interaction are depicted below in Figure 4.1.71 and 4.1.72.

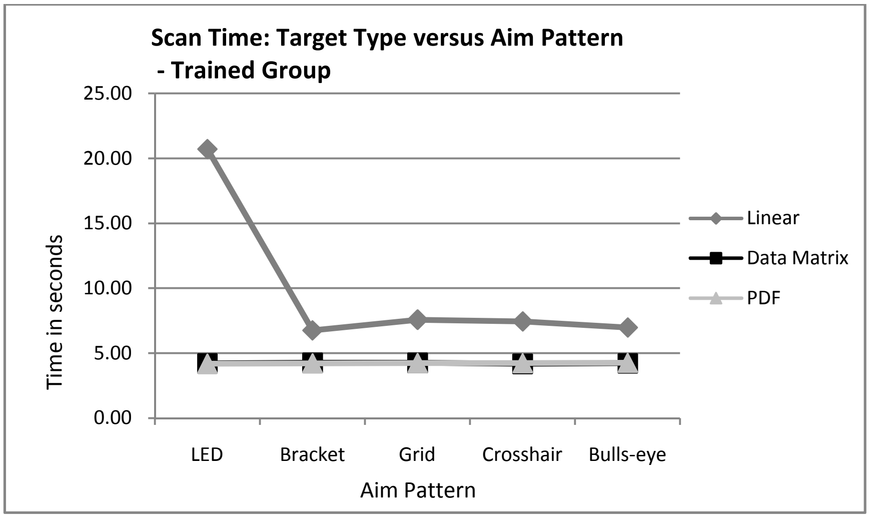


Figure 4.1.71: Scan Time: Target Type versus Aim Pattern – Trained Group, Interaction Plot

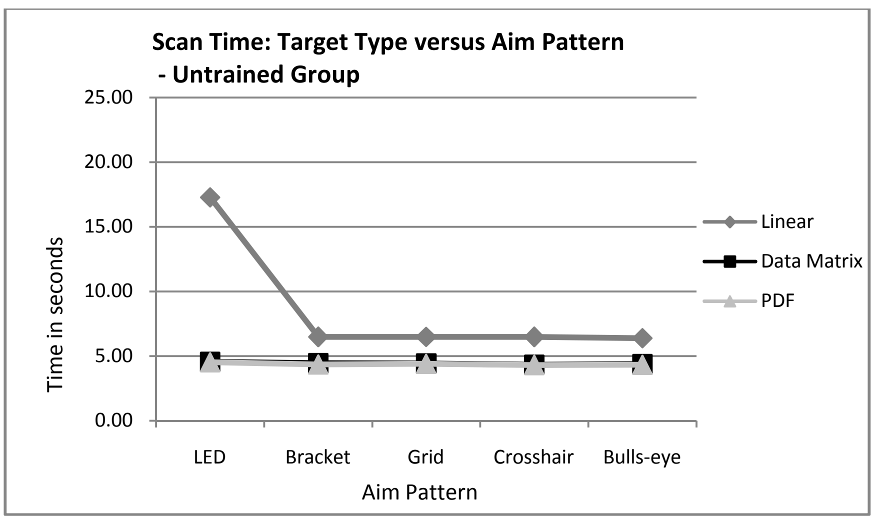


Figure 4.1.72: Scan Time: Target Type versus Aim Pattern – Untrained Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group, for each Target Type to determine statistically significant differences between Aim Patterns. For the Linear Target Type and Trained Group, Aim Pattern is statistically significant ($F_{4,\ 1560}$=47.46, P=0.000). There is a statistically significant difference between the LED Aim Pattern and the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns (P=0.0000, 0.0000, 0.0000, and 0.0000 respectively). The LED Aim Pattern results in an average 13.54 seconds longer Scan Time than the other Aim Patterns. There is no statistically significant difference (at a .05 or .10 level) between the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when the Trained Group scans the Linear Target Type.

For the Linear Target Type and Untrained Group, Aim Pattern is statistically significant ($F_{4, 1560}$=28.29, P=0.000). There is a statistically significant difference between the LED Aim Pattern and all other Aim Patterns (P=0.0000, 0.0000, 0.0000, and 0.0000 respectively). The LED Aim Pattern results in an average 10.83 seconds longer Scan Time than the other Aim Patterns. There is no statistically significant difference (at a .05 or .10 level) between the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when the Untrained Group scans the Linear Target Type.

For the Linear Target Type, Group is not statistically significant for the LED, Bracket, Grid, Crosshair or Bulls-eye Aim Patterns (LED: $F_{1, 624}$=1.40, P=0.256; Bracket: $F_{1, 624}$=0.18, P=0.677 Grid: $F_{1, 624}$=2.17, P=0.163; Crosshair: $F_{1, 624}$=1.72, P=0.211; Bulls-eye: $F_{1, 624}$=1.40, P=0.257). There is no difference between Groups for any Aim Pattern for the Linear Target Type. Figure 4.1.73 depicts the average Scan Time for the Linear Target Type for each Aim Pattern, by Group.

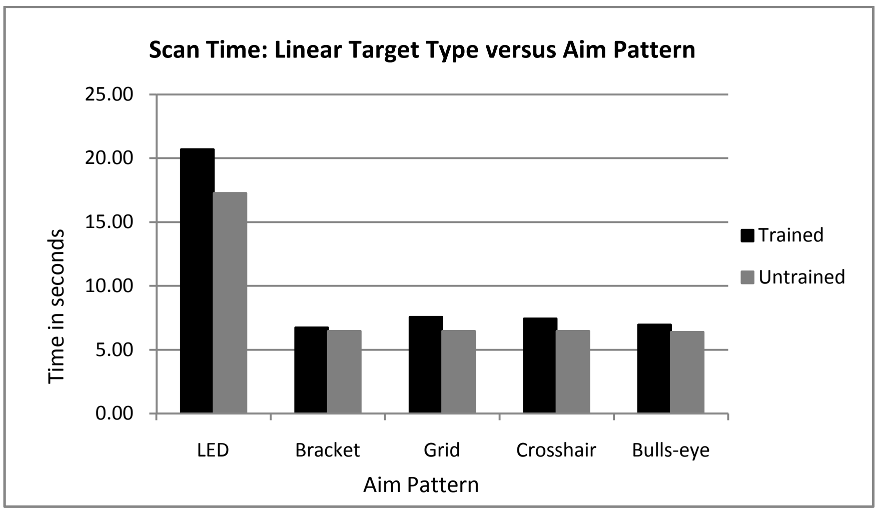


Figure 4.1.73: Scan Time: Linear Target Type versus Aim Pattern

For the Data Matrix Target Type and the Trained Group, Aim Pattern is not statistically significant ($F_{4, 1560}$=0.90, P=0.477). There is no statistically significant difference (at a .05 or .10 level) between the LED, Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when the Trained Group scans the Data Matrix Target Type.

For the Data Matrix Target Type and the Untrained Group, Aim Pattern is not statistically significant ($F_{4, 1560}$=1.47, P=0.238). There is no statistically significant difference (at a .05 or .10 level) between the LED, Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when the Untrained Group scans the Data Matrix Target Type.

Group is not statistically significant for the LED, Bracket, Grid, Crosshair or Bulls-eye Aim Pattern (LED: $F_{1, 624}$=1.87, P=0.193; Bracket: $F_{1, 624}$=0.53, P=0.480; Grid: $F_{1, 624}$=0.43, P=0.522; Crosshair: $F_{1, 624}$=0.36, P=0.560; Bulls-eye: $F_{1, 624}$=0.30, P=0.593). There is no difference between Groups for any Aim Pattern for the Data Matrix Target Type. Figure 4.1.74 depicts the average Scan Time for the Data Matrix Target Type for each Aim Pattern, by Group.

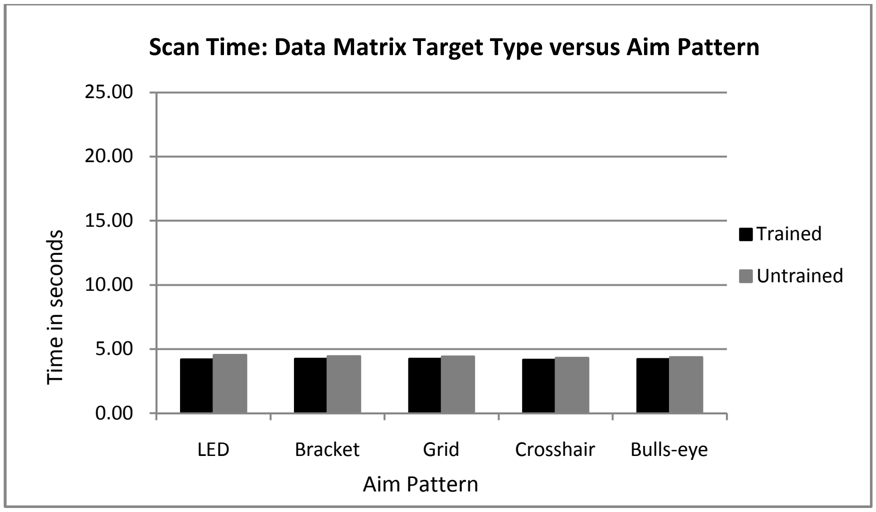


Figure 4.1.74: Scan Time: Data Matrix Target Type versus Aim Pattern

For the PDF Target Type and the Trained Group, Aim Pattern is not statistically significant ($F_{4, 1560}$=0.55, P=0.699). There is no statistically significant difference (at a .05 or .10 level) between the LED, Bracket, Grid, Crosshair and Bulls-eye Aim Patterns when the Trained Group scans the PDF Target Type.

For the PDF Target Type and the Untrained Group, Aim Pattern is statistically significant at a .10 level ($F_{4, 1560}$=2.31, P=0.083). There is a statistically significant difference between the LED Aim Pattern and the Crosshair Aim Pattern (P=0.0761). The LED Aim Pattern results in an average 0.24 seconds longer Scan Time than the Crosshair Aim Pattern. There are no other statistically significant differences (at a .05 or .10 level) between Aim Patterns when scanning the PDF Target Type.

Group is not statistically significant for the Bracket, Grid, Crosshair or Bulls-eye Aim Pattern (Bracket: $F_{1, 624}$=0.53, P=0.477; Grid: $F_{1, 624}$=0.55, P=0.469; Crosshair: $F_{1, 624}$=0.12, P=0.734; Bulls-eye: $F_{1, 624}$=0.07, P=0.802). The LED Aim Pattern is statistically significant at a .10 level ($F_{1,}$

$_{624}$=3.19, P=0.096). The Trained Group is an average 0.346 seconds faster than the Untrained Group. Figure 4.1.75 depicts the average Scan Time for the PDF Target Type for each Aim Pattern, by Group.

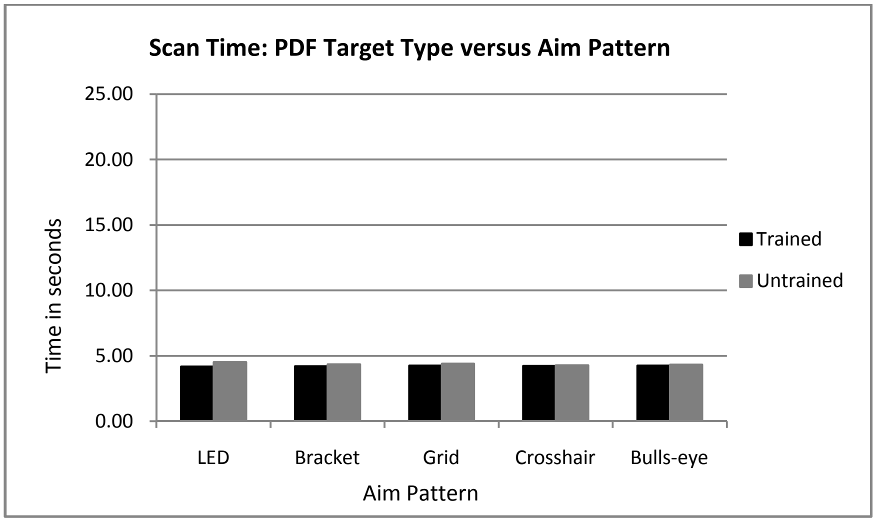


Figure 4.1.75: Scan Time: PDF Target Type versus Aim Pattern

Aim Pattern is statistically significant for the Linear Target Type for both Groups. The LED Aim Pattern results in a slower Scan Time than the other Aim Patterns (Trained Group: 13.54 seconds slower; Untrained Group: 10.83 seconds slower). Aim Pattern is not statistically significant for the Data Matrix Target Type in either Group. Aim Pattern is not statistically significant for the PDF Target Type for the Trained Group. Aim Pattern is statistically significant for the PDF Target Type in the Untrained Group at a .10 level. The LED Aim Pattern results in a significantly greater Scan Time than the Crosshair (.24 seconds greater). Group is significant for the PDF Target Type and LED Aim Pattern at a .10 level. The Trained Group is .346 seconds faster than the Untrained Group.

4.1.2.2 Day*Target Type

Data were separated by Target Type to analyze the effect of Day. An interaction plot for the Day*Target Type two-way interaction is depicted below in Figure 4.1.76.

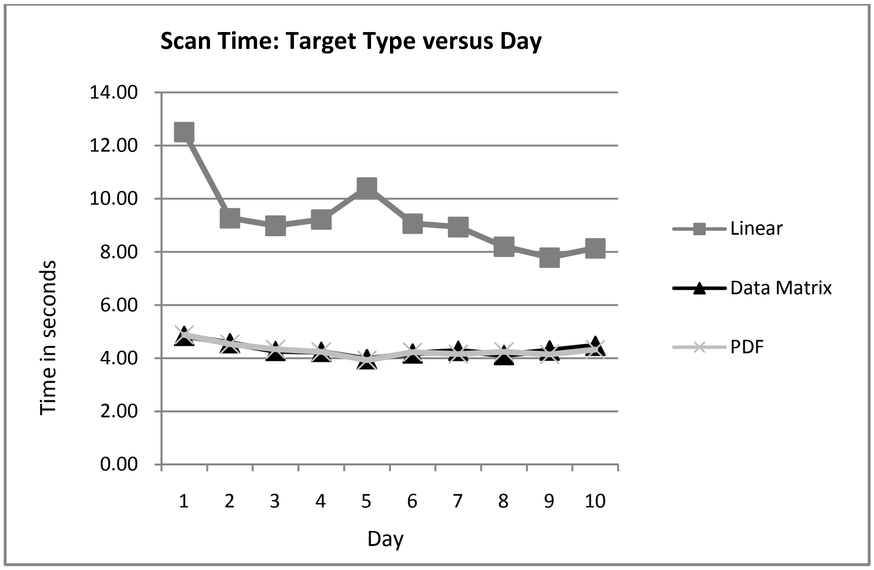


Figure 4.1.76: Scan Time: Target Type versus Day, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Target Type to determine statistically significant differences between Days. For the Linear Target Type, Day is statistically significant ($F_{9, 3175}$=7.53, P=0.000). Day 1 is different from Day 2, 3, 4, 6, 7, 8, 9 and 10 at a .05 level (P=0.0059, 0.0016, 0.0047, 0.0023, 0.0012, 0.0000, 0.0000 and 0.0000 respectively). Day 5 is different from Day 9 at a .10 level (P=0.0642). There are no other significant differences between Days at a .05 or .10 level for the Linear Target Type. Figure 4.1.77 depicts the average Scan Time for the Linear Target Type by Day.

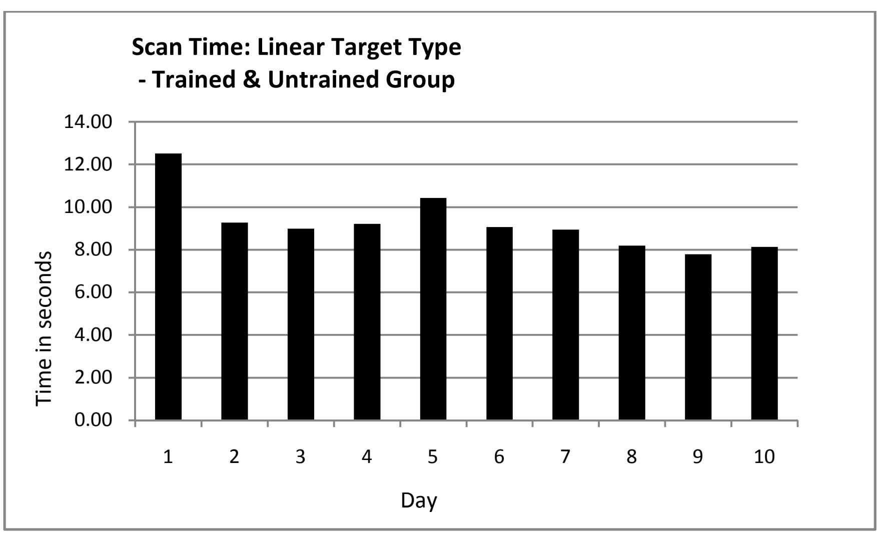


Figure 4.1.77: Scan Time: Linear Target Type versus Day

For the Data Matrix Target Type, Day is statistically significant ($F_{9, 3175}$=29.93, P=0.000). Day 1 is different from Days 2, 3, 4, 5, 6, 7, 8, 9 and 10 at a .05 level (P=0.0007, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000 and 0.0000 respectively). Day 2 is different from Days 3-9 at a .05 (P=0.0002, 0.0000, 0.0000, 0.0000, 0.0004, 0.0000 and 0.0007 respectively). Day 3 is different from Day 5 at a .05 level (P=0.0001) and Day 10 at a .10 level (P=0.0783). Day 4 is different from Day 5 and 10 at a .05 level (P=0.0006 and 0.0170 respectively). Day 5 is different from Days 6, 7, 9 and 10 at a .05 level (P=0.0286, 0.0000, 0.0000 and 0.0000 respectively). Day 6 is different from Day 10 (P=0.0003). Day 8 is different from Day 10 (P=0.0000). There are no other significant differences between Days at a .05 or .10 level for the Data Matrix Target Type. Figure 4.1.78 depicts the average Scan Time for the Data Matrix Target Type by Day.

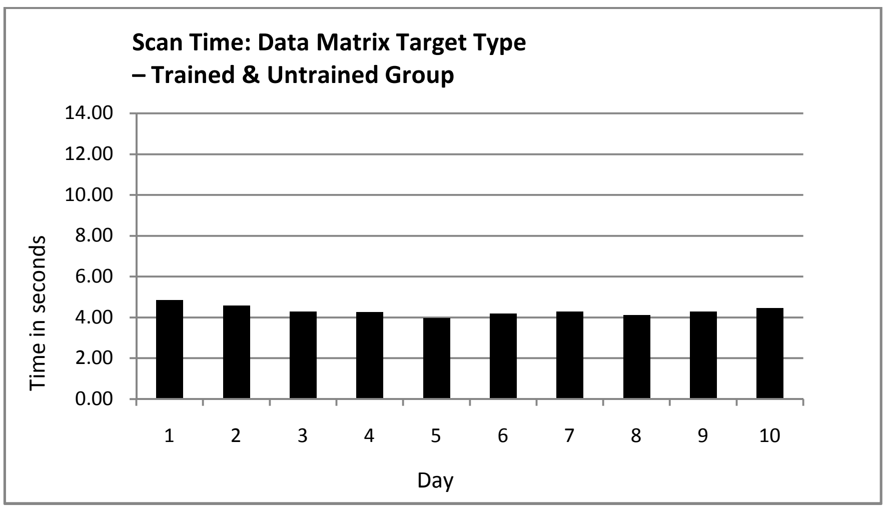


Figure 4.1.78: Scan Time: Data Matrix Target Type versus Day

For the PDF Target Type, Day is statistically significant ($F_{9, 3175}$=28.70, P=0.000). Day 1 is significantly different from Days 2, 3, 4, 5, 6, 7, 8, 9 and 10 at a .05 level (P=0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000 and 0.0000 respectively). Day 2 is significantly different from Days 4, 5, 6, 7, 8 and 9 at a .05 level (P=0.0008, 0.0000, 0.0005, 0.0000, 0.0006 and 0.0000 respectively). Day 2 is different from Day 10 at a .10 level (P=0.0602). Day 3 is different from Day 5 at a .05 level (P=0.0000). Day 4 is different from Day 5 at a .05 level (P=0.0001). Day 5 is different from Days 6, 7, 8, 9 and 10 at a .05 level (0.0002, 0.0196, 0.0002, 0.0483 and 0.0000 respectively). There are no other significant differences between Days at a .05 or .10 level for

the PDF Target Type. Figure 4.1.79 depicts the average Scan Time for the PDF Target Type by Day.

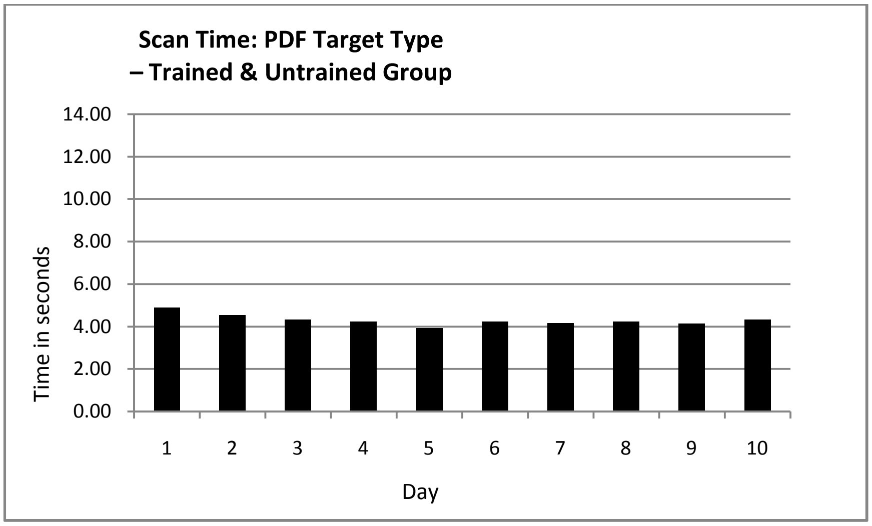


Figure 4.1.79: Scan Time: PDF Target Type versus Day

Day is statistically significant at a .05 level for all three Target Types. Pair-wise differences for Day vary between Target Types, but Day 1 is statistically different from Days 2-10 at a .05 level for the Data Matrix and PDF Target Types with similar results for the Linear Target Type.

4.1.2.3 Group*Target Type (Target Type Main Effect)

Data were separated by Group (Trained and Untrained) to analyze the effect of Target Type. An interaction plot for the Group*Target Type two-way interaction is depicted below in Figure 4.1.80.

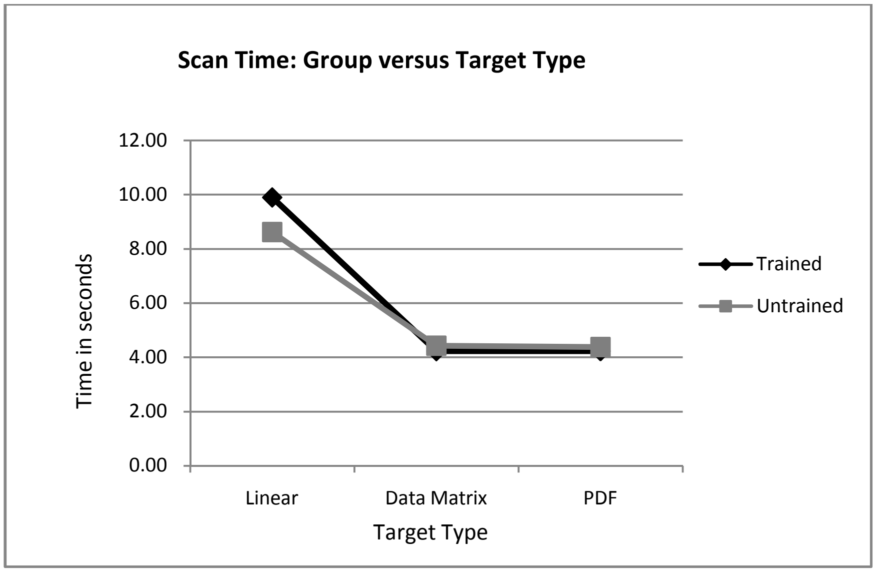


Figure 4.1.80: Scan Time: Target Type Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Target Types. For the Trained Group, Target Type is statistically significant ($F_{2, 4776}$=81.68, P=0.000). The Linear Target Type is different from the Data Matrix and PDF Target Types (P=0.000 and 0.000 respectively). The Linear Target Type results in an average 5.67 second slower Scan Time than the other Target Types. The Data Matrix and PDF Target Types are not significantly different at a .05 or .10 level.

For the Untrained Group, Target Type is statistically significant ($F_{2, 4776}$=32.46, P=0.000). The Linear Target Type is different from the Data Matrix and PDF Target Types (P=0.000 and 0.000 respectively). The Linear Target Type results in an average 4.22 seconds slower Scan Time than the other Target Types. The Data Matrix and PDF Target Types are not significantly different at a .05 or .10 level.

Group is not statistically significant for any Target Type (Linear: $F_{1, 3184}$=1.58, P=0.249; Data Matrix: $F_{1, 3184}$=0.69, P=0.435; PDF: $F_{1, 3184}$=0.54, P=0.485). When scanning the Linear, Data matrix or PDF Target Type, there is no significant difference between Scan Times for the Trained and Untrained Groups. Figure 4.1.81 depicts the average Scan Time for Target Type by Group.

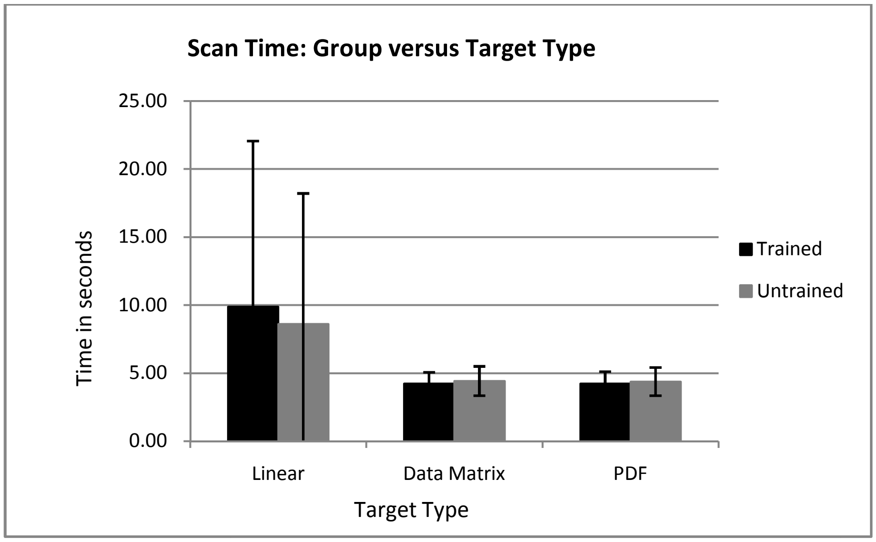


Figure 4.1.81: Scan Time: Target Type Main Effect by Group

4.1.2.4 Group*Day (Day Main Effect)

Data were separated by Group (Trained and Untrained) to analyze the effect of Day. An interaction plot for the Group*Day two-way interaction is depicted below in Figure 4.1.82.

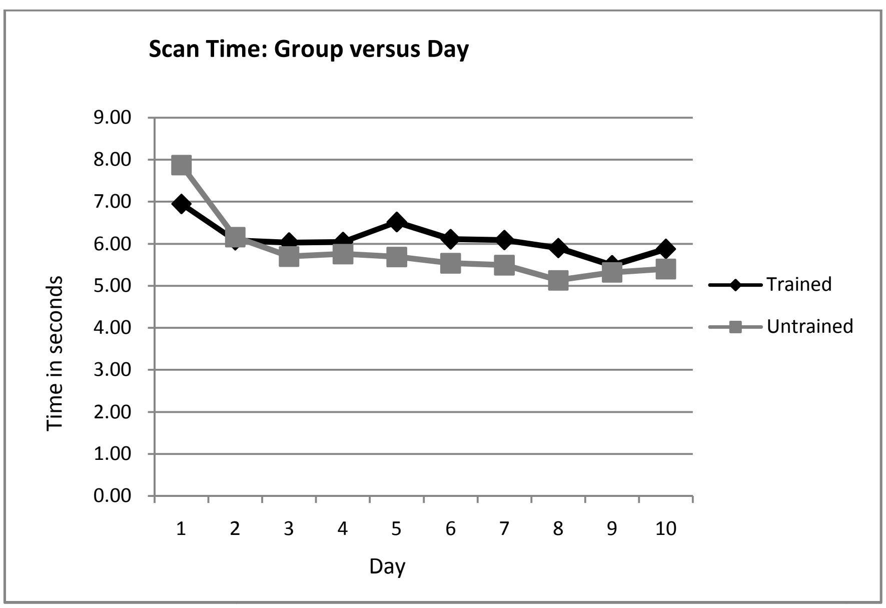


Figure 4.1.82: Scan Time: Day Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Days. For the Trained Group, Day is statistically significant ($F_{9,}$

$_{4720}$=2.18, P=0.036). Day 1 is different from Day 9 at a .05 level (P=0.0081). There are no other significant differences between Days at a .05 or .10 level.

For the Untrained Group, Day is statistically significant ($F_{9,4720}$=8.92, P=0.000). Day 1 is different from Days 2-10 at a .05 level (P=0.0007, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, 0.0000, and 0.0000 respectively). There are no other significant differences between Days at a .05 or .10 level. Figure 4.1.83 and 4.1.84 depict the average Scan Time by Day for each Group.

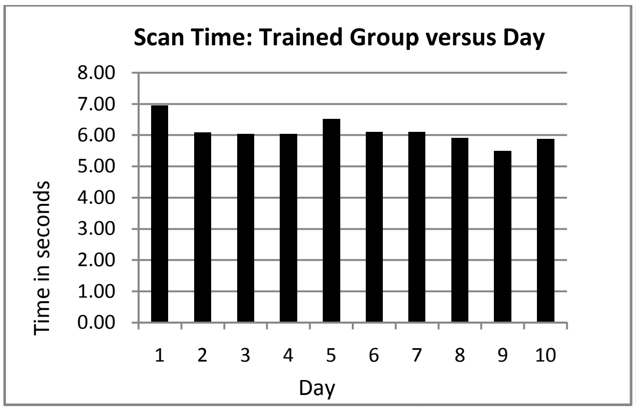


Figure 4.1.83: Scan Time: Day Main Effect – Trained Group

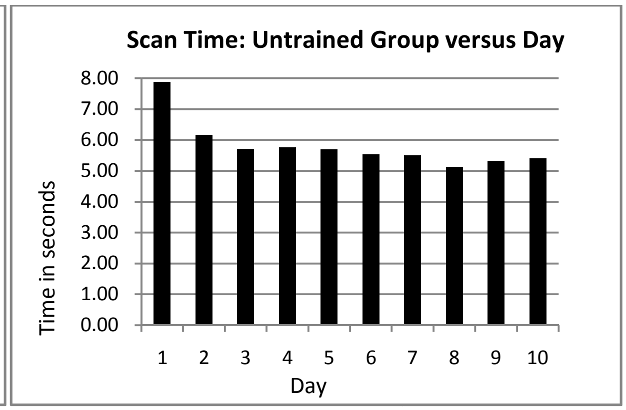


Figure 4.1.84: Scan Time: Day Main Effect – Untrained Group

For the Trained Group, Day 1 is different from Day 9 at a .05 level. For the Untrained Group, Day 1 is different from Days 2-10 at a .05 level. For the Untrained Group, Scan Time is significantly higher on Day 1 than the other Days.

4.1.3 Group Main Effect

Because of the complexity of the results, the difficulty in interpreting the interaction effects and since training is such an important concept in this study, the Group Main Effect was analyzed including only the independent variables Group, Subject(Group), and Aim Pattern for all original dependent variables for ergonomics and efficiency. Day and Target Type were removed from the model to get a better idea of the effect of training. Day was chosen for removal based on

previous results lacking any notable trends. Target Type was removed since it is an environmental factor that cannot be altered by scanner product design. A summary of this resulting ANOVA analysis is depicted in Table 4.1.3.

	Group	Subject (Group)	Aim Pattern	Group*Aim Pattern
Supination	0.143	0.000	0.000	0.451
Pronation	0.05*	0.000	0.395	0.055
Flexion	0.568	0.000	0.000	0.000*
Extension	0.680	0.000	0.061	0.002*
Ulnar	0.430	0.000	0.651	0.261
Time	0.301	0.000	0.000	0.221

*Significant at .05 alpha level

Table 4.1.3: Self-Paced Task Ergonomics and Efficiency ANOVA Results – Group Main Effect

Pronation, Flexion and Extension, the postures in which the Group*Aim Pattern interaction is significant have already been analyzed in Sections 4.1.1.2.2, 4.1.1.3.4, and 4.1.1.4.3 respectively. Group is statistically significant at a.05 level for Pronation only (P=0.050). The Trained Group results in an average 2.41 degrees less forearm deviation than the Untrained Group. Figure 4.1.85 depicts the average Pronation by Group.

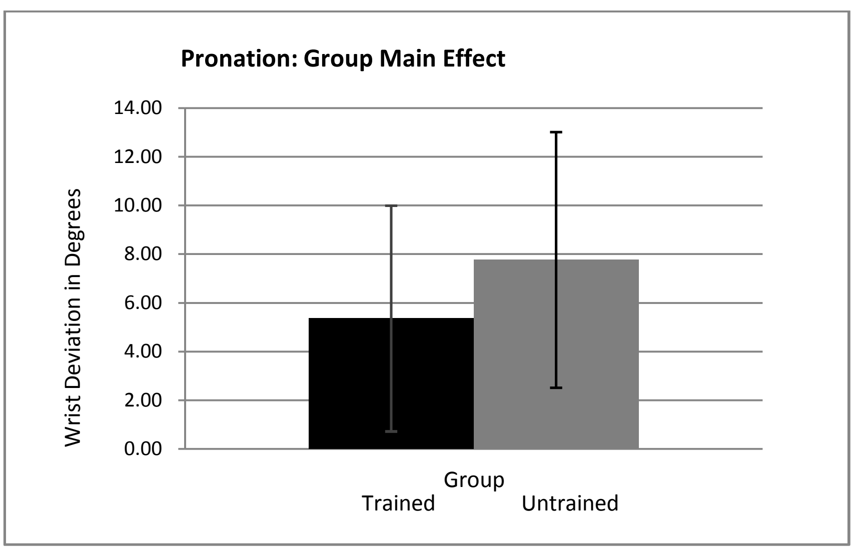


Figure 4.1.85: Pronation: Group Main Effect

4.1.4 Subjective Ratings and Rank

An ANOVA for repeated measures was completed on the Subjective Ratings assessing Perceived Comfort and Usability. Below in Table 4.1.4 is a summary of the ANOVA results for Comfort and Usability Ratings. To assess Subjective Rank, Frequency of Rank was used. Table 4.1.5 depicts a summary of Rank for each Aim Pattern by Group.

	Subject (Group)	Group	Day	Aim Pattern	Group*Day	Group*Aim Pattern	Day*Aim Pattern	Group*Day*Aim Pattern
Comfort	0.000*	0.685	0.576	0.000*	0.014*	0.039*	0.971	0.994
Usability	0.000*	0.625	0.001*	0.000*	0.705	0.313	0.989	0.913

*Significant at .05 alpha level Fully Analyzed

Table 4.1.4: Self-Paced Task Subjective Ratings ANOVA Results

Rank 1=best	Trained Group					Untrained Group				
	LED	Bracket	Grid	Crosshair	Bulls-eye	LED	Bracket	Grid	Crosshair	Bulls-eye
1	0	35	24	15	6	0	41	3	19	17
2	0	18	18	21	23	0	10	19	30	21
3	5	15	17	23	20	3	13	25	15	24
4	2	12	20	18	28	4	15	30	15	16
5	73	0	1	3	3	73	1	3	1	2

Table 4.1.5: Self-Paced Task Aim Pattern Frequency of Rank Summary

4.1.4.1 Subjective Aim Pattern Rating for Perceived Comfort

All Minitab results for Comfort in the Self-Paced Task can be found in Appendix J.

*4.1.4.1.1 Group*Aim Pattern (Aim Pattern Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the effect of Aim Pattern. An interaction plot for the Group*Aim Pattern two-way interaction is depicted below in Figure 4.1.86.

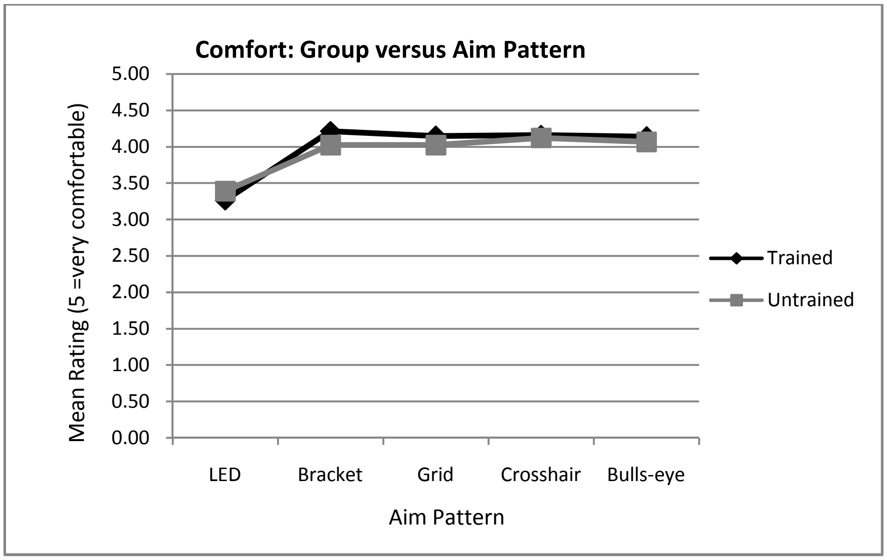


Figure 4.1.86: Comfort: Aim Pattern Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Aim Patterns. For the Trained Group, Aim Pattern is statistically significant ($F_{4, 360}$=15.84, P=0.000). The LED Aim Pattern is different from all other Aim Patterns (P=0.0000 for all pair-wise comparisons). There are no other statistically significant pair-wise differences (at a .05 or .10 level) between Aim Patterns.

For the Untrained Group, Aim Pattern is statistically significant ($F_{4, 360}$=10.79, P=0.000). The LED Aim Pattern is different from the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns (P=0.0004, 0.0004, 0.0001 and 0.0002 respectively). There are no other statistically significant pair-wise differences (at a .05 or .10 level) between Aim Patterns.

Group is not statistically significant for any Aim Pattern (LED: $F_{1, 144}$=0.45, P=0.524; Bracket: $F_{1, 144}$=1.24, P=0.302; Grid: $F_{1, 144}$=0.58, P=0.472; Crosshair: $F_{1, 144}$=0.05, P=0.903; Bulls-eye: $F_{1, 144}$=0.16, P=0.702). When scanning with the Led, Bracket, Grid, Crosshair or Bulls-eye Aim Patterns, there is no significant difference between Comfort Ratings for the Trained and Untrained Groups. Figure 4.1.87 depicts the average Comfort Rating for each Aim Pattern by Group.

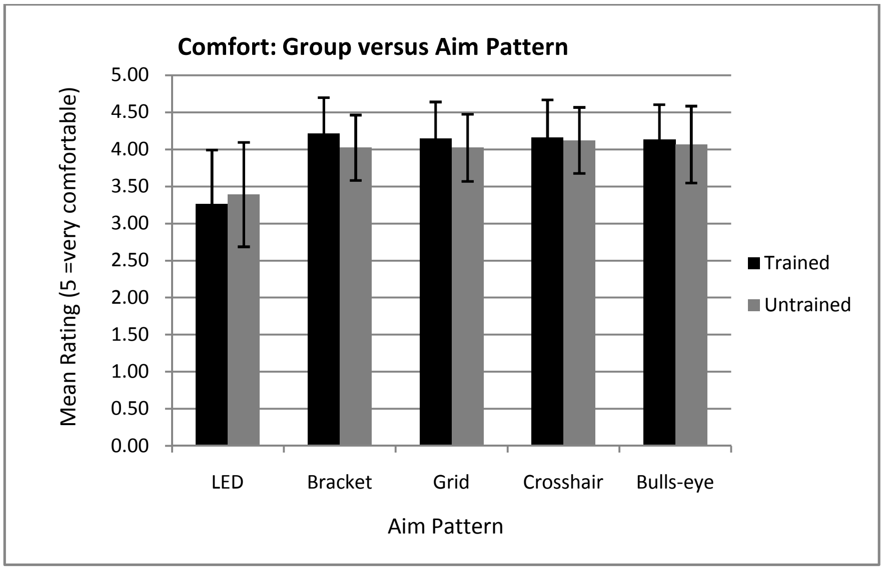


Figure 4.1.87: Comfort: Aim Pattern Main Effect by Group

The LED Aim Pattern resulted in a significantly worse Comfort Rating than the other Aim Patterns for both Groups. For the Trained Group, this difference had greater significance.

*4.1.4.1.2 Group*Day (Day Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the effect of Day. An interaction plot for the Group*Day two-way interaction is depicted below in Figure 4.1.88.

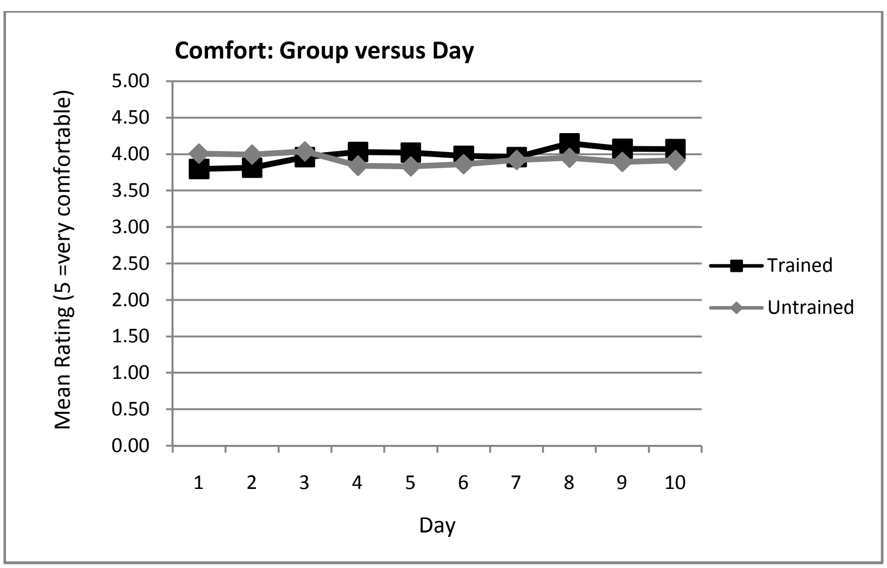


Figure 4.1.88: Comfort: Day Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Days. For the Trained Group, Day is not statistically significant ($F_{9, 320}$=1.31, P=0.248). For the Untrained Group, Day is not statistically significant ($F_{9, 320}$=1.58, P=0.141). There are no significant differences (at a .05 or.10 level) between Days for either Group. Figure 4.1.89 depicts the average Comfort Rating for each Day by Group.

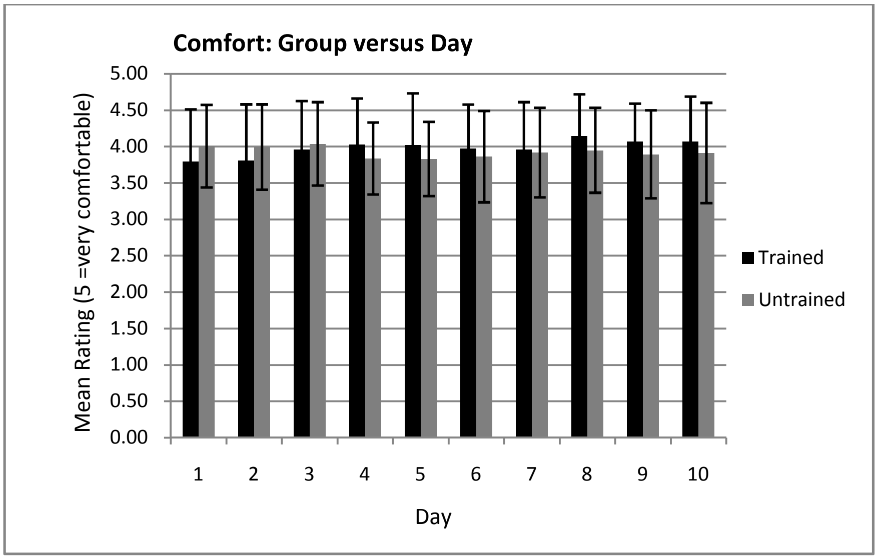


Figure 4.1.89: Comfort: Day Main Effect by Group

There are no statistically significant differences between Days for either Group however Day has greater significance in the Untrained Group than in the Trained Group. No obvious trends emerge in either Group.

4.1.4.2 Subjective Aim Pattern Rating for Perceived Usability

All Minitab results for Usability in the Self-Paced Task can be found in Appendix K.

*4.1.4.2.1 Group*Aim Pattern (Aim Pattern Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the effect of Aim Pattern. An interaction plot for the Group*Aim Pattern two-way interaction is depicted below in Figure 4.1.90.

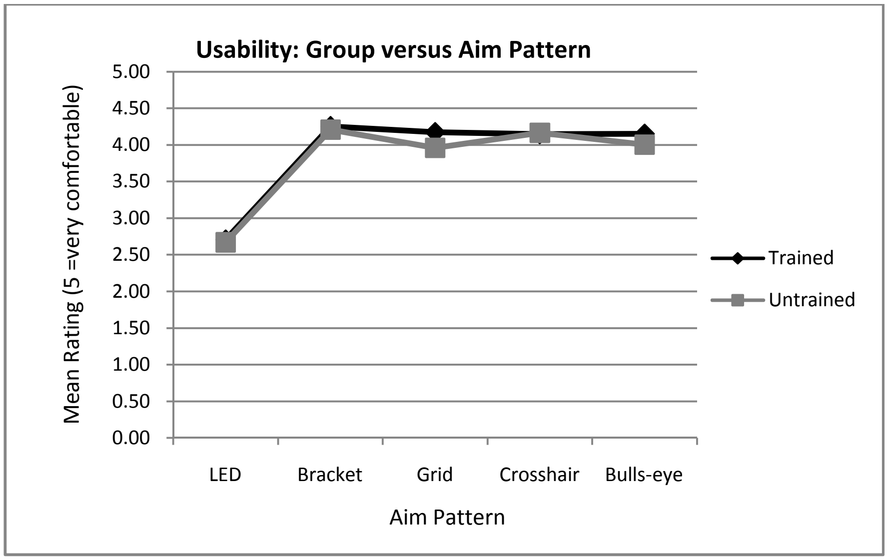


Figure 4.1.90: Usability: Aim Pattern Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Aim Patterns. For the Trained Group, Aim Pattern is statistically significant ($F_{4, 360}$=58.01, P=0.000). The LED Aim Pattern is different from all other Aim Patterns (P=0.0000 for all pair-wise comparisons). There are no other statistically significant pair-wise differences at .05 or .10 level.

For the Untrained Group, Aim Pattern is statistically significant ($F_{4, 360}$=28.97, P=0.000). The LED Aim Pattern is different from all other Aim Patterns (P=0.0000 for all pair-wise comparisons). There are no other statistically significant pair-wise differences at .05 or .10 level.

Group is not statistically significant for any Aim Pattern (LED: $F_{1, 144}$=0.01, P=0.920; Bracket: $F_{1, 144}$=0.07, P=0.805; Grid: $F_{1, 144}$=1.84, P=0.218; Crosshair: $F_{1, 144}$=0.01, P=0.921; Bulls-eye: $F_{1, 144}$=0.78, P=0.407). When scanning with the Led, Bracket, Grid, Crosshair or Bulls-eye Aim Patterns, there is no significant difference between Usability Ratings for the Trained and Untrained Groups. Figure 4.1.91 depicts the average Usability Rating for each Aim Pattern by Group.

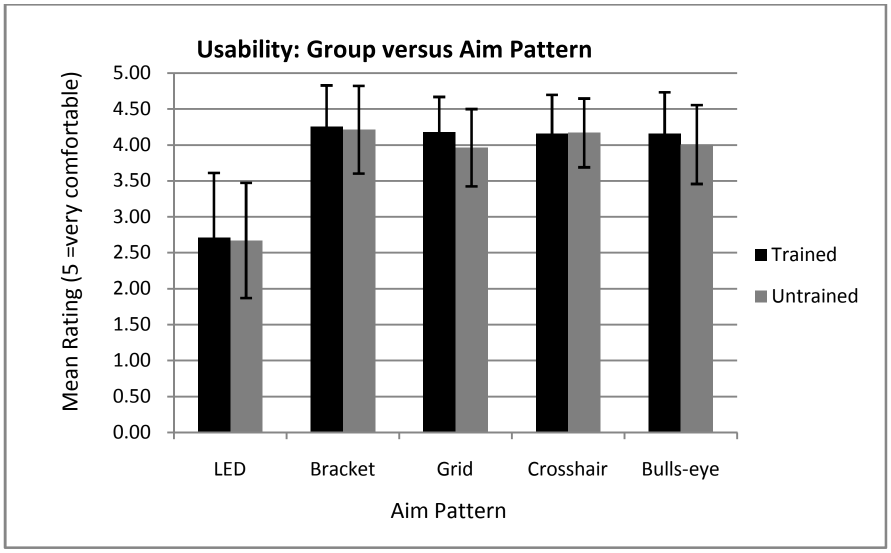


Figure 4.1.91: Usability: Aim Pattern Main Effect by Group

The LED Aim Pattern resulted in a significantly worse Usability Rating than the other Aim Patterns for both Groups. For the Trained Group, this difference had greater significance.

*4.1.4.2.2 Group*Day (Day Main Effect)*

Data were separated by Group (Trained and Untrained) to analyze the effect of Day. An interaction plot for the Group*Day two-way interaction is depicted below in Figure 4.1.92.

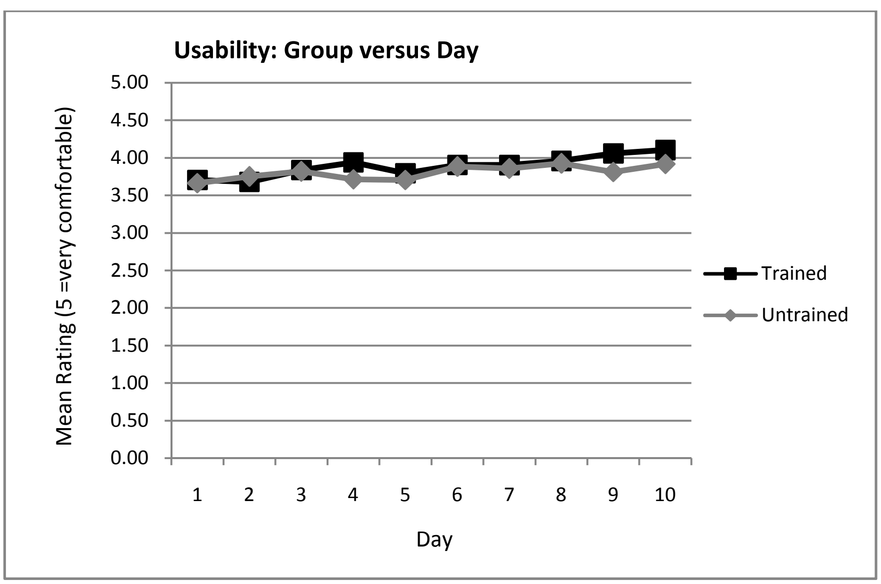


Figure 4.1.92: Usability: Day Main Effect by Group, Interaction Plot

Tukey's HSD Post Hoc Test was completed for each Group to determine statistically significant differences between Days. For the Trained Group, Day is not statistically significant ($F_{9, 320}$=1.57, P=0.143). For the Untrained Group, Day is not statistically significant ($F_{9, 320}$=0.95, P=0.487). There are no significant differences (at a .05 or .10 level) between Days for either Group. Figure 4.1.93 depicts the average Usability Rating for each Day by Group.

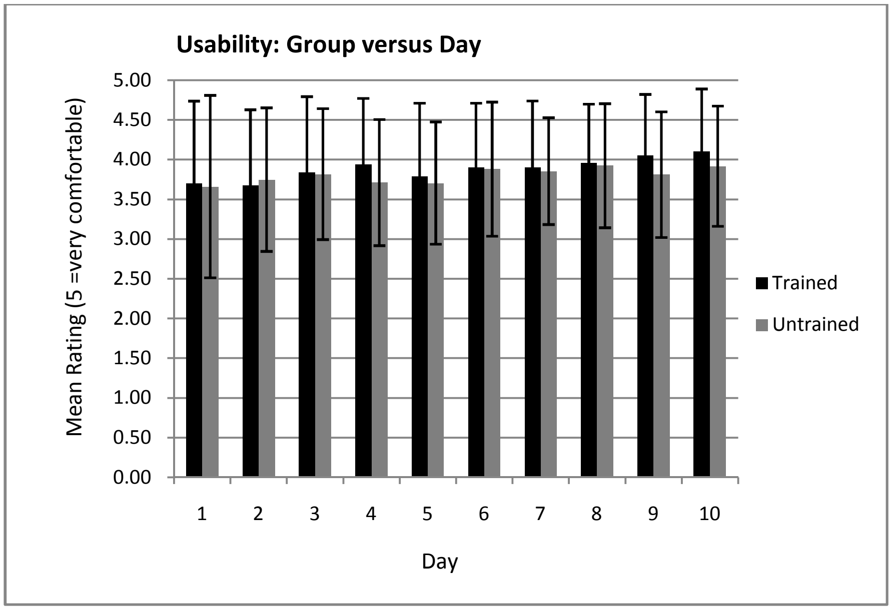


Figure 4.1.93: Usability: Day Main Effect by Group

There are no statistically significant differences between Days for either Group however Day has greater significance in the Trained Group than in the Untrained Group. No obvious trends emerge in either Group.

4.1.4.3 Subjective Aim Pattern Rank

Subjects were asked to Rank the Aim Patterns in order from best to worst at the end of each of the ten days. A summary for each Aim Pattern was compiled based on median Rank. Figure 4.1.94 depicts the median Rank for each Aim Pattern by Group.

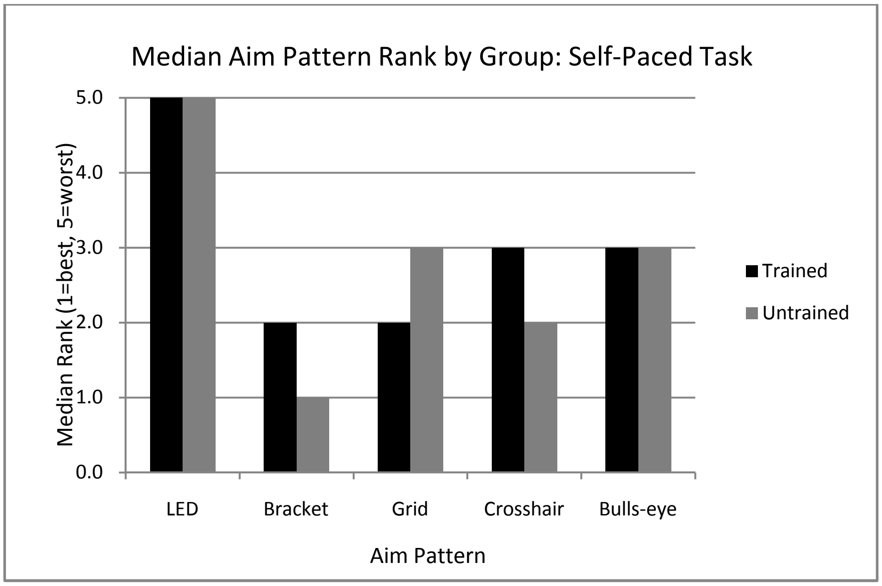


Figure 4.1.94: Median Aim Pattern Rank – Self-Paced Task

Both the Trained and Untrained Group ranked the LED Aim Pattern the worst Aim Pattern, giving it a median rank of 5. The Untrained Group ranked the Bracket Aim Pattern as the best Aim Pattern, giving it a median rank of 1. The Untrained Group ranked the Crosshair Aim Pattern as second best, giving it a median rank of 2 and the Grid and Bulls-eye were both ranked 3. The Trained Group ranked both the Bracket and the Grid Aim Patterns as the best, giving them both a median rank of 2. The Trained Group ranked the Crosshair and Bulls-eye both 3.

4.2 Time Stress-Paced Task

During the time stress-paced task, participants were instructed to complete the scanning task as fast as possible. An ANOVA for repeated measures was completed on wrist deviations and scan time to assess ergonomics and efficiency. Analysis was completed identical to the Self-Paced Task except for the addition of the *Task* variable to assess the effect of pace. Since the purpose of this analysis was to assess pace, only the Main Effect of Task and its Interaction effects were looked at. Table 4.2.1 and 4.2.2 depict a summary of the ANOVA results.

	Subject (Group)	Task	Group	Day	Aim Pattern	Target Type	Task* Group	Task* Day	Task* Aim Pattern	Task* Target Type	Group* Day	Group* Aim Pattern	Group* Target Type	Day* Aim Pattern	Day* Target Type	Aim Pattern* Target Type	Task* Group* Day	Task* Group* Aim Pattern	Task* Day* Aim Pattern	Task* Group* Target Type	Task* Day* Target Type	Task* Aim Pattern* Target Type
Supination	0.000*	0.000*	0.241	0.000*	0.000*	0.000*	0.036*	0.147	0.392	0.337	0.000*	0.643	0.000*	0.162	0.017*	0.000*	0.223	0.725	0.048*	0.828	0.117	0.990
Pronation	0.000*	0.000*	0.085	0.000*	.0371	0.684	0.001*	0.668	0.854	0.612	0.001*	0.013*	0.000*	0.902	0.014*	0.814	0.035*	0.943	0.084	0.118	0.762	0.887
Flexion	0.000*	0.970	0.517	0.000*	0.000*	0.000*	0.056	0.643	0.308	0.804	0.057	0.000*	0.000*	0.588	0.002*	0.000*	0.945	0.237	0.471	0.942	0.164	0.937
Extension	0.000*	0.000*	0.645	0.000*	0.013*	0.561	0.182	0.704	0.432	0.060	0.033*	0.152	0.131	0.975	0.000*	0.908	0.713	0.861	0.248	0.909	0.210	0.976
Ulnar	0.000*	0.000*	0.257	0.000*	0.354	0.000*	0.832	0.950	0.863	0.309	0.000*	0.952	0.490	0.298	0.481	0.796	0.058	0.973	0.823	0.978	0.972	0.944
Scan Time	0.000*	0.000*	0.238	0.007*	0.000*	0.000*	0.408	0.638	0.980	0.488	0.336	0.046*	0.000*	0.000*	0.000*	0.000*	0.918	0.943	0.930	0.912	0.680	1.000

*Significant at .05 alpha level

Table 4.2.1: Time Stress-Paced Task Ergonomics and Efficiency ANOVA Results 1

	Subject (Group)	Task	Group	Day	Aim Pattern	Target Type	Task* Group	Task* Day	Task* Aim Pattern	Task* Target Type	Group* Day	Group* Aim Pattern	Group* Target Type	Day* Aim Pattern	Day* Target Type	Aim Pattern* Target Type	Task* Group* Day	Task* Group* Aim Pattern	Task* Day* Aim Pattern	Task* Group* Target Type	Task* Day* Target Type	Task* Aim Pattern* Target Type
Supination	0.000*	0.000*		0.000*	0.000*	0.000*	0.036*				0.000*		0.000*		0.017*	0.000*			0.048*			
Pronation	0.000*	0.000*		0.000*			0.001*				0.001*	0.013*	0.000*		0.014*		0.035*					
Flexion	0.000*			0.000*	0.000*	0.000*						0.000*	0.000*		0.002*	0.000*						
Extension	0.000*	0.000*		0.000*	0.013*						0.033*				0.000*							
Ulnar	0.000*	0.000*		0.000*		0.000*					0.000*											
Scan Time	0.000*	0.000*		0.007*	0.000*	0.000*						0.046*	0.000*	0.000*	0.000*	0.000*						

*Significant at .05 alpha level   Fully Analyzed

Table 4.2.2: Time Stress-Paced Task Ergonomics and Efficiency ANOVA Results 2

4.2.1 Ergonomics

4.2.1.1 Supination

All Minitab results for Supination in the Time Pressure-Paced Task can be found in Appendix L.

*4.2.1.1.1 Task*Day*Aim Pattern*

Data were separated by Day (only Day 5 and Day 10 were used). Within each Day, data were then separated by Task (Task 1: Self-Paced and Task 2: Time Stress-Paced) to analyze the effect of Aim Pattern. Interaction plots for the Task*Day*Aim Pattern three-way interaction are depicted below in Figures 4.2.1 and 4.2.2.

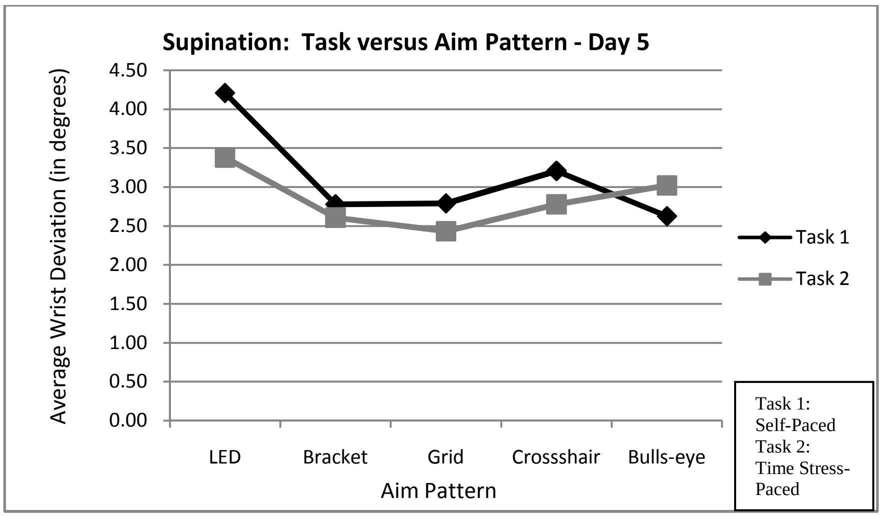


Figure 4.2.1: Supination: Task versus Aim Pattern – Day 5, Interaction Plot

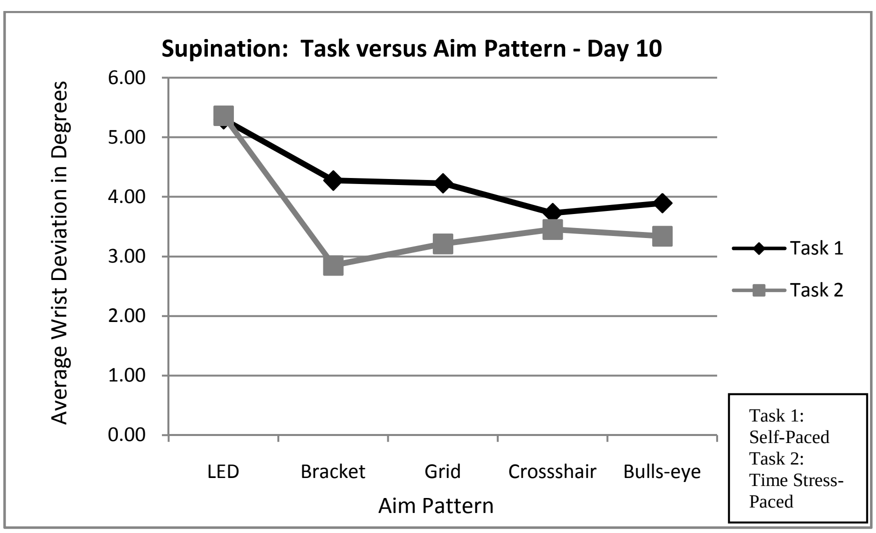


Figure 4.2.2: Supination: Task versus Aim Pattern – Day 10, Interaction Plot

For each Task within each Day, Tukey's HSD Post Hoc Test was completed for Aim Pattern to determine statistically significant differences between Aim Patterns. For Day 5 and Task 1, Aim Pattern is statistically significant ($F_{4, 920}$=4.71, P=0.005). The LED Aim Pattern is different from the Bracket, Grid and Bulls-eye Aim Patterns (P=0.0159, 0.0169, 0.0065 respectively). There are no other significant differences (at a .05 or .10 level) between Aim Pattern.

For Day 5 and Task 2, Aim Pattern is not statistically significant ($F_{4, 920}$=0.90, P=0.477). There are no significant differences (at a .05 or .10 level) between Aim Patterns. Figure 4.2.3 depicts the average Supination for Day 5 for each Task by Aim Pattern.

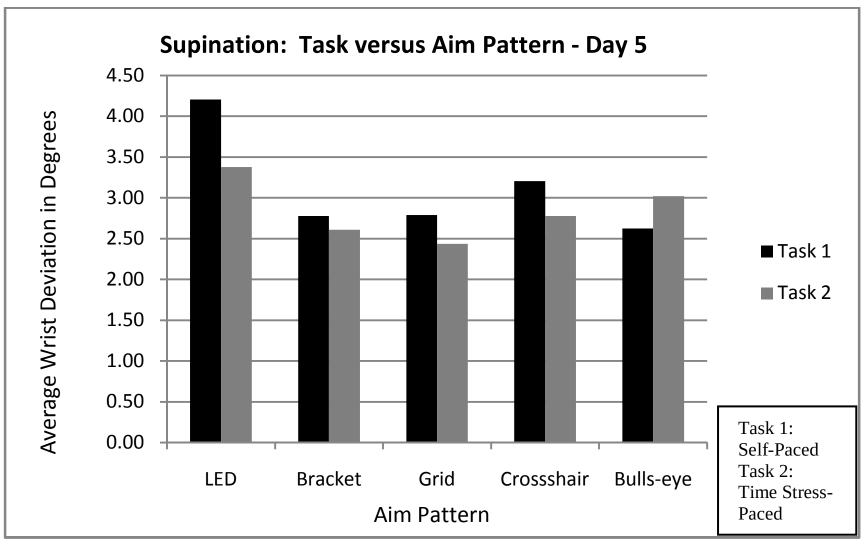


Figure 4.2.3: Supination: Task versus Aim Pattern – Day 5

For Day 10 and Task 1, Aim Pattern is statistically significant ($F_{4, 920}$=2.97, P=0.037). The LED Aim Pattern is different from the Crosshair Aim Pattern at a .05 level (P= 0.0307). The LED Aim Pattern is different from the Bulls-eye Aim Pattern at a .10 level (P=0.0639).

For Day 10 and Task 2, Aim Pattern is statistically significant ($F_{4, 920}$=6.90, P=0.001). The LED Aim Pattern is different from the Bracket, Grid, Crosshair and Bulls-eye Aim Patterns at a .05 level (P=0.0005, 0.0031, 0.0101 and 0.0059 respectively). There are no other significant differences (at a .05 or .10 level) between Aim Patterns. Figure 4.2.4 depicts the average Supination for Day 10 for each Task by Aim Pattern.

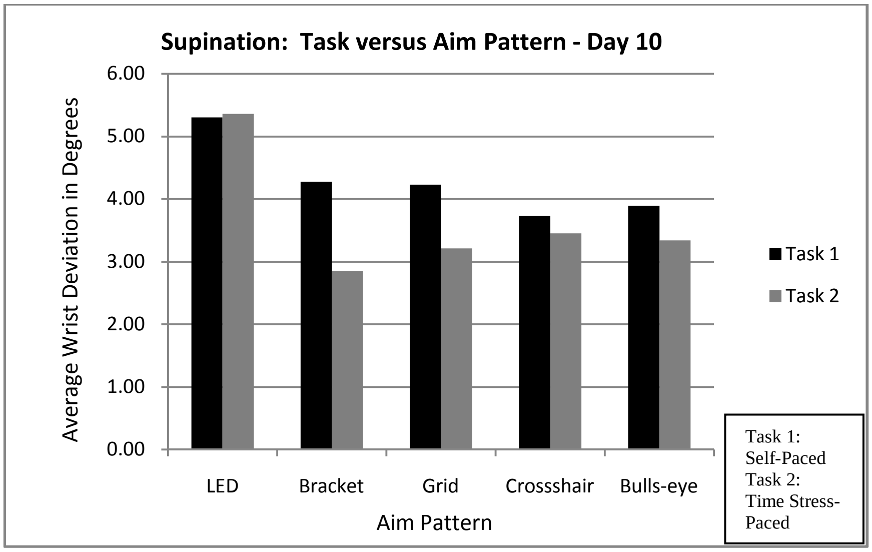


Figure 4.2.4: Supination: Task versus Aim Pattern – Day 10, Interaction Plot

*4.2.1.1.2 Task*Group (Task Main Effect)*

Data were separated by Task (Task 1: Self-Paced and Task 2: Time Pressure-Paced) to analyze the effect of Group. An interaction plot for the Task*Group two-way interaction is depicted below in Figures 4.2.5.

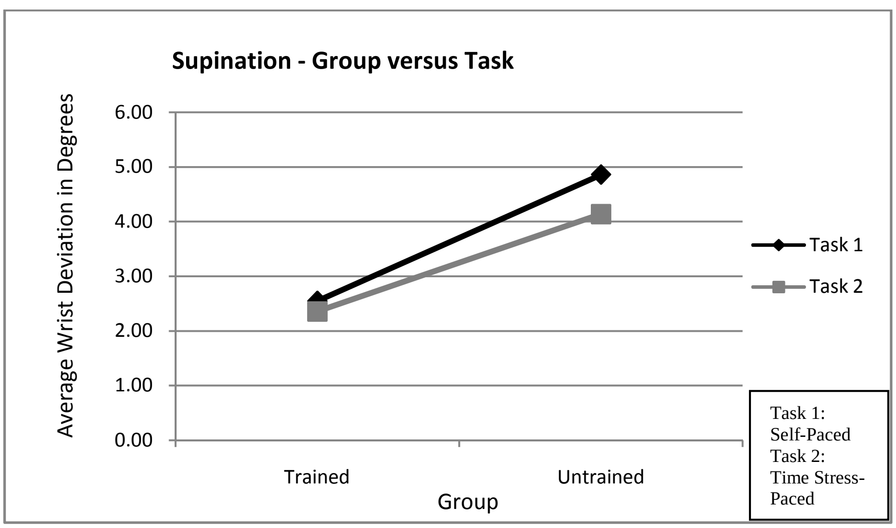


Figure 4.2.5: Supination: Task Main Effect by Group, Interaction Plot

For each Task, Tukey's HSD Post Hoc Test was completed for Group to determine statistically significant differences between Groups. For the Trained Group, Task is not

statistically significant ($F_{1, 1904}$=0.20, P=0.668). For the Untrained Group, Task is not statistically significant ($F_{1, 1904}$=2.75, P=0.141). Task did not have a significant effect on Supination in either Group.

For Task 1, Group is not statistically significant ($F_{1, 1904}$=1.42, P=0.273). For Task 2, Group is not statistically significant ($F_{1, 1904}$=1.37, P=0.280). Within each Task, there is no significant difference between Groups. Figure 4.2.6 depicts the average Supination for each Task by Group.

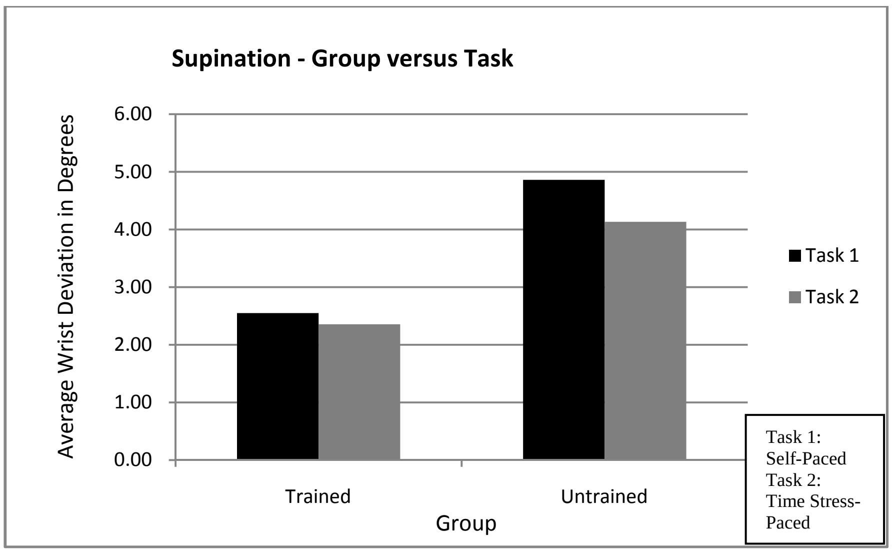


Figure 4.2.6: Supination: Task Main Effect by Group

4.2.1.2 Pronation

All Minitab results for Pronation in the Time Pressure-Paced Task can be found in Appendix M.

*4.2.1.2.1 Task*Group*Day*

Data were separated by Day (Day 5 and Day 10). Within each Day, data were then separated by Task (Task 1: Self-Paced and Task 2: Time Pressure-Paced) to analyze the effect of Group. Interaction plots for the Task*Group*Day three-way interaction are depicted below in Figures 4.2.7 and 4.2.8.

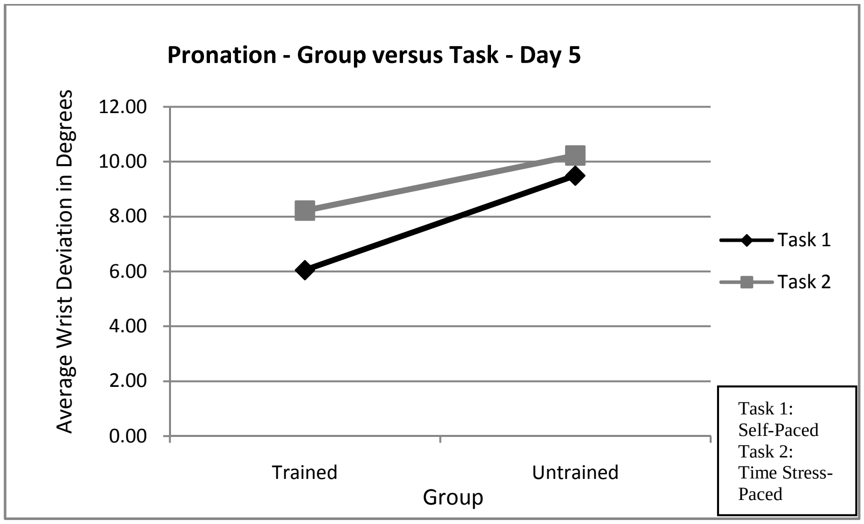


Figure 4.2.7: Pronation: Group versus Task – Day 5, Interaction Plot

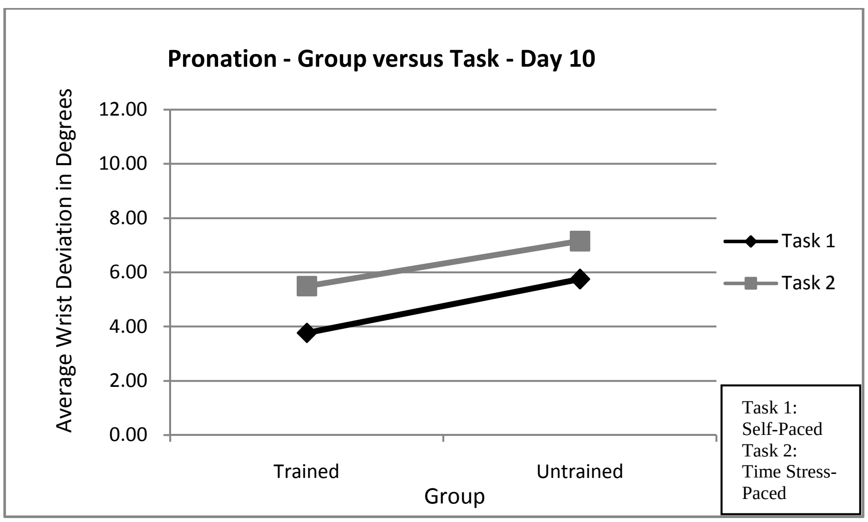


Figure 4.2.8: Pronation: Group versus Task – Day 10, Interaction Plot

For each Task within each Day, Tukey's HSD Post Hoc Test was completed for Group to determine statistically significant differences between Groups. For Day 5 and Task 1, Group is statistically significant ($F_{1,\ 1904}$=9.37, P=0.018). The Untrained Group had an average 3.44 degrees greater Pronation than the Trained Group (P=0.0183). For Day 5 and Task 2, Group is not statistically significant ($F_{1,\ 1904}$=4.67, P=0.068). Although the Untrained Group had greater Pronation than the Trained Group, it is not a statistically significant difference.

For Day 5 and the Trained Group, Task is statistically significant ($F_{1,\ 944}$=6.81, P=0.035). Task 1 resulted in an average 2.169 degrees less Pronation than Task 2 (P=0.0349). For Day 5

and the Untrained Group, Task is not statistically significant ($F_{1, 944}$=1.19, P=0.312). There is no significant difference (at a .05 or .10 level) between Task 1 and Task 2 Pronation for the Untrained Group. Figure 4.2.9 depicts the average Pronation for Day 5 for each Task by Group.

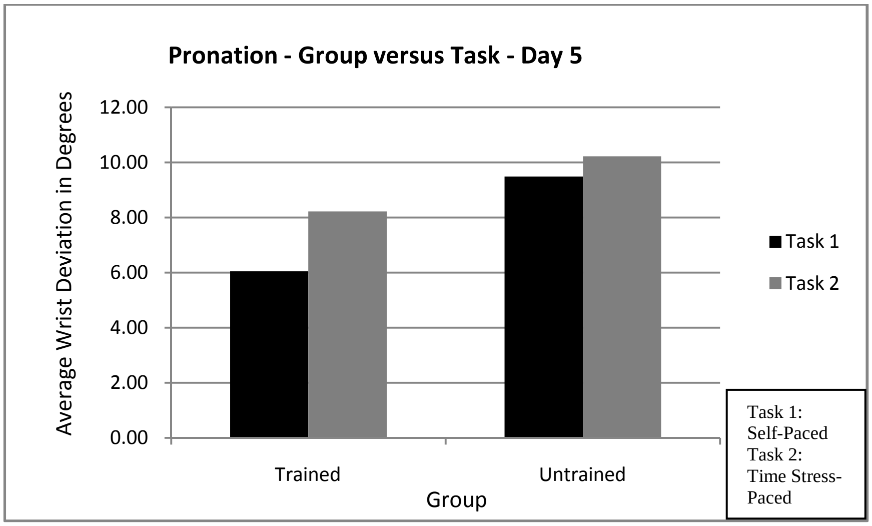


Figure 4.2.9: Pronation: Group versus Task – Day 5

For Day 10 and Task 1, Group is not statistically significant ($F_{1, 1904}$=1.15, P=0.318). Although the Untrained Group had greater Pronation than the Trained Group, it is not a significant difference. For Day 10 and Task 2, Group is not statistically significant ($F_{1, 1904}$=0.79, P=0.404). Although the Untrained Group had greater Pronation than the Trained Group, it is not a significant difference.

For Day 10 and the Trained Group, Task is statistically significant ($F_{1, 944}$=9.76, P=0.017). Task 1 resulted in an average 1.725 degrees less Pronation than Task 2 (P=0.0167). For Day 10 and the Untrained Group, Task is not statistically significant ($F_{1, 944}$=3.14, P=0.120). There is no significant difference (at. a 05 or .10 level) between Task 1 Pronation for the Untrained Group. Figure 4.2.10 depicts the average Pronation for Day 10 for each Task by Group.

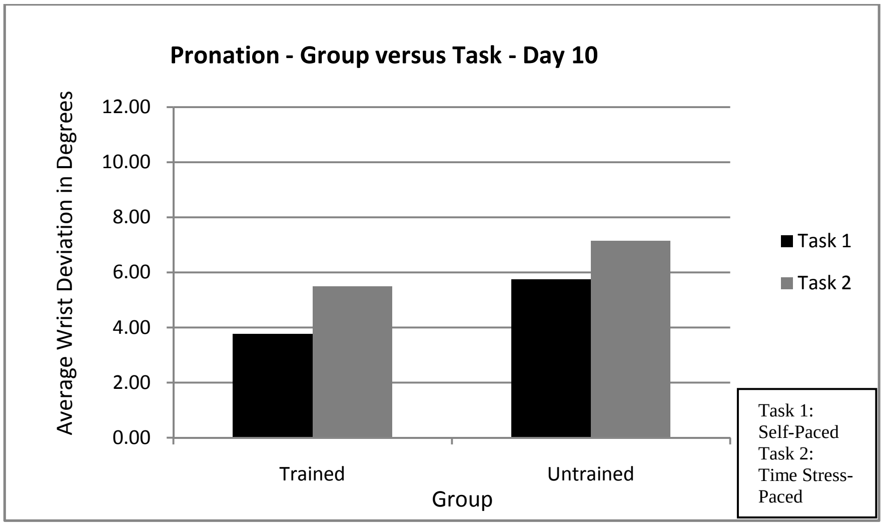


Figure 4.2.10: Pronation: Group versus Task – Day 10

4.2.1.3 Flexion

All Minitab results for Flexion in the Time Pressure-Paced Task can be found in Appendix N.

Task was not statistically significant for Flexion. There was no significant difference (at a .05 or .10 level) between Task 1 and Task 2 for Flexion. Figure 4.2.11 depicts the average Flexion for each Task by Group.

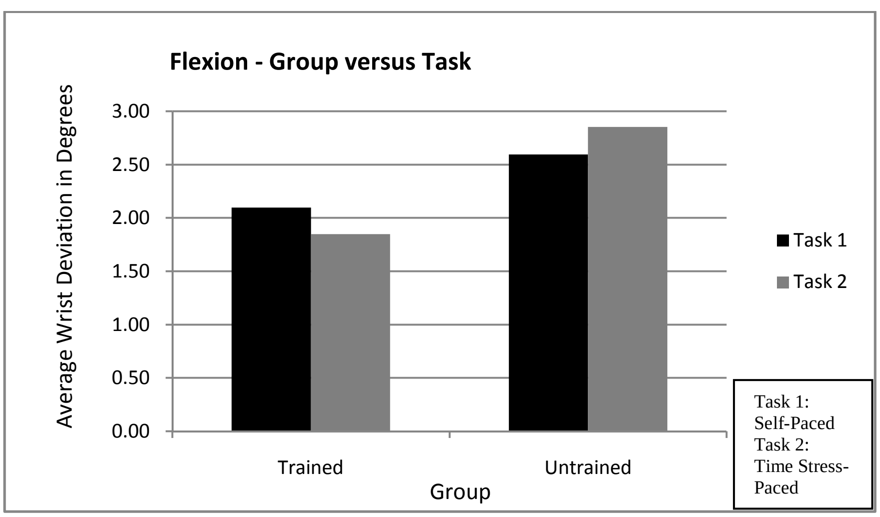


Figure 4.2.11: Flexion: Group versus Task

4.2.1.4 Extension

All Minitab results for Extension in the Time Pressure-Paced Task can be found in Appendix O.

*4.2.1.4.1 Task*Group (Task Main Effect)*

Data were separated by Task (Task 1: Self-Paced and Task 2: Time Pressure-Paced) to analyze the effect of Group. An interaction plot for the Task*Group two-way interaction is depicted below in Figures 4.2.12.

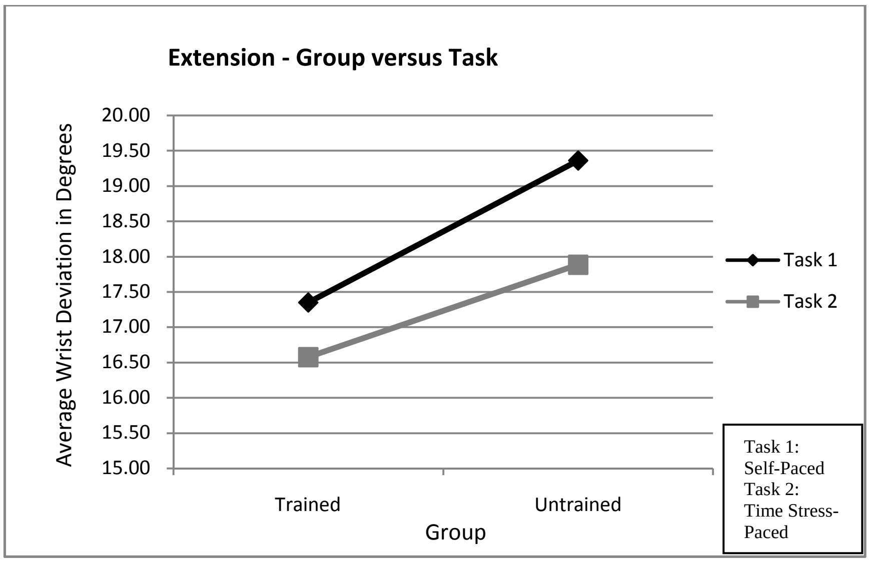


Figure 4.2.12: Extension: Task Main Effect by Group, Interaction Plot

For each Task, Tukey's HSD Post Hoc Test was completed for Group to determine statistically significant differences between Groups. For the Trained Group, Task is not statistically significant ($F_{1,\ 1904}$=1.00, P=0.352). For the Untrained Group, Task is not statistically significant ($F_{1,\ 1904}$=2.34, P=0.170). Task did not have a significant effect on Extension in either Group.

For Task 1, Group is not statistically significant ($F_{1,\ 1904}$=0.73, P=0.421). For Task 2, Group is not statistically significant ($F_{1,\ 1904}$=0.39, P=0.554). Within each Task, there is no significant difference between Groups. Figure 4.2.13 depicts the average Extension for each Task by Group.

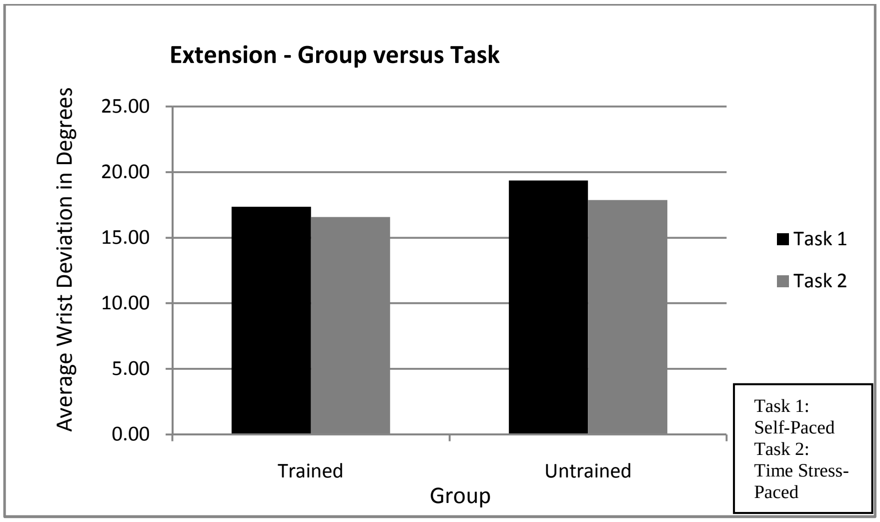


Figure 4.2.13: Extension: Task Main Effect by Group

4.2.1.5 Ulnar Deviation

All Minitab results for Ulnar Deviation in the Time Pressure-Paced Task can be found in Appendix P.

*4.2.1.5.1 Task*Group (Task Main Effect)*

Data were separated by Task (Task 1: Self-Paced and Task 2: Time Pressure-Paced) to analyze the effect of Group. An interaction plot for the Task*Group two-way interaction is depicted below in Figures 4.2.14.

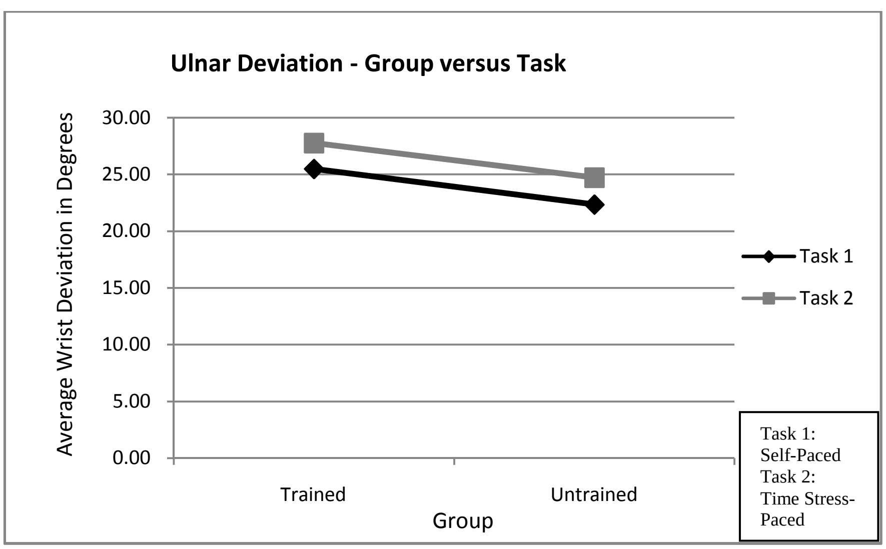


Figure 4.2.14: Ulnar Deviation: Task Main Effect by Group, Interaction Plot

For each Task, Tukey's HSD Post Hoc Test was completed for Group to determine statistically significant differences between Days. For the Trained Group, Task is statistically significant ($F_{1, 1904}$=21.71, P=0.002). Task 1 resulted in an average 2.272 degrees less Ulnar Deviation than Task 1 (P=0.0023). For the Untrained Group, Task is statistically significant ($F_{1, 1904}$=7.34, P=0.030). Task 1 resulted in an average 2.368 degrees less Ulnar Deviation than Task 2 (P=0.0302).

For Task 1, Group is not statistically significant ($F_{1, 1904}$=1.44, P=0.270). For Task 2, Group is not statistically significant ($F_{1, 1904}$=1.02, P=0.346). Within each Task, there is no significant difference between Groups. Figure 4.2.15 depicts the average Ulnar Deviation for each Task by Group.

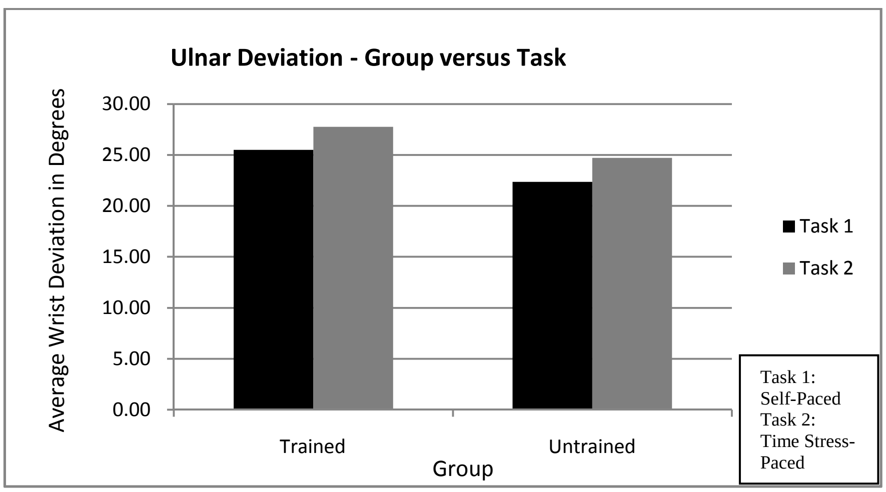


Figure 4.2.15: Ulnar Deviation: Task Main Effect by Group

4.2.2 Efficiency: Scan Time

All Minitab results for Scan Time in the Time Pressure-Paced Task can be found in Appendix Q.

4.2.2.1 Task*Group (Task Main Effect)

Data were separated by Task (Task 1: Self-Paced and Task 2: Time Pressure-Paced) to analyze the effect of Group. An interaction plot for the Task*Group two-way interaction is depicted below in Figure 4.16.

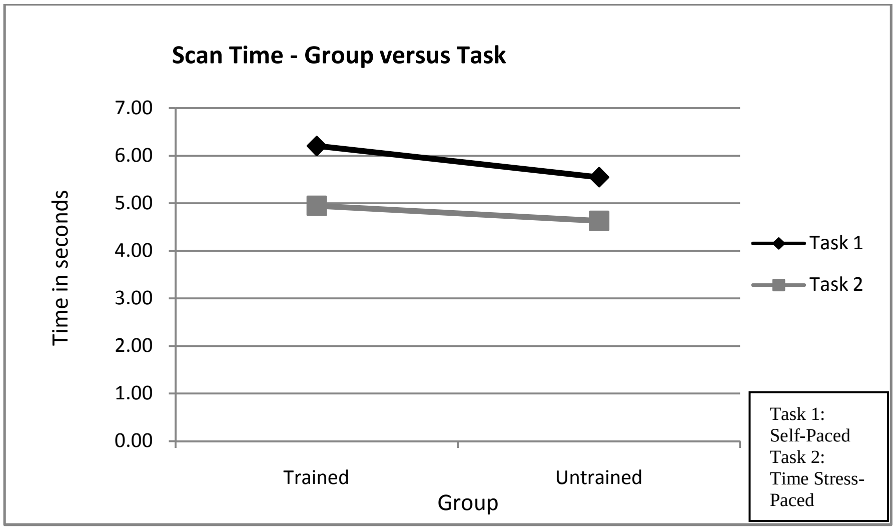


Figure 4.2.16: Scan Time: Task Main Effect by Group, Interaction Plot

For each Task, Tukey's HSD Post Hoc Test was completed for Group to determine statistically significant differences between Groups. For the Trained Group, Task is statistically significant ($F_{1, 1904}$=18.79, P=0.003). Task 1 resulted in an average 1.258 seconds longer Scan Time than Task 2. (P=0.0034). For the Untrained Group, Task is statistically significant ($F_{1, 1904}$=54.87, P=0.000). Task 1 resulted in an average 0.9176 seconds longer Scan Time than Task 2 (P=0.0002).

For Task 1, Group is not statistically significant ($F_{1, 1904}$=1.55, P=0.254). For Task 2, Group is not statistically significant ($F_{1, 1904}$=0.42, P=0.536). Within each Task, there is no significant difference between Groups. Figure 4.2.17 depicts the average Scan Time for each Task by Group.

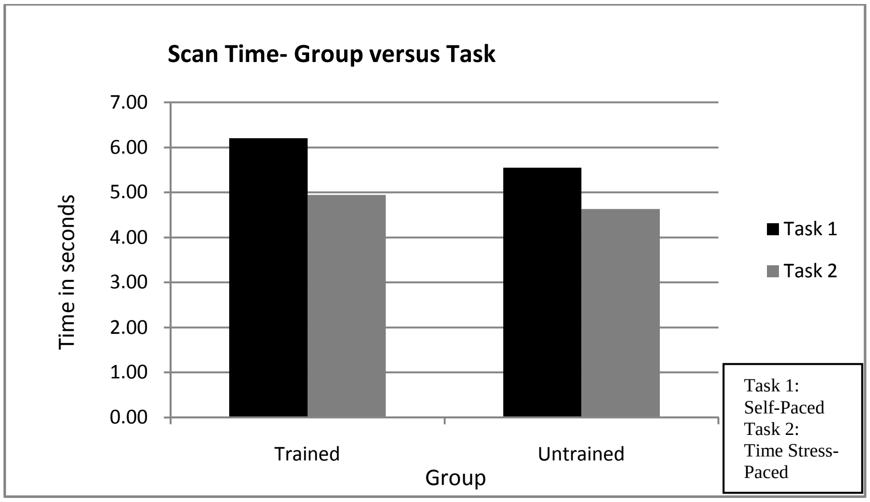


Figure 4.2.17: Scan Time: Task Main Effect by Group

4.2.3 Group Main Effect

The Group Main Effect was also analyzed for the comparison of the Self-Paced Task to the Time-Stress-Paced Task due to the complex interpretation of the results and the important concept of training in this study. Again, only the independent variables Group, Subject(Group), and Aim Pattern were included in this model with the addition of the independent variable Task as well, for all original dependent variables for ergonomics and efficiency. Day and Target Type were removed from the model to get a better idea of the effect of training. Day was chosen for removal based on previous results lacking any trends. Target Type was removed since it is an environmental factor that cannot be altered by scanner product design. A summary of this ANOVA analysis is depicted in Table 4.2.3.

	Group	Subject (Group)	Task	Aim Pattern	Group*Aim Pattern	Task*Group	Task*Aim Pattern	Task*Group*Aim Pattern
Supination	0.241	0.000*	0.001*	0.000*	0.691	0.047*	0.452	0.765
Pronation	0.085	0.000*	0.000*	0.441	0.025*	0.002*	0.882	0.954
Flexion	0.517	0.000*	0.971	0.000*	0.000*	0.065	0.346	0.272
Extension	0.645	0.000*	0.000*	0.023*	0.197	0.205	0.488	0.883
Ulnar	0.257	0.000*	0.000*	0.398	0.959	0.839	0.880	0.977
Time	0.238	0.000*	0.000*	0.000*	0.115	0.469	0.988	0.965

*Significant at .05 alpha level Fully Analyzed

Table 4.2.3: Time-Stress-Paced Task Ergonomics and Efficiency ANOVA Results – Group Main Effect

What is meant by Group Main Effect for this model is any interaction containing Group, as well as Task since the Time Stress comparison is the original purpose for this analysis. As a result, Pronation and Supination in the Task*Group interaction are statistically significant at a .05 level. The interaction for Supination has previously been analyzed in Section 4.2.1.1.2. In the Task*Group interaction, Task is statistically significant in both Groups (Trained: $F_{1, 1911}$=119.40, P=0.000; Untrained: $F_{1, 1911}$=23.91, P=0.000), but has much greater significant in the Trained Group. The Trained Group has an average 1.95 degrees less Pronation during the Self-Paced Task when compared to the Time Stress-Paced Task. The Untrained Group has an average 1.07 degrees less Pronation during the Self-Paced Task when compared to the Time Stress-Paced Task. Group is statistically significant in the Self-Paced Task, but not in the Time Stress-Paced Task (Self-Paced: $F_{1, 1904}$=4.85, P=0.045; Time Stress-Paced: $F_{1, 1904}$=1.83, P=0.198). In the Self-Paced Task, the Trained Group has an average 2.71 degrees less Pronation than the Untrained Group. In the Time Stress-Paced Task, the Trained Group has an average 1.83 degrees less Pronation than the Untrained Group, but this is not a significant difference. Figure 4.2.18 depicts the average Pronation for each Task by Group.

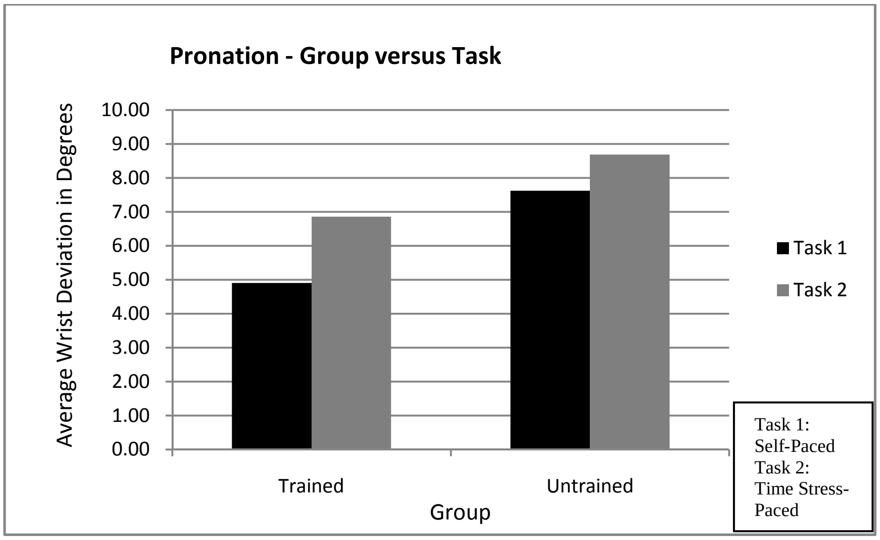


Figure 4.2.18: Pronation: Group versus Task

4.2.4 Subjective Ratings and Rank

An ANOVA for repeated measures was completed on the Subjective Ratings assessing Perceived Comfort and Usability for the Time Stress-Paced Task. Below in Table 4.2.4 is a summary of the ANOVA results. To assess Subjective Rank, Frequency of Rank was used. Table 4.2.5 depicts a summary of Rank for each Aim Pattern by Group.

	Subject (Group)	Task	Group	Day	Aim Pattern	Task* Group	Task* Day	Task* Aim Pattern	Group* Day	Group* Aim Pattern	Day* Aim Pattern	Task* Group* Day	Task* Group* Aim Pattern	Task* Day* Aim Pattern
Comfort	0.000*	0.704	0.107	0.072	0.000*	0.091	0.561	0.990	0.661	0.129	0.519	0.448	0.875	0.817
Usability	0.000*	0.143	0.206	0.000*	0.000*	0.149	0.852	0.406	0.727	0.669	0.310	0.217	0.532	0.515

*Significant at .05 alpha level   Fully Analyzed

Table 4.2.4: Time Stress-Paced Task Subjective Ratings ANOVA Results

Rank (1=best)	Trained Group					Untrained Group				
	LED	Bracket	Grid	Crosshair	Bulls-eye	LED	Bracket	Grid	Crosshair	Bulls-eye
1	0	4	6	4	2	0	8	2	4	2
2	0	5	4	4	2	1	4	4	4	3
3	0	5	4	3	4	0	2	5	2	7
4	0	2	2	5	7	1	2	5	6	2
5	16	0	0	0	0	14	0	0	0	2

Table 4.2.5: Time Stress-Paced Task Aim Pattern Frequency of Rank Summary

4.2.4.1 Subjective Aim Pattern Rating for Perceived Comfort

All Minitab results for Comfort in the Time Stress-Paced Task can be found in Appendix R. Neither the Task Main Effect nor any Task interactions are statistically significant. There was no difference in Comfort (at a .05 or .10 level) between Task 1 and Task 2. Figure 4.2.19 depicts the average Comfort for Task 2 by Aim Pattern.

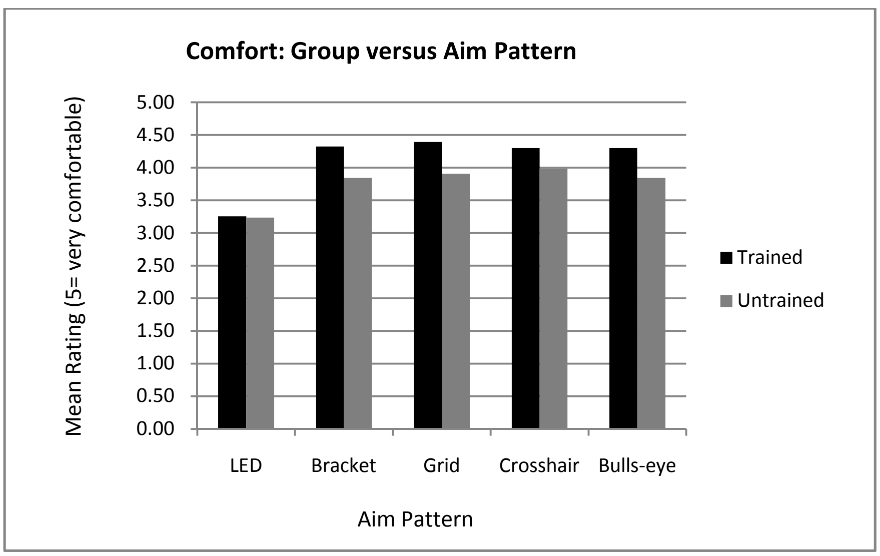


Figure 4.2.19: Comfort: Aim Pattern Main Effect by Group

4.2.4.2 Subjective Aim Pattern Rating for Perceived Usability

All Minitab results for Usability in the Time Stress-Paced Task can be found in Appendix S. Neither the Task Main Effect nor any Task interactions are statistically significant. There was no

significant difference in Usability (at a .05 or .10 level) between Task 1 and Task 2. Figure 4.2.20 depicts the average Usability for Task 2 by Aim Pattern.

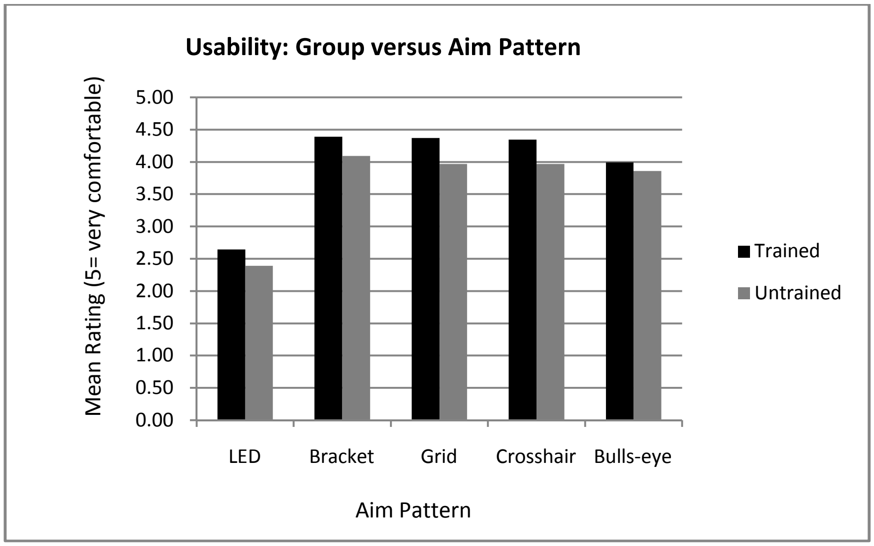


Figure 4.2.20: Usability: Aim Pattern Main Effect by Group

4.2.4.3 Subjective Aim Pattern Rank

Subjects were asked to Rank the Aim Patterns in order from best to worst at the end of each Time-Stress Paced Task. A summary for each Aim Pattern was compiled based on median of Rank. Figure 4.2.21 depicts the median of Rank for each Aim Pattern by Group.

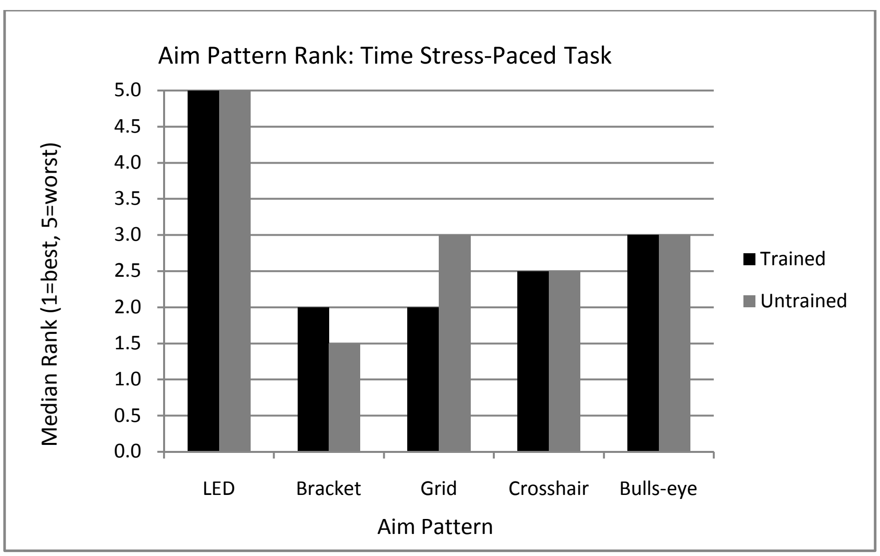


Figure 4.2.21: Aim Pattern Rank: Time Stress-Paced Task

Just as the LED Aim Pattern was ranked worst in Task 1 by both Groups, it was also ranked worst in Task 2 by both Groups, with a median rank of 5. For the Untrained Group, the Bracket Aim Pattern remained the second best Aim Pattern, but received a median rank of 1.5 instead of 1.0. The Untrained Group again ranked the Crosshair as the next best Aim Pattern, but gave it a median rank of 2.5 instead of 2.0. For the Untrained Group, the Grid and Bulls-eye Aim Patterns were again the least favorite besides the LED Aim Pattern, receiving the same median rank of 3. For the Trained Group, the Bracket and Grid Aim Patterns were again ranked as the best, with the same median rank of 2.0. The Crosshair Aim Pattern moved up in preference for the Trained Group, receiving a median rank of 2.5 instead of 3.0. For the Trained Group, the Bulls-eye Aim Pattern was again ranked as the least favorite besides the LED Aim Pattern, receiving the same median rank of 3.0.

Section 5

Discussion

The hypotheses developed for the purpose of this thesis related to the effect of training, aim pattern and target type on ergonomics and efficiency. Wrist and forearm deviations were used for the ergonomic measure, and scan time was used for the efficiency measure. It was hypothesized that training would result in increased use of the omni-directional functionality, thereby reducing wrist and forearm deviation and improving ergonomics, while also improving efficiency during scanning tasks. Additionally, it was hypothesized that over time, the performance of untrained subjects would approach that of trained subjects in terms of ergonomics and efficiency. A third hypothesis was that Aim Pattern preference would be a function of Training level. Finally, it was proposed that regardless of Training level, time pressure would cause subjects to abandon the use of omni-directionality, resulting in a negative effect on ergonomics.

5.1 Training Effect on Ergonomics

In general, the results support that trained subjects made better use of omni-directionality than untrained subjects, resulting in reduced wrist and forearm posture for trained subjects. As a result of Training, ergonomics did improve. This improvement in ergonomics due to use of a design feature coincides with the study conducted by Lehman and Marras (1994) where a bi-optic design feature on a scanner was not utilized by almost half of participants resulting in poorer ergonomics and efficiency, solidifying that use of the bi-optic scanner improved efficiency and ergonomics.

Increased use of the omni-directional functionality of the scanner for trained subjects is most prominently shown by reduced Pronation and Supination. A possible reason Pronation and Supination are the most affected by Training level is that the twisting motion required to align the Aim Pattern with the Target if not using the omni-directional functionality could translate into these increased forearm motions observed in the Untrained Group.

The Trained Group had less postural deviation overall, however the difference was only statistically significant at a .05 level for Pronation. Training resulted in a 31% reduction in Pronation (Figure 4.1.85).

In terms of Pronation and Supination, differences between Target Types were significant for some comparisons but not others within each Group. In general, the Trained Group had less Supination and Pronation for all Target Types compared to the Untrained Group (Figures 4.1.12 and 4.1.36, respectively).

The Trained Group had greater Supination for the Linear Target Type than for the other two Target Types. The Untrained Group had greater Supination for the Linear Target Type than for the Data Matrix Target Type only. This could imply that the Linear and PDF Target Types could have been treated similarly for the Untrained Group, possibly due to their similar rectangular shape that could provoke more twisting of the forearm for alignment.

Although no statistically significant differences are present at a .05 or .10 level for Flexion and Extension, results do support that trained subjects made better use of omni-directionality. In general, the Trained Group had less Flexion and Extension when scanning any Target Type with any Aim Pattern (Figures 4.1.47, 4.1.49, 4.1.62 and 4.1.64). In general, Extension remained static or level over time (Figures 4.1.54, 4.1.55 and 4.1.62). The natural posture the wrist takes when scanning results in the wrist remaining in slight extension throughout the scanning process.

Unlike the other postural measures, Training resulted in 5.0%, 7.8% and 11.9% increases in Ulnar Deviation for the Linear, Data Matrix and PDF Target Types (Figure 4.1.67). To make fine-tuned adjustments to the placement of the Aim Pattern over the target, vertical movement is needed. This vertical movement translates into Ulnar Deviation. Since the Trained Group was not concerned with orientation of the Aim Pattern, it is possible that there was heightened concern for these vertical adjustments. Greater Ulnar Deviation in the Trained Group could be the result of the trained subject's concern with accurately aiming the scanner to be on the target.

Despite differences in postural deviation between Groups, no differences were greater than five degrees, even for statistically significant differences. Relative to the range of motion

of the forearm and wrist, this is only about 3% of each plane's range of motion. Since there are no established thresholds for what is deemed a practically significant difference in range of motion, there is a judgment call that needs to be made as to whether this information is beneficial. The Untrained Group did have greater average wrist deviation, often in multiple planes of motion at once. According to Bernard (1997) this type of extreme and complex wrist deviation puts the Untrained Group at higher risk for CTDs than the Trained Group.

5.2 Training Effect on Efficiency

It was hypothesized that training would improve efficiency overall; however training had an effect on efficiency depending on the Target Type scanned. When scanning the Linear Target Type, the Untrained Group had faster Scan Times using every Aim Pattern (Figure 4.1.73); however the differences were not statistically significant. The Trained Group was faster than the Untrained Group when scanning the Data Matrix and PDF Target Types (Figures 4.1.74 and 4.1.75, respectively); however this difference was not significant for any Aim Pattern with all differences less than 0.5 seconds.

Surprisingly, Training did not always improve efficiency and when it did, it was not a statistically significant improvement. In the case of the Linear Target Type, the difference in Scan Times between Groups could have practical significance. When faced with a poor quality Target, it is possible that the Trained Group kept their wrists neutral as they were trained to do, to the detriment of efficiency. In the Untrained Group, even if subjects did use the omni-directional functionality, eventually they could have lost patience and aligned the Aim Pattern and Target Type by moving their wrist and forearm out of neutral postures. As a result, the Untrained Group was more efficient when scanning the Linear Target Type, but there was a trade-off between ergonomics and efficiency in the Untrained Group.

In the case of the Data Matrix and PDF Target Types, Training did improve efficiency, just not to a statistically significant level. A possible reason the Trained Group did not gain any significant efficiency benefits is that the difference between Groups was in the wrist and forearm movement of scanning, but not in the actual movement from target to target. The

Untrained Group could have positioned their wrist and forearm while in motion to the next target thereby losing no time.

Scan Time is the time to scan five targets. Realistically, a much larger number of targets would be scanned in a given work-day, resulting in a greater difference in scan times between Groups that may have more practical significance. An example of this point is that for the Linear Target Type, the Untrained Group scanned an average 1.3 seconds faster than the Trained Group. If 5 targets take an average 9.3 seconds to scan (average for Linear Target Type-both Groups), this is the equivalent of an 8.4 minute difference between Groups for an hour of dedicated scanning.

5.3 Learning Effect on Ergonomics and Efficiency

It was hypothesized that over time, the performance of untrained subjects would approach that of trained subjects in terms of ergonomics and efficiency. There were no trends found for wrist ergonomics. Generally, the Untrained Group had poorer ergonomics across all ten Days. For Supination, Pronation, Flexion, Extension and Ulnar Deviation, Day is statistically significant in at least one interaction effect due to statistically significant pair-wise differences between Days. In all cases, these Day to Day differences had no assignable cause and no trends emerged. Overall, there was no practical significance to the statistically significant differences between Days in terms of ergonomics.

For efficiency, there was a trend found with the Untrained Group. Scan Time was significantly greater on Day 1 than on any other Day (Figure 4.1.84). For the Untrained Group, after Day 1 there was an overall 28% reduction in Scan Time. This trend was not present for the Trained Group (Figure 4.1.83). For the Trained Group, Day 1 was significantly different from Day 9 only, which has no practical significance. This trend implies that the Untrained Group could have experienced a quick learning curve of one day.

5.4 Training Effect on Aim Pattern Preference

It was hypothesized that Aim Pattern preference would be a function of training. Subjective results for Aim Pattern Rank show that there is some variation in preference depending on training (Figure 4.1.94). Both the Trained and Untrained Group ranked the LED Aim Pattern the worst Aim Pattern, giving it a median rank of 5. The Untrained Group ranked the Bracket Aim Pattern as the best Aim Pattern, giving it a median rank of 1. The Untrained Group ranked the Crosshair Aim Pattern as second best, giving it a median rank of 2 and the Grid and Bulls-eye were both ranked 3. The Trained Group ranked both the Bracket and the Grid Aim Patterns as the best, giving them both a median rank of 2. The Trained Group ranked the Crosshair and Bulls-eye Aim Patterns both 3. In general, the LED was the least favorite Aim Pattern and the Bracket was the most favorite Aim Pattern across Groups. A noticeable difference between Group preferences is that the Trained Group preferred the Grid Aim Pattern as much as the Bracket Aim Pattern, whereas the Untrained Group tended to rank it much lower.

There was no difference between Groups for Subjective Ratings of Comfort or Subjective Ratings of Usability. Both the Trained and Untrained Groups considered the LED Aim Pattern to result in the least comfort with an average Comfort Rating of 3.33. Both Groups considered there to be no difference between the other Aim Patterns regarding Comfort and they received an average Comfort Rating of 4.12 (Figure 4.1.87). Both the Trained and Untrained Groups considered the LED Aim Pattern to be the least easy to use giving it an average Usability Rating of 2.69 whereas they considered there to be no difference in Usability for any of the other Aim Patterns, giving them an average Usability rating of 4.14 (Figure 4.1.91).

Although reduced wrist posture and scan time do not indicate an actual Aim Pattern preference, they can demonstrate those Aim Patterns that improve ergonomics and efficiency, when compared to other Aim Patterns.

There was obvious difficulty when scanning the Linear Target Type across all subjects. This difficulty was most prominent when using the LED Aim Pattern. The Subjective Rank for Aim Pattern Preference reflects this difficulty, since both Groups ranked the LED the worst. For both Groups, the Linear Target Type and LED Aim Pattern combination resulted in significantly

greater Supination and Flexion (Figures 4.1.15 and 4.1.40, respectively) and a significantly slower Scan Time (Figure 4.1.73) than the other Aim Patterns with the Linear Target Type. Ergonomically, the Trained Group dealt better with the problematic Linear Target Type and LED Aim Pattern combination shown by the significant 48% reduction in Supination compared to the Untrained Group. Reasons for this obvious difficulty are unknown, but it is possible that the Linear Target Type used was of poor quality and the scanner had greater difficulty reading it. It is curious that the LED Aim Pattern, the newer technology aim pattern compared to the other laser Aim Patterns used, had the greatest difficulty of all Aim Patterns with the Linear Target Type. The reason for its readability problem is unknown. Although problematic, results regarding the Linear Target Type were still beneficial to this thesis since they can give insight into the best approach to scanning degraded targets.

For Pronation, using the LED or Grid Aim Pattern resulted in significantly less deviation for the Trained Group compared to the Untrained Group. The Grid Aim Pattern was also ranked very high by the Trained Group, compared to the Untrained Group.

For the Trained Group, there was no significant difference in Flexion between Aim Patterns for the Data Matrix Target Type. For the Trained Group and PDF Target Type, the Bracket Aim Pattern resulted in greater Flexion than the Grid and Crosshair Aim Patterns. Overall, Flexion for the Trained Group was greatest with the LED and Bracket Aim Patterns (Figure 4.1.42). Although the Trained Group ranked the Bracket Aim Pattern high, it tended to result in greater Flexion than the other Aim Patterns (except LED). For the Untrained Group and PDF Target Type, the LED Aim Pattern resulted in greater Flexion than the Bulls-eye Aim Pattern. Overall, Flexion for the Untrained Group was greatest with the LED Aim Pattern (Figure 4.1.42), consistent with the Untrained Group's ranking.

In Extension for the Trained Group, the LED Aim Pattern resulted in a significant deviation decrease compared to the Bulls-eye Aim Pattern only, but close to a significant decrease compared to the other Aim Patterns, which is not consistent with the Trained Group's ranking for the LED Aim Pattern. As previously mentioned, the Extension position was the default position, so a decrease in Extension for the LED Aim Pattern could actually imply greater motion in general, and thus poorer ergonomics, which is consistent with the ranking. Extension

in the Untrained Group was unchanged based on the Aim Pattern used and Ulnar Deviation was unchanged by the Aim Pattern used for both Groups.

For the Trained Group, there was no difference in efficiency based on Aim Pattern for the Data Matrix and PDF Target Types. For the Untrained Group, there was no difference between Aim Patterns for the Data Matrix Target Type, but for the PDF Target Type, the LED Aim Pattern was significantly slower than the Crosshair Aim Pattern, implying the Crosshair Aim Pattern was significantly faster. These least and most efficient Aim Patterns are consistent with the Untrained Group's ranking of worst and best Aim Patterns.

5.5 Time Stress Effect on Ergonomics and Efficiency

It was hypothesized that regardless of training level, time pressure would cause subjects to abandon the use of omni-directionality, resulting in negative effects on ergonomics. The reasoning behind this hypothesis was based on the observation, in a previous RIT scanner study, that when the scanner had difficulty reading a target, the subject would become frustrated and increase wrist movements despite knowledge of omni-directionality.

It was predicted that regardless of Training, Time Stress would result in abandonment of the use of omni-directional functionality, resulting in poorer ergonomics. For Supination, the opposite occurred since the Time Stress-Paced Task resulted in reduced Supination. This reduction was not statistically significant, but it was closer to significant for the Untrained Group. A possible reason for a reduction in forearm Supination could be that subjects tried to save time by depressing the trigger early in preparation for scanning each target. Due to omni-directionality, the result would be that the scanner would read the target before subjects twisted their forearm to align the Aim Pattern.

For Pronation, as predicted, there was greater forearm deviation for the Time Stress-Paced Task than for the Self-Paced Task, but it was only significant for the Trained Group. The Untrained Group Pronation was not significantly changed by Task. For Ulnar Deviation, the Time Stress-Paced Task resulted in greater deviation in both Groups, although it was more significant for the Trained Group. For Extension, there was no significant difference between Tasks for

either Group, although the Untrained Group was closer to being significance. There was no statistically significant change in Flexion when comparing the two Tasks.

For two of the three postures that were affected, as predicted, time stress had a detrimental effect on ergonomics. This effect was most significant for the Trained Group. This was expected, since the nature of the hypothesis was abandonment of omni-directionality, which was typically only used by the Trained Group. Overall, Trained Group ergonomics were negatively affected by time stress, possibly portraying that the Trained Group abandoned their training, at least to some degree, during the Time Stress-Paced Task.

As expected, Scan Time for the Time Stress-Paced Task was significantly less than Scan Time for the Self-Paced Task, with the significance for the Untrained Group much greater than the significance for the Trained Group. For Comfort and Usability, there was no difference between the Self-Paced and Time Stress-Paced Tasks. For Aim Pattern Rank, although there were subtle changes in median rank for some Aim Patterns in the Time Stress-Paced Task, the overall order of rank for each Group remained unchanged between Tasks.

5.6 Limitations

Certain aspects of the study could have affected the results of this thesis. Below is a list of the most relevant limitations.

- All participants were engineering college students resulting in a sample drawn from a narrow population of most likely very technically savvy people. The sample was only a partial representation of those who would use hand held scanners. Increasing the subject diversity to include a larger span of potential hand held scanner users, such as using retail or manufacturing workers, could help to establish more applicable results.

- The sample size was small with only 8 subjects in each Group. Results were not always statistically significant and were often difficult to interpret, but increasing the sample size could reduce variability and reveal a clearer picture in future results.

- The time span in which this study took place was only ten days. Since no practical trends emerged for ergonomics, the untrained user may take more time to reach the same performance level as a trained user. If the study is conducted over a longer period of time, perhaps beneficial trends could emerge.

- There were evident issues with the Linear Target Type, possibly due to poor quality although no assignable cause is present. In future assessments of the effect of Target Type, multiple different targets of each type should be used instead of only one to avoid situations where a scanner has difficulty reading a target for unknown reasons. This approach could also be used to assess the effects of poor quality barcodes on ergonomics and efficiency.

5.7 Future Work

Based on this thesis, there are several suggestions for future work on hand held scanning.

- Trained and Untrained users are narrowly defined. Training was defined as having received information about the omni-directional functionality, getting a demonstration of proper hand held scanner use and having the opportunity to practice. Untrained was defined as receiving no knowledge or practice regarding hand held scanner use and omni-directionality except for basic functionality of the scanner. Increased and more distinct levels of training as well as exploration into other training methods could provide more meaningful results about training in hand held scanner use.

- Time Stress was narrowly defined. Time Stress was defined purely based on the instruction given to participants at the beginning of the scanning task. There are many other factors that can induce stress that were not addressed in this study. Using other methods of stress instead of simply telling the subject to complete the task as fast as possible could be more practically useful. If the study took place in an actual work environment or if an auditory stress was used instead, the results of stress on ergonomics and efficiency could be very different and possibly more applicable.

Section 6

Conclusion

This thesis investigated the effect of Training, Aim Pattern and Target Type on ergonomics and efficiency in hand held barcode scanner use. A total of 8 subjects performed scanning tasks for each of two Training level Groups. Wrist ergonomics and task completion time were measured in order to assess ergonomics and efficiency. Additionally, subjective ratings of Comfort and Usability and Aim Pattern Rank were recorded to assess Aim Pattern preference.

The main discovery of this study is that Training has an effect on ergonomics. In general, trained subjects made better use of omni-directionality than untrained subjects, resulting in reduced wrist and forearm posture for trained subjects. As a result of Training, ergonomics did improve. Increased use of the omni-directional functionality of the scanner for trained subjects is most prominently shown by reduced Pronation and Supination.

Training had an effect on efficiency depending on the Target Type scanned. When scanning the Linear Target Type, the Untrained Group had faster Scan Times using every Aim Pattern; however it was not statistically significant. The Trained Group was faster than the Untrained Group when scanning the Data Matrix and PDF Target Types; however this difference was not significant for any Aim Pattern with all differences less than 0.5 seconds. Surprisingly, Training did not always improve efficiency and when it did, it was not a statistically significant improvement. In the case of the Linear Target Type, the difference in Scan Times between Groups could have practical significance. When faced with a poor quality Target, it is possible that the Trained Group kept their wrists neutral as they were trained to do, to the detriment of efficiency. No trends were apparent across Days in either Group for wrist ergonomics, however in terms of efficiency, the Untrained Group had a quick learning curving that ended after Day 1.

There was no difference between Groups in terms of Comfort and Usability. Both Groups rated the LED Aim Pattern as the worst, and rated the other Aim Patterns as no different from each other. In ranking the Aim Patterns, again the LED Aim Pattern was considered the worst, and both Groups also considered the Bracket Aim Pattern to be the best.

Pronation, Supination and Ulnar Deviation were affected by Time Stress. For Pronation and Ulnar Deviation, as predicted, time stress had a detrimental effect on ergonomics. This effect was most significant for the Trained Group, possibly portraying that the Trained Group abandoned their training, at least to some degree, during the Time Stress-Paced Task.

This thesis provides useful information regarding hand held scanner use. Little research has been completed on this hand held device and this thesis begins to assess the design and functionality of the hand held scanner. Hand held scanner designers can derive useful information about the design and functionality of the scanner and can not only consider the information in future designs, but can also pass on information learned to the customer. Any industry where these types of hand held scanners are used can derive useful information from this study on the benefits of training workers in the use of the omni-directional functionality and on which Aim Pattern to choose depending on the Target Type and Training level.

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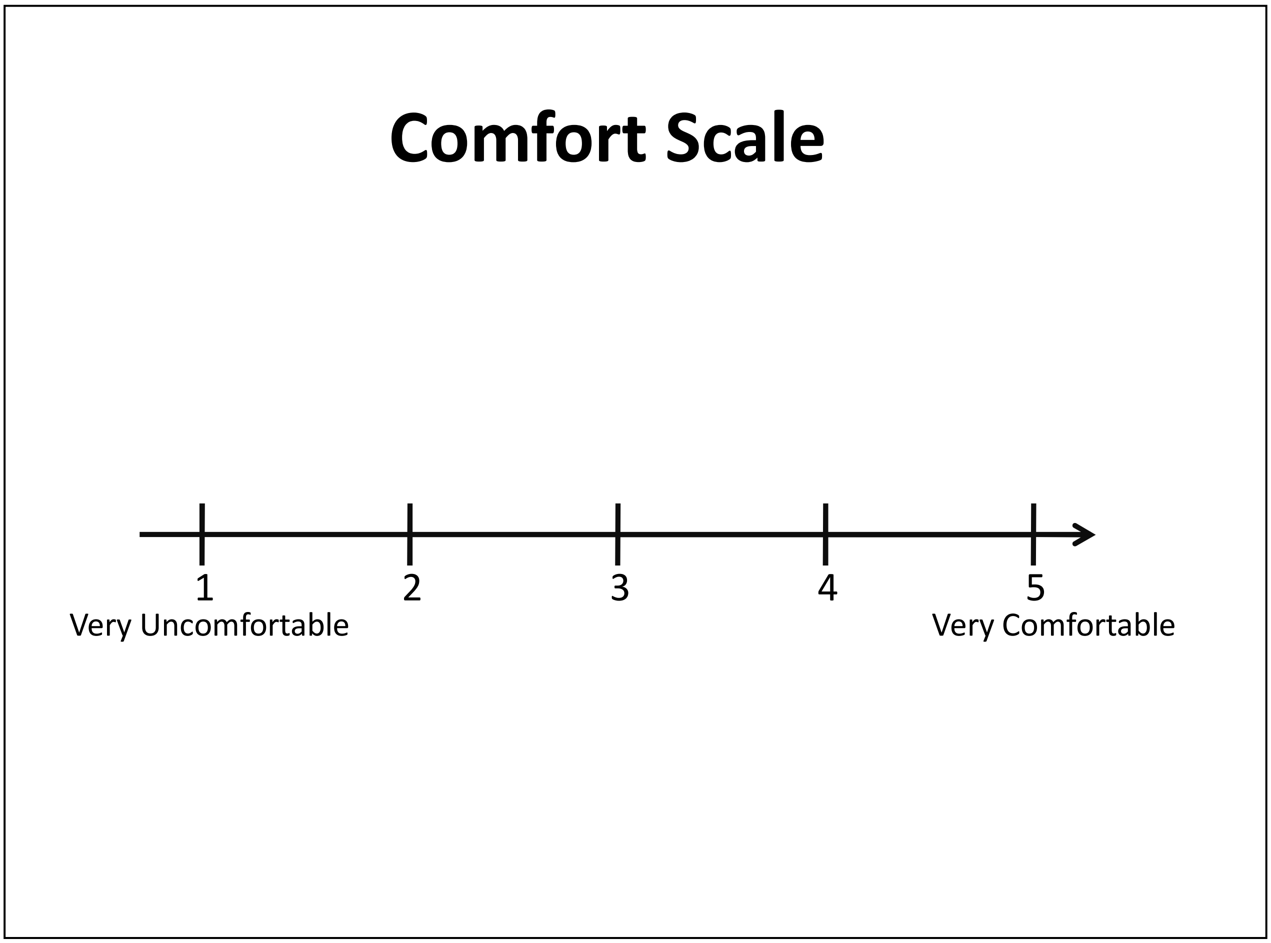
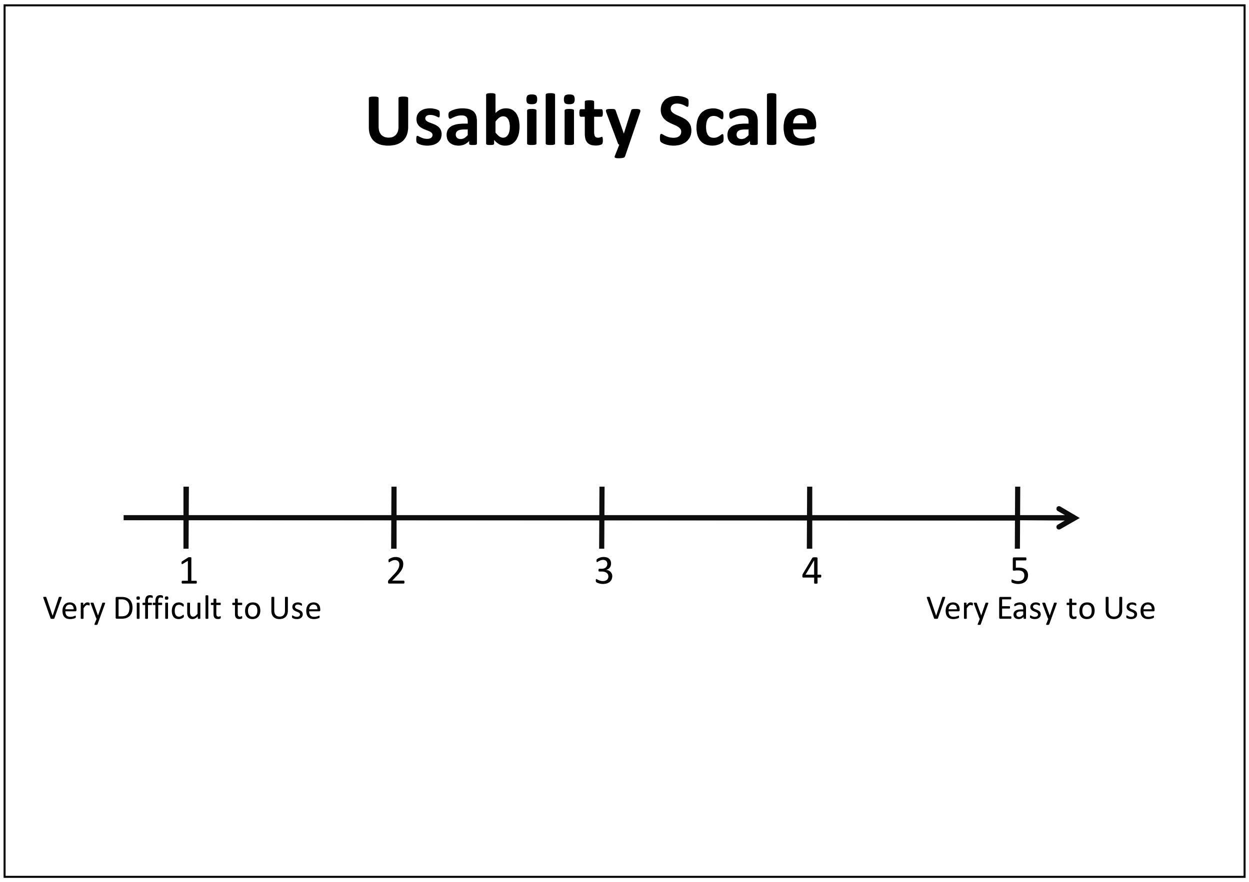
Appendix A



Appendix B


Usability Scale
1
2
3
4
5
Very Difficult to Use
Very Easy to Use

Appendix C

CONSENT FORM

Evaluation of Scanners

Investigator: Matthew M. Marshall, Ph.D
Rochester Institute of Technology; Phone: 585-475-7260

I understand that I am being asked to voluntarily participate in a research study conducted by Rochester Institute of Technology, in conjunction with Hand Held Products, which involves evaluating the wrist deviation associated with using handheld scanners. The purpose of this study is to evaluate how the type of scanner affects the wrist angle of the user and to assess whether this effect changes when performed over repeated daily trials. The results will be used to help Hand Held Products identify how the design of their scanners minimizes wrist deviation so that the ergonomics of the products may be improved. This may lead to a reduction in wrist pain and discomfort associated with using these products.

This study involves having electrogoniometers placed over the wrist of my dominant hand. These instruments will be connected by a cable to a computer for data collection. The investigator will demonstrate and describe the instruments prior to placing them on my arms. The sensors are intended for human use and should not create any discomfort. Once the sensors are attached, I will perform a simple scanning task for approximately 30 minutes, during which time the instrumentation will remain on my arms. The scanning task will involve scanning targets (UPC codes) on a series of scan boards**.** The entire experiment (set-up and data collection) will take approximately thirty minutes each day, but the experiment will be repeated over ten days.

The risks of the study are minimal. The cables extending from the instrumentation to the portable computer might interfere with the simulated work activity, although every attempt will be made to minimize this potential problem. I understand that my participation in this study is voluntary and I may stop at any time, without penalty. I am under no pressure to participate, but payment will only be received upon completion of the full experiment. The data collected during this experiment will remain anonymous and confidential. The data collected will be saved under the anonymous labeling of "subject 1," "subject 2," etc., so that I am not identified by my name.

I will receive $60.00 for my participation in this study. I realize that I am voluntarily participating in this project and can withdraw from participation at any time. I have read (or had explained) the information given above. I understand the meaning of this information. Project personnel have offered to answer any questions I may have concerning the study and have provided complete answers to all my questions. I hereby consent to participate in the study. One copy of this document will be kept together with our research records on this study at RIT. As a participant I will receive a copy to keep if I request it.

Name____ Date___________

Witness____ Date____________

Appendix D

Supination

Self-Paced Task ANOVA

Factor	Type	Levels	Values
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Supination, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Group	1	25939.5	25939.5	25939.5	2.40	0.143
Subject(Group)	14	151057.7	151057.7	10789.8	668.91	0.000
Day	9	4061.4	4061.4	451.3	27.98	0.000
Aim Pattern	4	1498.7	1498.7	374.7	23.23	0.000
Target Type	2	5725.9	5725.9	2863.0	177.49	0.000
Group*Day	9	2325.9	2325.9	258.4	16.02	0.000
Group*Aim Pattern	4	65.6	65.6	16.4	1.02	0.397
Group*Target Type	2	1882.3	1882.3	941.1	58.35	0.000
Day*Aim Pattern	36	724.0	724.0	20.1	1.25	0.148
Day*Target Type	18	1319.3	1319.3	73.3	4.54	0.000
Aim Pattern*Target Type	8	1626.7	1626.7	203.3	12.61	0.000
Group*Day*Aim Pattern	36	507.2	507.2	14.1	0.87	0.685
Group*Day*Target Type	18	854.7	854.7	47.5	2.94	0.000
Group*Aim Pattern*Target Type	8	45.9	45.9	5.7	0.36	0.944
Day*Aim Pattern*Target Type	72	674.2	674.2	9.4	0.58	0.998
Error	9358	150948.2	150948.2	16.1		
Total	9599	349257.2				

S = 4.01627   R-Sq = 56.78%   R-Sq(adj) = 55.67%

Supination

Time Stress-Paced Task ANOVA

Factor	Type	Levels	Values
Task	fixed	2	1, 2
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	2	5, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Supination, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Task	1	203.32	203.32	203.32	13.30	0.000
Group	1	4016.90	4016.90	4016.90	1.50	0.241
Subject(Group)	14	37589.32	37589.32	2684.95	175.64	0.000
Day	1	925.81	925.81	925.81	60.56	0.000
Aim Pattern	4	1148.21	1148.21	287.05	18.78	0.000
Target Type	2	3776.98	3776.98	1888.49	123.54	0.000
Task*Group	1	67.46	67.46	67.46	4.41	0.036
Task*Day	1	32.21	32.21	32.21	2.11	0.147
Task*Aim Pattern	4	62.82	62.82	15.71	1.03	0.392
Task*Target Type	2	33.23	33.23	16.62	1.09	0.337
Group*Day	1	553.98	553.98	553.98	36.24	0.000
Group*Aim Pattern	4	38.36	38.36	9.59	0.63	0.643
Day*Aim Pattern	4	100.02	100.02	25.01	1.64	0.162
Group*Target Type	2	653.97	653.97	326.98	21.39	0.000
Day*Target Type	2	124.45	124.45	62.23	4.07	0.017
Aim Pattern*Target Type	8	1084.96	1084.96	135.62	8.87	0.000
Task*Group*Day	1	22.68	22.68	22.68	1.48	0.223
Task*Group*Aim Pattern	4	31.46	31.46	7.87	0.51	0.725
Task*Day*Aim Pattern	4	146.52	146.52	36.63	2.40	0.048
Task*Group*Target Type	2	5.77	5.77	2.89	0.19	0.828
Task*Day*Target Type	2	65.69	65.69	32.84	2.15	0.117
Task*Aim Pattern*Target Type	8	25.07	25.07	3.13	0.21	0.990
Error	3766	57569.18	57569.18	15.29		
Total	3839	108278.38				

S = 3.90980   R-Sq = 46.83%   R-Sq(adj) = 45.80%

Appendix E

Pronation

Self-Paced Task ANOVA

Factor	Type	Levels	Values
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Pronation, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F
Group	1	13935.19	13935.19	13935.19	4.61
Subject(Group)	14	42344.05	42344.05	3024.58	158.79
Day	9	8240.79	8240.79	915.64	48.07
Aim Pattern	4	82.40	82.40	20.60	1.08
Target Type	2	337.88	337.88	168.94	8.87
Group*Day	9	1849.39	1849.39	205.49	10.79
Group*Aim Pattern	4	187.13	187.13	46.78	2.46
Group*Target Type	2	167.48	167.48	83.74	4.40
Day*Aim Pattern	36	1007.89	1007.89	28.00	1.47
Day*Target Type	18	867.81	867.81	48.21	2.53
Aim Pattern*Target Type	8	55.92	55.92	6.99	0.37
Group*Day*Aim Pattern	36	1195.05	1195.05	33.20	1.74
Group*Day*Target Type	18	534.98	534.98	29.72	1.56
Group*Aim Pattern*Target Type	8	43.00	43.00	5.38	0.28
Day*Aim Pattern*Target Type	72	755.00	755.00	10.49	0.55
Error	9358	178252.12	178252.12	19.05	
Total	9599	249856.08			

Source	P
Group	0.050
Subject(Group)	0.000
Day	0.000
Aim Pattern	0.364
Target Type	0.000
Group*Day	0.000
Group*Aim Pattern	0.044
Group*Target Type	0.012
Day*Aim Pattern	0.035
Day*Target Type	0.000
Aim Pattern*Target Type	0.938
Group*Day*Aim Pattern	0.004
Group*Day*Target Type	0.061
Group*Aim Pattern*Target Type	0.972
Day*Aim Pattern*Target Type	0.999
Error	
Total	

S = 4.36441   R-Sq = 28.66%   R-Sq(adj) = 26.82%

Pronation

Time Stress-Paced Task ANOVA

Factor	Type	Levels	Values
Task	fixed	2	1, 2
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	2	5, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Pronation, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Task	1	2184.84	2184.84	2184.84	130.08	0.000
Group	1	4958.95	4958.95	4958.95	3.43	0.085
Subject(Group)	14	20242.97	20242.97	1445.93	86.09	0.000
Day	1	8379.01	8379.01	8379.01	498.88	0.000
Aim Pattern	4	71.65	71.65	17.91	1.07	0.371
Target Type	2	12.78	12.78	6.39	0.38	0.684
Task*Group	1	184.45	184.45	184.45	10.98	0.001
Task*Day	1	3.10	3.10	3.10	0.18	0.668
Task*Aim Pattern	4	22.53	22.53	5.63	0.34	0.854
Task*Target Type	2	16.52	16.52	8.26	0.49	0.612
Group*Day	1	196.23	196.23	196.23	11.68	0.001
Group*Aim Pattern	4	212.48	212.48	53.12	3.16	0.013
Day*Aim Pattern	4	17.62	17.62	4.41	0.26	0.902
Group*Target Type	2	298.30	298.30	149.15	8.88	0.000
Day*Target Type	2	142.94	142.94	71.47	4.26	0.014
Aim Pattern*Target Type	8	74.86	74.86	9.36	0.56	0.814
Task*Group*Day	1	74.48	74.48	74.48	4.43	0.035
Task*Group*Aim Pattern	4	12.89	12.89	3.22	0.19	0.943
Task*Day*Aim Pattern	4	138.30	138.30	34.57	2.06	0.084
Task*Group*Target Type	2	71.69	71.69	35.85	2.13	0.118
Task*Day*Target Type	2	9.15	9.15	4.58	0.27	0.762
Task*Aim Pattern*Target Type	8	61.40	61.40	7.67	0.46	0.887
Error	3766	63252.64	63252.64	16.80		
Total	3839	100639.78				

S = 4.09826   R-Sq = 37.15%   R-Sq(adj) = 35.93%

Appendix F

Flexion

Self-Paced Task ANOVA

Factor	Type	Levels	Values
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Flexion, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F
Group	1	1071.59	1071.59	1071.59	0.34
Subject(Group)	14	43984.93	43984.93	3141.78	180.62
Day	9	3011.34	3011.34	334.59	19.24
Aim Pattern	4	2138.20	2138.20	534.55	30.73
Target Type	2	5047.53	5047.53	2523.76	145.09
Group*Day	9	5664.93	5664.93	629.44	36.19
Group*Aim Pattern	4	682.00	682.00	170.50	9.80
Group*Target Type	2	965.30	965.30	482.65	27.75
Day*Aim Pattern	36	573.84	573.84	15.94	0.92
Day*Target Type	18	891.63	891.63	49.54	2.85
Aim Pattern*Target Type	8	2084.18	2084.18	260.52	14.98
Group*Day*Aim Pattern	36	590.32	590.32	16.40	0.94
Group*Day*Target Type	18	501.34	501.34	27.85	1.60
Group*Aim Pattern*Target Type	8	810.30	810.30	101.29	5.82
Day*Aim Pattern*Target Type	72	814.23	814.23	11.31	0.65
Error	9358	162775.42	162775.42	17.39	
Total	9599	231607.09			

Source	P
Group	0.568
Subject(Group)	0.000
Day	0.000
Aim Pattern	0.000
Target Type	0.000
Group*Day	0.000
Group*Aim Pattern	0.000
Group*Target Type	0.000
Day*Aim Pattern	0.612
Day*Target Type	0.000
Aim Pattern*Target Type	0.000
Group*Day*Aim Pattern	0.567
Group*Day*Target Type	0.051
Group*Aim Pattern*Target Type	0.000
Day*Aim Pattern*Target Type	0.991
Error	
Total	

S = 4.17064   R-Sq = 29.72%   R-Sq(adj) = 27.91%

Flexion

Time Stress-Paced Task ANOVA

Factor	Type	Levels	Values
Task	fixed	2	1, 2
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	2	5, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Flexion, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Task	1	0.02	0.02	0.02	0.00	0.970
Group	1	540.03	540.03	540.03	0.44	0.517
Subject(Group)	14	17072.39	17072.39	1219.46	71.94	0.000
Day	1	1087.63	1087.63	1087.63	64.17	0.000
Aim Pattern	4	1549.14	1549.14	387.28	22.85	0.000
Target Type	2	2312.41	2312.41	1156.20	68.21	0.000
Task*Group	1	61.95	61.95	61.95	3.65	0.056
Task*Day	1	3.64	3.64	3.64	0.21	0.643
Task*Aim Pattern	4	81.50	81.50	20.37	1.20	0.308
Task*Target Type	2	7.41	7.41	3.71	0.22	0.804
Group*Day	1	61.29	61.29	61.29	3.62	0.057
Group*Aim Pattern	4	464.66	464.66	116.16	6.85	0.000
Day*Aim Pattern	4	47.87	47.87	11.97	0.71	0.588
Group*Target Type	2	293.96	293.96	146.98	8.67	0.000
Day*Target Type	2	209.37	209.37	104.68	6.18	0.002
Aim Pattern*Target Type	8	1332.98	1332.98	166.62	9.83	0.000
Task*Group*Day	1	0.08	0.08	0.08	0.00	0.945
Task*Group*Aim Pattern	4	93.86	93.86	23.47	1.38	0.237
Task*Day*Aim Pattern	4	60.10	60.10	15.03	0.89	0.471
Task*Group*Target Type	2	2.02	2.02	1.01	0.06	0.942
Task*Day*Target Type	2	61.38	61.38	30.69	1.81	0.164
Task*Aim Pattern*Target Type	8	50.08	50.08	6.26	0.37	0.937
Error	3766	63833.15	63833.15	16.95		
Total	3839	89226.92				

S = 4.11702   R-Sq = 28.46%   R-Sq(adj) = 27.07%

Appendix G

Extension

Self-Paced Task ANOVA

Factor	Type	Levels	Values
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Extension, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Group	1	3422.7	3422.7	3422.7	0.18	0.680
Subject(Group)	14	269484.1	269484.1	19248.9	263.10	0.000
Day	9	18037.9	18037.9	2004.2	27.39	0.000
Aim Pattern	4	680.2	680.2	170.1	2.32	0.054
Target Type	2	2184.0	2184.0	1092.0	14.93	0.000
Group*Day	9	6358.5	6358.5	706.5	9.66	0.000
Group*Aim Pattern	4	1273.2	1273.2	318.3	4.35	0.002
Group*Target Type	2	774.4	774.4	387.2	5.29	0.005
Day*Aim Pattern	36	2616.9	2616.9	72.7	0.99	0.480
Day*Target Type	18	2515.6	2515.6	139.8	1.91	0.011
Aim Pattern*Target Type	8	429.6	429.6	53.7	0.73	0.662
Group*Day*Aim Pattern	36	2273.5	2273.5	63.2	0.86	0.702
Group*Day*Target Type	18	2734.1	2734.1	151.9	2.08	0.005
Group*Aim Pattern*Target Type	8	410.6	410.6	51.3	0.70	0.691
Day*Aim Pattern*Target Type	72	1336.1	1336.1	18.6	0.25	1.000
Error	9358	684659.6	684659.6	73.2		
Total	9599	999191.0				

S = 8.55354   R-Sq = 31.48%   R-Sq(adj) = 29.71%

Extension

Time Stress-Paced Task ANOVA

Factor	Type	Levels	Values
Task	fixed	2	1, 2
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	2	5, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Extension, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Task	1	1220.7	1220.7	1220.7	18.36	0.000
Group	1	2642.9	2642.9	2642.9	0.22	0.645
Subject(Group)	14	166692.2	166692.2	11906.6	179.08	0.000
Day	1	26949.7	26949.7	26949.7	405.33	0.000
Aim Pattern	4	841.7	841.7	210.4	3.16	0.013
Target Type	2	76.9	76.9	38.4	0.58	0.561
Task*Group	1	118.6	118.6	118.6	1.78	0.182
Task*Day	1	9.6	9.6	9.6	0.14	0.704
Task*Aim Pattern	4	253.7	253.7	63.4	0.95	0.432
Task*Target Type	2	374.1	374.1	187.0	2.81	0.060
Group*Day	1	304.2	304.2	304.2	4.58	0.033
Group*Aim Pattern	4	446.1	446.1	111.5	1.68	0.152
Day*Aim Pattern	4	32.3	32.3	8.1	0.12	0.975
Group*Target Type	2	270.4	270.4	135.2	2.03	0.131
Day*Target Type	2	2049.2	2049.2	1024.6	15.41	0.000
Aim Pattern*Target Type	8	225.2	225.2	28.1	0.42	0.908
Task*Group*Day	1	9.0	9.0	9.0	0.14	0.713
Task*Group*Aim Pattern	4	86.5	86.5	21.6	0.33	0.861
Task*Day*Aim Pattern	4	359.7	359.7	89.9	1.35	0.248
Task*Group*Target Type	2	12.7	12.7	6.3	0.10	0.909
Task*Day*Target Type	2	207.6	207.6	103.8	1.56	0.210
Task*Aim Pattern*Target Type	8	142.5	142.5	17.8	0.27	0.976
Error	3766	250396.0	250396.0	66.5		
Total	3839	453721.3				

S = 8.15405   R-Sq = 44.81%   R-Sq(adj) = 43.74%

Appendix H

Ulnar Deviation

Self-Paced Task ANOVA

Factor	Type	Levels	Values
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Ulnar, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Group	1	7637.4	7637.4	7637.4	0.66	0.430
Subject(Group)	14	162084.0	162084.0	11577.4	252.72	0.000
Day	9	11163.9	11163.9	1240.4	27.08	0.000
Aim Pattern	4	118.6	118.6	29.6	0.65	0.629
Target Type	2	2455.7	2455.7	1227.9	26.80	0.000
Group*Day	9	11993.9	11993.9	1332.7	29.09	0.000
Group*Aim Pattern	4	253.9	253.9	63.5	1.39	0.236
Group*Target Type	2	772.6	772.6	386.3	8.43	0.000
Day*Aim Pattern	36	1018.2	1018.2	28.3	0.62	0.965
Day*Target Type	18	894.0	894.0	49.7	1.08	0.361
Aim Pattern*Target Type	8	467.9	467.9	58.5	1.28	0.250
Group*Day*Aim Pattern	36	1857.8	1857.8	51.6	1.13	0.277
Group*Day*Target Type	18	632.0	632.0	35.1	0.77	0.742
Group*Aim Pattern*Target Type	8	253.7	253.7	31.7	0.69	0.699
Day*Aim Pattern*Target Type	72	979.7	979.7	13.6	0.30	1.000
Error	9358	428709.2	428709.2	45.8		
Total	9599	631292.5				

S = 6.76846   R-Sq = 32.09%   R-Sq(adj) = 30.34%

Ulnar Deviation

Time Stress-Paced Task ANOVA

Factor	Type	Levels	Values
Task	fixed	2	1, 2
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	2	5, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Ulnar, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Task	1	5167.5	5167.5	5167.5	103.70	0.000
Group	1	9184.0	9184.0	9184.0	1.40	0.257
Subject(Group)	14	92136.5	92136.5	6581.2	132.06	0.000
Day	1	6400.3	6400.3	6400.3	128.43	0.000
Aim Pattern	4	219.7	219.7	54.9	1.10	0.354
Target Type	2	1107.1	1107.1	553.5	11.11	0.000
Task*Group	1	2.2	2.2	2.2	0.04	0.832
Task*Day	1	0.2	0.2	0.2	0.00	0.950
Task*Aim Pattern	4	64.2	64.2	16.0	0.32	0.863
Task*Target Type	2	117.1	117.1	58.5	1.17	0.309
Group*Day	1	9499.2	9499.2	9499.2	190.62	0.000
Group*Aim Pattern	4	34.5	34.5	8.6	0.17	0.952
Day*Aim Pattern	4	244.0	244.0	61.0	1.22	0.298
Group*Target Type	2	71.1	71.1	35.6	0.71	0.490
Day*Target Type	2	73.0	73.0	36.5	0.73	0.481
Aim Pattern*Target Type	8	230.6	230.6	28.8	0.58	0.796
Task*Group*Day	1	178.9	178.9	178.9	3.59	0.058
Task*Group*Aim Pattern	4	25.2	25.2	6.3	0.13	0.973
Task*Day*Aim Pattern	4	75.8	75.8	18.9	0.38	0.823
Task*Group*Target Type	2	2.2	2.2	1.1	0.02	0.978
Task*Day*Target Type	2	2.8	2.8	1.4	0.03	0.972
Task*Aim Pattern*Target Type	8	141.4	141.4	17.7	0.35	0.944
Error	3766	187673.9	187673.9	49.8		
Total	3839	312651.3				

S = 7.05930   R-Sq = 39.97%   R-Sq(adj) = 38.81%

Appendix I

Scan Time

Self-Paced Task ANOVA

Factor	Type	Levels	Values
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Scan Time (s), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Group	1	222.6	222.6	222.6	1.15	0.301
Subject(Group)	14	2700.2	2700.2	192.9	6.03	0.000
Day	9	2699.5	2699.5	299.9	9.37	0.000
Aim Pattern	4	25940.8	25940.8	6485.2	202.68	0.000
Target Type	2	52082.1	52082.1	26041.1	813.86	0.000
Group*Day	9	562.4	562.4	62.5	1.95	0.041
Group*Aim Pattern	4	248.1	248.1	62.0	1.94	0.101
Group*Target Type	2	1129.3	1129.3	564.7	17.65	0.000
Day*Aim Pattern	36	1282.6	1282.6	35.6	1.11	0.294
Day*Target Type	18	2997.3	2997.3	166.5	5.20	0.000
Aim Pattern*Target Type	8	50106.1	50106.1	6263.3	195.74	0.000
Group*Day*Aim Pattern	36	896.3	896.3	24.9	0.78	0.826
Group*Day*Target Type	18	353.3	353.3	19.6	0.61	0.892
Group*Aim Pattern*Target Type	8	770.7	770.7	96.3	3.01	0.002
Day*Aim Pattern*Target Type	72	2660.5	2660.5	37.0	1.15	0.175
Error	9358	299429.4	299429.4	32.0		
Total	9599	444081.3				

S = 5.65660   R-Sq = 32.57%   R-Sq(adj) = 30.84%

Scan Time

Self-Paced Task ANOVA

Factor	Type	Levels	Values
Task	fixed	2	1, 2
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	2	5, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5
Target Type	fixed	3	1, 2, 3

Analysis of Variance for Scan Time (s), using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F
Task	1	1135.53	1135.53	1135.53	28.05
Group	1	225.78	225.78	225.78	1.52
Subject(Group)	14	2078.64	2078.64	148.47	3.67
Day	1	299.51	299.51	299.51	7.40
Aim Pattern	4	13366.48	13366.48	3341.62	82.54
Target Type	2	20169.61	20169.61	10084.81	249.10
Task*Group	1	27.74	27.74	27.74	0.69
Task*Day	1	8.94	8.94	8.94	0.22
Task*Aim Pattern	4	17.30	17.30	4.33	0.11
Task*Target Type	2	58.13	58.13	29.07	0.72
Group*Day	1	37.52	37.52	37.52	0.93
Group*Aim Pattern	4	393.64	393.64	98.41	2.43
Day*Aim Pattern	4	879.18	879.18	219.79	5.43
Group*Target Type	2	621.70	621.70	310.85	7.68
Day*Target Type	2	1185.15	1185.15	592.58	14.64
Aim Pattern*Target Type	8	25962.70	25962.70	3245.34	80.16
Task*Group*Day	1	0.42	0.42	0.42	0.01
Task*Group*Aim Pattern	4	30.88	30.88	7.72	0.19
Task*Day*Aim Pattern	4	34.74	34.74	8.68	0.21
Task*Group*Target Type	2	7.50	7.50	3.75	0.09
Task*Day*Target Type	2	31.24	31.24	15.62	0.39
Task*Aim Pattern*Target Type	8	28.63	28.63	3.58	0.09
Error	3766	152468.90	152468.90	40.49	
Total	3839	219069.87			

Source	P
Task	0.000
Group	0.238
Subject(Group)	0.000
Day	0.007
Aim Pattern	0.000
Target Type	0.000
Task*Group	0.408
Task*Day	0.638
Task*Aim Pattern	0.980
Task*Target Type	0.488
Group*Day	0.336
Group*Aim Pattern	0.046
Day*Aim Pattern	0.000
Group*Target Type	0.000
Day*Target Type	0.000
Aim Pattern*Target Type	0.000
Task*Group*Day	0.918
Task*Group*Aim Pattern	0.943
Task*Day*Aim Pattern	0.930
Task*Group*Target Type	0.912
Task*Day*Target Type	0.680
Task*Aim Pattern*Target Type	1.000
Error	
Total	

S = 6.36283   R-Sq = 30.40%   R-Sq(adj) = 29.05%

Appendix J

Comfort

Self-Paced Task ANOVA

Factor	Type	Levels	Values
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5

Analysis of Variance for Comfort, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Group	1	0.7200	0.7200	0.7200	0.17	0.685
Subject(Group)	14	58.8678	58.8678	4.2048	19.11	0.000
Day	9	1.6719	1.6719	0.1858	0.84	0.576
Aim Pattern	4	78.6461	78.6461	19.6615	89.34	0.000
Group*Day	9	4.5891	4.5891	0.5099	2.32	0.014
Group*Aim Pattern	4	2.2280	2.2280	0.5570	2.53	0.039
Day*Aim Pattern	36	4.7401	4.7401	0.1317	0.60	0.971
Group*Day*Aim Pattern	36	3.9426	3.9426	0.1095	0.50	0.994
Error	686	150.9641	150.9641	0.2201		
Total	799	306.3697				

S = 0.469110   R-Sq = 50.72%   R-Sq(adj) = 42.61%

Time Stress-Paced Task ANOVA

Factor	Type	Levels	Values
Task	fixed	2	1, 2
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	2	5, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5

Analysis of Variance for Comfort, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Task	1	0.0320	0.0320	0.0320	0.14	0.704
Group	1	5.5125	5.5125	5.5125	2.97	0.107
Subject(Group)	14	26.0180	26.0180	1.8584	8.38	0.000
Day	1	0.7220	0.7220	0.7220	3.26	0.072
Aim Pattern	4	38.8559	38.8559	9.7140	43.82	0.000
Task*Group	1	0.6390	0.6390	0.6390	2.88	0.091
Task*Day	1	0.0750	0.0750	0.0750	0.34	0.561
Task*Aim Pattern	4	0.0660	0.0660	0.0165	0.07	0.990
Group*Day	1	0.0428	0.0428	0.0428	0.19	0.661
Group*Aim Pattern	4	1.5941	1.5941	0.3985	1.80	0.129
Day*Aim Pattern	4	0.7198	0.7198	0.1799	0.81	0.519
Task*Group*Day	1	0.1280	0.1280	0.1280	0.58	0.448
Task*Group*Aim Pattern	4	0.2700	0.2700	0.0675	0.30	0.875
Task*Day*Aim Pattern	4	0.3438	0.3438	0.0859	0.39	0.817
Error	274	60.7453	60.7453	0.2217		
Total	319	135.7642				

S = 0.470848   R-Sq = 55.26%   R-Sq(adj) = 47.91%

Appendix K

Usability

Self-Paced Task ANOVA

Factor	Type	Levels	Values
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	10	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5

Analysis of Variance for Usability, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Group	1	1.4112	1.4112	1.4112	0.25	0.625
Subject(Group)	14	78.8836	78.8836	5.6345	19.02	0.000
Day	9	8.0850	8.0850	0.8983	3.03	0.001
Aim Pattern	4	270.2356	270.2356	67.5589	228.02	0.000
Group*Day	9	1.8800	1.8800	0.2089	0.71	0.705
Group*Aim Pattern	4	1.4121	1.4121	0.3530	1.19	0.313
Day*Aim Pattern	36	5.6691	5.6691	0.1575	0.53	0.989
Group*Day*Aim Pattern	36	7.3920	7.3920	0.2053	0.69	0.913
Error	686	203.2508	203.2508	0.2963		
Total	799	578.2195				

S = 0.544320   R-Sq = 64.85%   R-Sq(adj) = 59.06%

Time Stress-Paced Task ANOVA

Factor	Type	Levels	Values
Task	fixed	2	1, 2
Group	fixed	2	1, 2
Subject(Group)	random	16	1, 2, 3, 4, 5, 6, 7, 8, 1, 2, 3, 4, 5, 6, 7, 8
Day	fixed	2	5, 10
Aim Pattern	fixed	5	1, 2, 3, 4, 5

Analysis of Variance for Usability, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Task	1	0.4961	0.4961	0.4961	2.16	0.143
Group	1	3.6551	3.6551	3.6551	1.76	0.206
Subject(Group)	14	29.0644	29.0644	2.0760	9.04	0.000
Day	1	5.0000	5.0000	5.0000	21.78	0.000
Aim Pattern	4	121.5603	121.5603	30.3901	132.37	0.000
Task*Group	1	0.4805	0.4805	0.4805	2.09	0.149
Task*Day	1	0.0080	0.0080	0.0080	0.03	0.852
Task*Aim Pattern	4	0.9218	0.9218	0.2304	1.00	0.406
Group*Day	1	0.0281	0.0281	0.0281	0.12	0.727
Group*Aim Pattern	4	0.5431	0.5431	0.1358	0.59	0.669
Day*Aim Pattern	4	1.1045	1.1045	0.2761	1.20	0.310
Task*Group*Day	1	0.3511	0.3511	0.3511	1.53	0.217
Task*Group*Aim Pattern	4	0.7265	0.7265	0.1816	0.79	0.532
Task*Day*Aim Pattern	4	0.7502	0.7502	0.1876	0.82	0.515
Error	274	62.9059	62.9059	0.2296		
Total	319	227.5955				

S = 0.479149   R-Sq = 72.36%   R-Sq(adj) = 67.82%