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Evaluation of a Novel Myoelectric Training Device

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EVALUATION OF A NOVEL MYOELECTRIC TRAINING DEVICE

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biomedical Engineering at Virginia Commonwealth University.

by

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List of Abbreviations

BNC = British Naval Connector

D = Digital

EMG = Electromyography

GEE = Generalized Estimated Equations

MVC = Maximum Voluntary Contraction

NASA TLX = National Aeronautics and Space Administration Task Load Index

PL = Proportional Linear

PNL = Proportional Non-Linear

PWM = Pulse Width Modulation

RMS = Root Mean Square

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Abstract

EVALUATION OF A NOVEL MYOELECTRIC TRAINING DEVICE

By Joshua Arenas, B.S. Mechanical Engineering

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Biomedical Engineering at Virginia Commonwealth University.

Virginia Commonwealth University, 2015

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Recent technological developments have implemented the use of proportional control in prosthetic hands, giving rise to the importance of appropriate myoelectric control. EMG models in the past have assumed a linear proportionality to simplify the EMG-force relationships. However, it has been shown that a non-linear EMG-force relationship may be a more effective model. This study focused on evaluating three different control algorithms for a novel myoelectric training device, consisting of a toy car controlled by EMG signals from the distal muscles in the arm. Sixteen healthy adult subjects (5 male and 11 female) with an average age of 23.6 years (SD = 2.7) were asked to drive the car through a slalom course. Completion times as well as number of errors (wall hits, cone hits, and reversals) were recorded to evaluate performance. The NASA TLX was administered to evaluate psychometrics such as mental demand, physical demand, frustration, and overall workload. The average total errors per trial on the final day of testing using the linear proportional algorithm was found to be statistically significantly ($p < 0.05$) lower than digital and non-linear proportional. The average course

completion time per trial and overall workload using the non-linear proportional algorithm was found to be statistically significantly ($p < 0.05$) lower than digital and linear proportional. These results suggest that a non-linear algorithm would be most appropriate for myoelectric control in prosthetic hands.

Chapter 1: Introduction

Losing a limb severely changes a person's everyday life and functionality (27). Sadly, thousands each year lose limbs and have to cope with this loss. The majority of limb loss is due to congenital deficiencies. Congenital upper limb deficiency is most common and has been suggested that 75% of all congenital, unilateral upper-extremity amputees will be missing their left arm below the elbow (13). There have also been studies that project there to be 3.6 million amputations by the year 2050 (28). With such an increase in limb loss, the need for functional prostheses to replace these limbs is at an all-time high.

1.1 Prosthetics

The history of prosthetics dates back to the ancient Egyptians. These prostheses didn't hold much value other than cosmetic appearance and were made out of leather and wood. Over the years, different materials were put into use to make the prosthetics more durable. Metals, such as bronze, were used in conjunction with the leather and wood materials of old. In the 1800's, an improvement in functionality was seen as wooden legs were outfitted with catgut tendons to allow the foot to plantar and dorsiflex (26). As technology improved, prostheses became more advanced and more functional than their predecessors. The first powered prostheses appeared in 1915 and were pneumatically controlled. The growth of electronics resulted in the development of the first myoelectric prostheses in the 1940's. As electronic developments continued (such as the creation of the transistor), a Swedish research group created the SVEN hand in the 1960's. This was one of the first myoelectric hand prostheses that was multifunctional and has been used extensively in research (4).

Myoelectric prostheses are advanced prostheses, where movement of the artificial limb is controlled through the measurement of the electrical signal associated with muscle activation. Many of the commercial artificial limbs available today use surface electrodes to sense the electrical activity of the user's muscles. Surgery is sometimes required to bring the muscle nerves closer to the skin which improves the signal strength of the muscle and makes it easier for the prosthesis to sense. Studies have shown that myoelectric prostheses provide a higher grasping force, increased functional performance, and greater range of motion over conventional prostheses (e.g. cable prosthesis system). Users also preferred a myoelectric prosthesis because it looked more natural and it provided them with higher self-esteem (24, 27).

1.2 Control Algorithms

The most commonly used control scheme for myoelectric prostheses is the direct control scheme. Direct myoelectric control schemes map a single EMG control signal to a single control variable, such as motor speed. Several commercial devices, such as the Ottobock System Electric Hand use this type of control scheme. These devices have only one function, which is to open and close the hand. Pattern based control schemes are currently being developed to allow for more functionality of hand prostheses, including multiple grasps and increased articulation (22). Although devices that employ direct myoelectric control schemes are limited, they do increase the functional capability of the user. In the past, these devices implemented digital control (on/off) to operate the opening and closing of the hand. Today, many of these devices use proportional control to vary the speed of the opening and closing of the hand as well as the grasping force, which is more physiologic than digital control and gives users a variety of objects they can handle with their prosthesis (23, 29).

It has been suggested since the 1950's, that in order to obtain a graded response from the myoelectric prosthesis, some form of proportional control would need to be implemented (2). Proportional control allows the user to perform small, precise movements as well as rapid, coarse movements. Since proportional control is currently available as a feature from all manufacturers of commercial myoelectric prostheses, appropriate myoelectric control has become increasingly important (3, 11). EMG models in the past have assumed a linear proportionality to simplify the EMG-force relationships. However, it has been shown that a non-linear EMG-force relationship may be a more effective model. Below is an equation that models the non-linear EMG-force relationship of the extrinsic muscles in the finger. EMG_N represents the non-linearly normalized EMG signal, F_m represents max force, EMG_L represents the EMG signal linearly normalized to 100% of maximum, and C is a constant to describe the non-linear curvature. A range of values was found for this constant depending on the type of filter as well as activation condition (flexion or extension) (17).

$$EMG_N = F_m \frac{e^{(-0.001 EMG_L C)} - 1}{e^{(-0.001 F_m C)} - 1}$$

Before an amputee can obtain a myoelectric prosthesis, they need to complete a training phase that allows them to develop the skills necessary for controlling these types of prostheses (25, 9). This includes having to learn how to produce a specific myoelectric signal to control each function of the prosthetic (3). Often times, training systems are used that do not hold the attention of the user. With so many advancements being made to increase the functionality of myoelectric prosthetics, it is important that these training systems not only engage the user, but also be affordable, portable, and adaptable to conventional state of the art control schemes (7). In order to solve this problem, a novel myoelectric training device was developed and evaluated.

The device utilized a toy car controlled by an EMG system, with the goal to keep users better engaged during the necessary training phase. Initial testing showed that users were engaged when using the training system and thought it was “fun to use.” However, limitations of the system included that it was not portable and only used a digital control algorithm (5).

1.3 Focus of Study

The overall goal of this research is to evaluate three different man-machine interface algorithms linking EMG to external device control. It is hoped that this understanding may lead to increased usability and an increased prosthesis acceptance rate (11). This study will follow the same concept of the training system mentioned in the previous section and utilize a toy car controlled through an EMG system to hold the user’s attention. The system will use a dual site, three-state control scheme, which is a direct control scheme that is used in many commercially available myoelectric prostheses (18, 19). However, this version of the training system will be capable of proportional control, unlike the previous version, which was solely controlled digitally. Two separate proportional control algorithms will be implemented: a linear proportional control and a non-linear proportional control based off the exponential equation mentioned previously.

Figure 1: EMG Training System

1.4 Specific Aims

With modifications to the previous myoelectric training device, this study will test three hypotheses:

Hypothesis 1: A man-machine control interface that more closely mimics the EMG-muscle force generation relationship will provide more functional control.

> Specific aim 1(a): To compare the performance between day 1 and day 2 of EMG controlled steering and direction of a remote controlled car in a predefined course by measuring course completion time and cumulative errors.
>
> Specific aim 1(b): To compare performance metrics with 3 different control algorithms; (1) digital, (2) proportional linear, and (3) proportional non-linear.

Hypothesis 2: A man-machine control interface that more closely mimics the EMG-muscle force generation relationship will appear more natural, have the quickest acclimation time, result in the least frustration, and have the least overall workload for the user.

> Specific aim 2a: To test the user's mental demand level using the NASA TLX.
>
> Specific aim 2b: To test the user's physical demand level using the NASA TLX.
>
> Specific aim 2c: To test the user's frustration level using the NASA TLX.
>
> Specific aim 2d: To test the user's overall workload level using the NASA TLX.
>
> Specific aim 2e: To evaluate the rate of learning for each algorithm by comparing the exponential regression for completion time, total errors, and overall workload of the three control algorithms.

Hypothesis 3: Subject capacity to learn, as elucidated by errors committed per unit time, will impact which control algorithm will produce the best results.

> Specific Aim 3a: To see if high-capacity vs. low-capacity learning impacts the rate at which each algorithm can be mastered.

Chapter 2: Materials and Methods

The study included 16 healthy adult subjects (5 male and 11 female), with an average age of 23.6 years (SD = 2.7). Data collection took place during two sessions that lasted approximately an hour and a half each. Participants were asked to come back for their second session within 48 hours of their first. This was done to maximize training carryover from the previous session. During each session, subjects were asked to control a remote controlled car through a 40ft long by 4ft wide serpentine course, with 7 turns. Light gates were placed at the beginning and end of the course to measure completion time. Subjects were asked to reach the end of the course as quickly as possible, without hitting any obstacles. Course times as well as the number of obstacle hits were recorded. Control of the car required muscle activation signals from both of the user's forearms. The subject's dominant arm controlled the steering of the car, while the non-dominant arm controlled forward and reverse movement.

2.1 Experimental Design

The subjects were recruited via a sample of convenience from a college age population at Virginia Commonwealth University to participate in this experiment. Before arriving to the lab for the experiment, participants were asked not to wear lotion on their forearms because this could possibly interfere with the EMG signal and to dress in a way that allowed easy access to the muscle in their forearms (14). Following an introduction and consent process, block randomization was used to assign the control algorithm order. In the block randomization, there were six possible interface combinations used that included all three control algorithms, while not allowing an algorithm to be repeated on the same day. Subjects had a different combination each day. With the subject seated in a chair positioned at the end of the demarcated slalom course, four muscle sensing electrode pairs were placed over the muscle bellies of the extrinsic wrist muscle flexors and extensors on both arms (16). These muscles were chosen because they are normally used in the control of myoelectric prosthetic arms (12). Electrode placement was standardized with electrodes placed approximately 5cm distal to the elbow. Subjects were asked to flex and extend their wrist against resistance and the electrode pair was placed in the center of the muscle mass that emerged in line with muscle fiber orientation (6). Figure 2 shows the relative placement of the electrodes. A reference electrode was also placed on the bony part of the subject's left wrist for the ground lead.

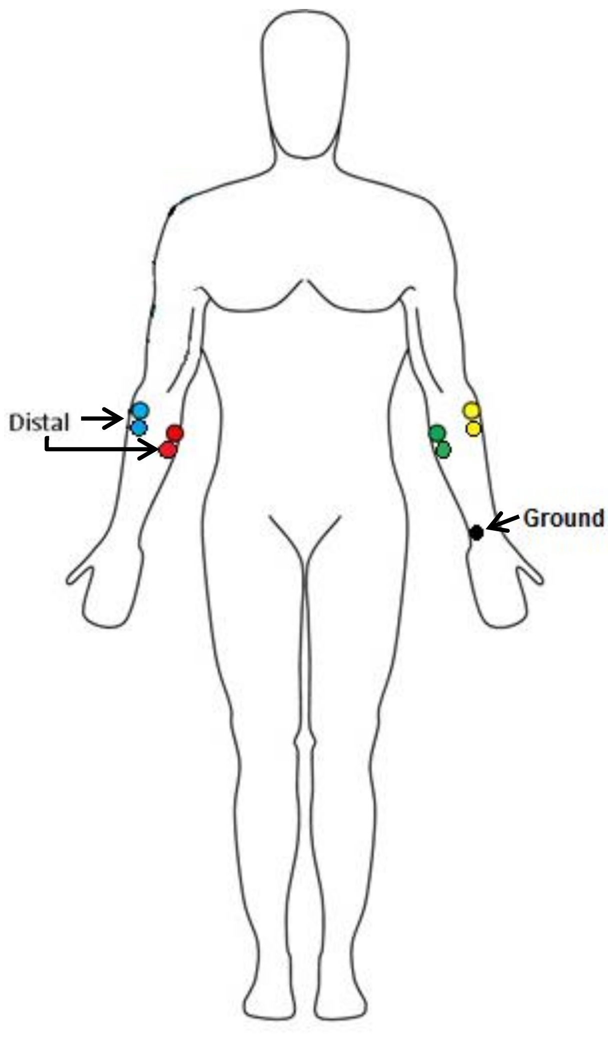

Figure 2: Relative placement of EMG electrodes

After all electrodes were connected to the EMG leads, participants were asked to put their forearms in wooden braces mounted to a table top in front of them (Figure 3), making sure the only electrode located inside the brace was the ground electrode. This position minimized the potential of introducing a motion artifact in the EMG signal. The braces were then adjusted to the arm size of the individual to minimize muscle movement so that isometric contractions could be used to control the vehicle (12, 15). This also allowed a healthy subject to mimic the type of contractions that an amputee would produce. In addition, participants were given instructions to flex with their fingertips and extend using their fingernails, but avoid curling their fingers in order to keep their hands as straight as possible (17). Again, this was to ensure that the subjects were giving the strongest EMG signal possible from the desired muscle groups by avoiding co-contraction and by activating muscles that crossed the most distal joints in the hand (12). Subjects then practiced producing maximum voluntary contractions (MVC) while watching an EMG signal magnitude on an oscilloscope screen. Calibration was performed by asking the subject to rest for two seconds and then perform a maximum contraction for two seconds with each muscle group independently. These values were used to normalize subsequent data by setting them equal to 0 and 100 percent respectively (resting and maximum) (20). This allowed the system controller to be scaled equally across users.

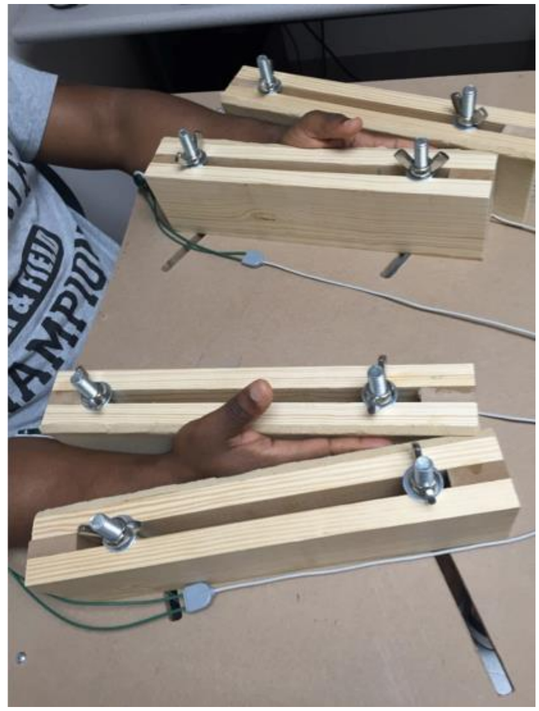

Figure 3: Wooden braces used to obtain isometric contractions

Subjects were trained to a standardized level of control of the car by completing what was called a "square test". Participants' dominant arm controlled steering and their non-dominant arm controlled forward and backward movement of the car (9). The car was placed in a 3ft by 3ft square wooden box (Figure 4) and participants were allowed to briefly practice the aforementioned controls. After they had successfully moved the wheels left and right as well as moved the car forward and backwards, they were given two minutes to drive the car through a full 360° of rotation in one direction to return to the original position. If they did not complete the task in less than two minutes, they were required to start over. Participants could not advance to the slalom course portion of the experiment until they successfully completed the square test.

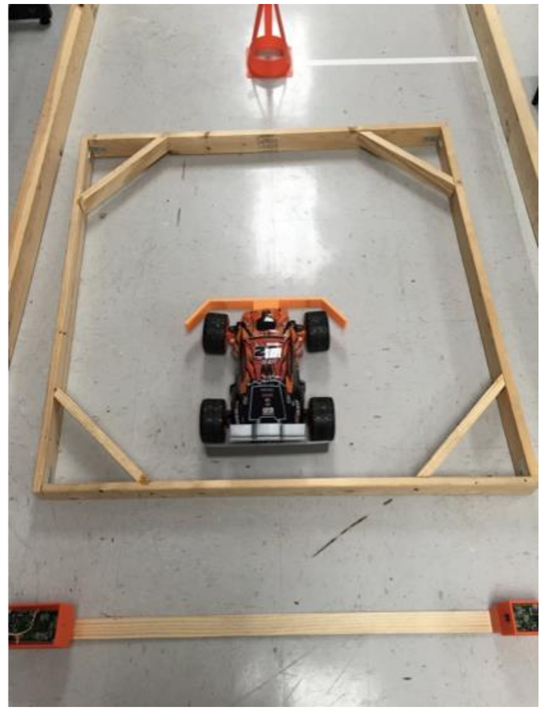

Figure 4: Square test

After the participant successfully completed the first square test, a modified National Aeronautics and Space Administration Task Load Index (NASA TLX) survey was administered to determine the subject's overall workload for the task. It has been determined that the NASA TLX should be administered if the goal is to predict performance of a particular individual in a task. This is because the NASA TLX produces high correlations between workload and performance and has been applied successfully in different multitask contexts, such as using remote-control vehicles and human machine interfaces (1, 21). The participant was shown the survey and asked to rate their perceived experience on a scale of 1-20 for each of the six categories: mental demand, physical demand, temporal demand, performance, effort, and frustration level*. The endpoint descriptors described the scale as very low (rating of 1) to very high (rating of 20), except for performance, which was described as perfect (rating of 1) to failure (rating of 20). For the second part of the survey, participants were randomly presented with 15 pairs of rating scale titles (e.g. Effort vs. Mental Demand) and asked which category was more important to their experience of workload in the task. This provided a weight for each category, which was used to find weighted ratings that were averaged to find the overall workload. The survey was taken after the first square test so participants could familiarize themselves with the rating scales and make sure they had developed a standard technique for dealing with the scales. After the first square test of the day, the NASA TLX was only administered after participants completed all trials of the slalom course for each control algorithm.

Following success in the square-test, participants were asked to drive the car through a slalom course as quickly as possible (Figure 5). The car was placed at the start line. The subjects were instructed to cross the start line (triggering the first light gate and automatically starting a course timer), pass through the slalom gates marked by white tape, avoid hitting the cones and the walls, and

Figure 5: Slalom Course

* For a full description of the six categories, see Appendix.

to pass through the finish line at the end of the course (triggering the second light gate and stopping the course timer). They were informed that three seconds would be added to their total time if they hit a cone. Completion time, number of wall and cone hits, and direction reversals were recorded as they completed the task. A wall hit was defined as any contact with the wall that prohibited or slowed forward progress of the course. Reversals were defined as any motion that didn't result in forward progress. There were instances where the car would be oriented in a position that resulted in no change of position in the course whether the car itself moved forward or backward. No errors were counted when this occurred. In addition, some subjects completed part of the course by driving backwards. This meant that errors were counted when the car drove forward because it no longer resulted in forward progress in the course.

All three control algorithms were tested in one session: digital, linear proportional, and non-linear proportional. After they completed six trials with one algorithm, participants were given a break and taken out of the wooden braces. During this time, the NASA TLX survey was administered to determine the overall workload of the task with the control algorithm they just used. Once the survey was completed, subjects were placed back into the wooden braces, the system was recalibrated, and the algorithm was switched. Participants were re-trained using the square test and, after successful completion, moved on to the slalom course. Again, the NASA TLX was only administered after the first square test and after all six trials of the slalom course were completed with one algorithm. This procedure was followed until the participant had tested all three algorithms, resulting in a total of 18 trials per day. The total time per session was about 2 hours and the subjects were asked to repeat the performance for 2 total sessions over 48 hours. Both sessions followed the same procedure.

2.2 Experimental Details

Toy Car

A remote control car with proportional control capabilities was purchased for this experiment. Unfortunately, the car was only capable of proportional control when sent voltages between 5.7 and 7.2 V. The speed at this control voltage was too fast for the course, so the stock control electronics were removed and replaced with an Arduino microcontroller. With the Arduino, the voltage supplied to the car could be varied, giving it full range of proportional control. This was done by using the pulse width modulation (PWM) feature of the digital outputs on the microcontroller. The Arduino alone was enough to power the servo motor used for steering, but was not enough to supply the DC brush motor used to control forward and reverse motion. In order to supply the necessary current for the DC motor, a Pololu motor driver (Pololu High-Power Motor Driver 18v15) was added. Brackets were designed using Solidworks and printed using a Makerbot Replicator 2x 3D printer. These were used to hold the new servo motor in place to steer the car. A housing stand was also printed to hold the Arduino microcontroller on top of the car. The stock battery that came with the car did not provide a long enough run time for one subject to complete the entire experiment. It was rated at 7.2V and 1000mAh. Batteries rated at 7.2V and 2200mAh were used, which provided more run time. The wiring of the car was modified for the new batteries and industrial strength Velcro was used to hold them in place (Figure 6).

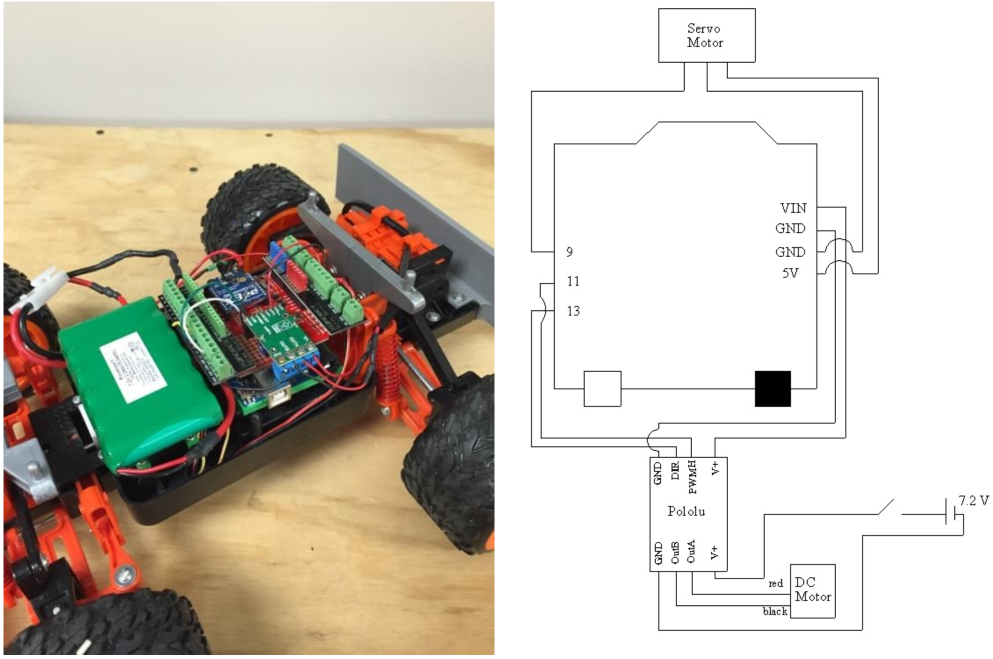

Figure 6: Toy Car

Data Processing: EMG Control Box

Since a new circuit was created for the toy car, the stock remote control was discarded and a new remote control was created. A multipurpose plastic enclosure was modified to serve as the new control box. It housed all of the necessary circuitry to process the EMG signal, calibrate the system to each individual user, and wirelessly control the car. The EMG amplification board from the previous study was modified to process integrated EMG signals instead of raw signals. The AD 524 precision instrumentation amplifiers were modified to create non-inverting amplifiers instead of inverting amplifiers. This was done because the integrated EMG signal from the Noraxon Myosystem 1200 is already rectified by using a 100ms root mean square (RMS) filter, which converts the negative voltage into positive voltage, so there was no need to invert the signal (15). The signal was then smoothed with a low pass filter RC filter having a cutoff frequency of 0.7875Hz. The time constant was set to 200ms because it has been shown that large time constants produce significant controller delays (10). This resulted in smooth control of the car without any noticeable delay. Figure 7 shows the diagram for the EMG amplification board. Since the microcontroller from the previous study was not being used, the gain on the amplification board needed to be adjusted to the specifications of the current microcontroller. This adjustment maximized the sensitivity of the system.

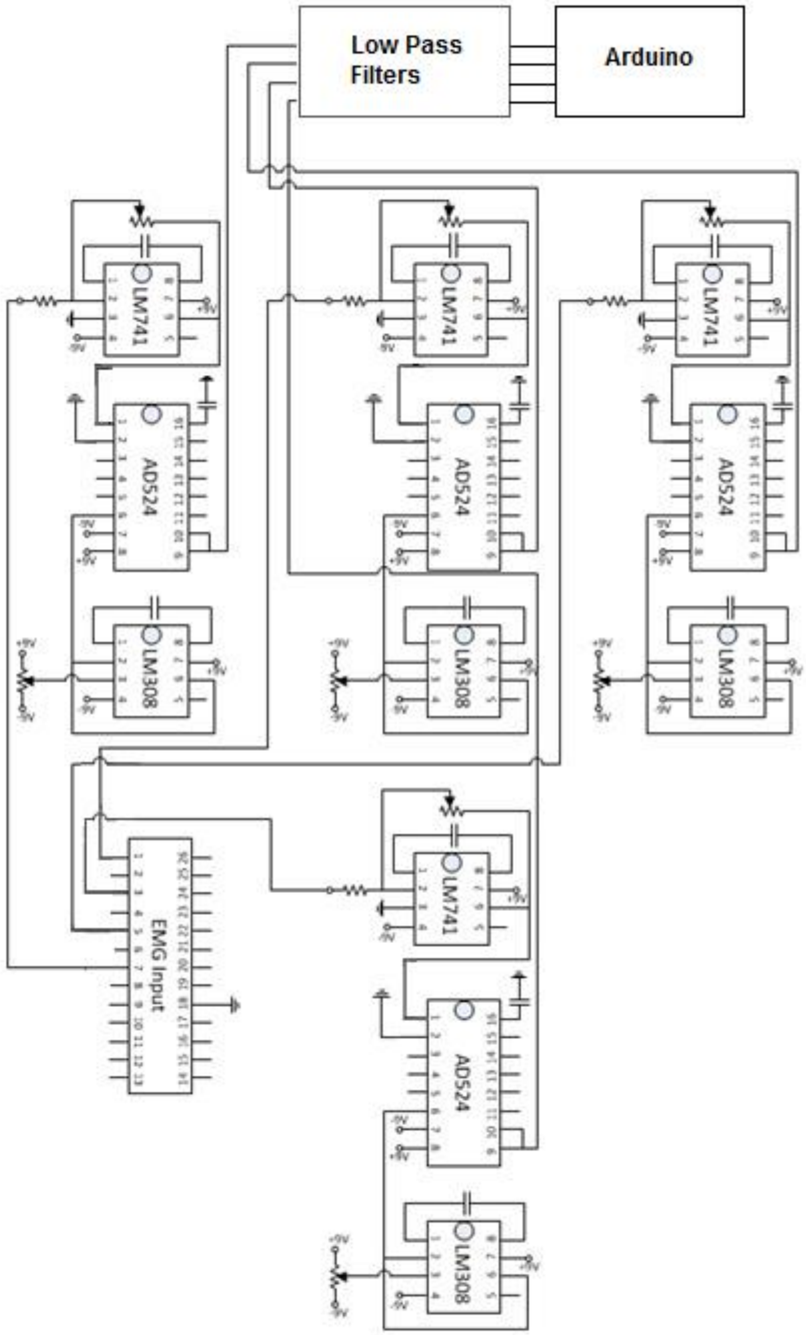

Figure 7: EMG Amplification Board Diagram

The power supply for the control box needed to power the amplification board, as well as the Arduino microcontroller. The amplification board was powered with ±9V and the Arduino was powered with +5V. A +10V step down transformer along with a series of voltage regulators were used to obtain the necessary voltages. In order to achieve the +9V needed for the EMG board, an LM2940T voltage regulator in combination with a 22 µF tantalum capacitor was used. The -9V for the EMG board used a 7909A voltage regulator with a 1 µF tantalum capacitor. An LM7805C voltage regulator was used for the +5V needed to power the Arduino microcontroller. Figure 8 illustrates the layout of the controller box.

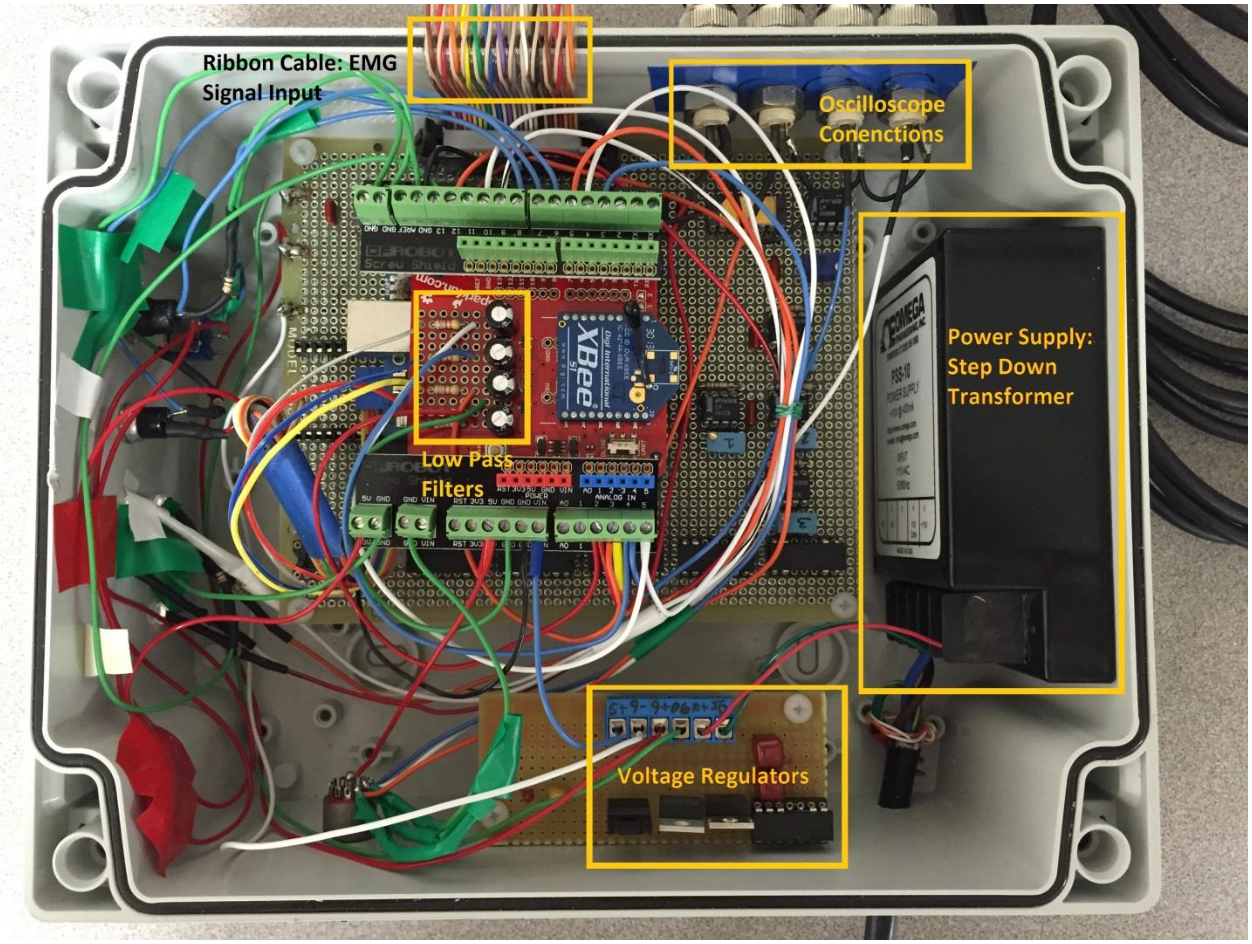

Figure 8: EMG Box. Amplification board is below Arduino microcontroller.

Switches and LEDs were needed to both serve as a guide for participants as well as control aspects of the written code in order to tailor the system to each individual. Holes were drilled in the plastic enclosure to house the LEDs, switches, power supply cord, and BNC connections for use with an oscilloscope (Figure 8). A push-button switch was used to initiate the calibration phase of the program, which calibrated the system to each individual user to customize the controls for each person. The LEDs were used to guide the user through the calibration sequence. Two LEDs labeled Left and Right showed which arm was being calibrated. A yellow LED indicated the rest phase of the calibration, while green and red LEDs signaled the flexion and extension portion respectively. A toggle switch was used to differentiate between right and left hand dominance because the user's dominant hand controlled steering of the car. A push-button switch was also used as an emergency stop switch. In case the car wasn't responding correctly, or the user needed to move their arms without a response from the car, the signal would not be sent as long as this button remained pushed down. A rotary-dial switch was used to move between the different algorithms to control the car. BNC connections were used to externalize the EMG data and were connected to an oscilloscope so the EMG signal could be seen (Figure 9). This allowed the user to see their max flexion during calibration and also showed any possible discrepancies that would require a re-calibration.

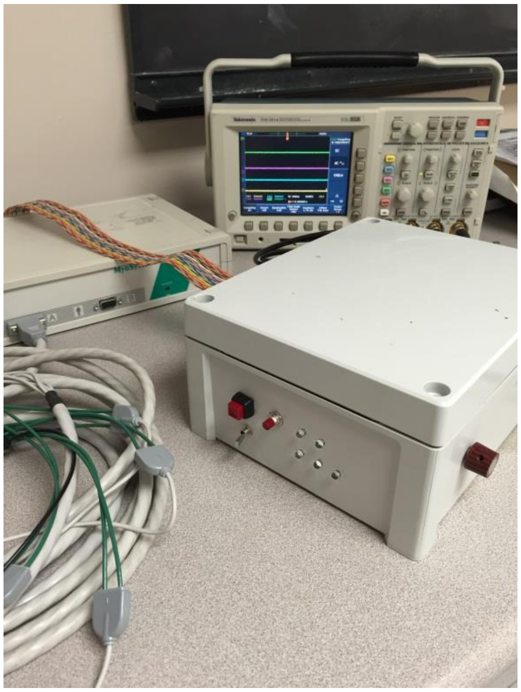

Figure 9: EMG setup

Following low pass filtering of the EMG signal in hardware, the signal was sampled via the analog inputs of the Arduino at 2500 Hz. The signal was normalized via software based on the previously obtained calibration limits. The user's resting voltage was normalized to zero and their max flexion/extension voltages were normalized to 100. This ensured that the EMG controller sent only values to which the car could respond. Regardless of which algorithm was being used (digital, proportional linear, or proportional non-linear), the car initiated motion when the user performed an isometric contraction of 10% of their maximum value. Once this threshold was reached, the actions of the car depended on which control algorithm the system was set to. In the digital control mode, the car would move at full speed in the forward and reverse directions and reach the full left and right turn values for steering once the 10% threshold was met. With the proportional linear algorithm, the car would be proportionally controlled for both steering and speed. The proportionality followed a linear EMG-muscle force relationship. The proportional non-linear algorithm was also proportionally controlled, but it followed an exponential curve based on an equation found in literature known to relate EMG signal to muscle force production (17). The maximum exponential constant (C) of 46 was chosen, so the non-linear curve would be as different from the proportional linear control algorithm as possible. The linearized EMG values were adjusted to the activation threshold and the max force variable was empirically found to fit the limits of the DC and servo motors. This resulted in the following equations for speed and steering:

$$Steering = \pm 29.50 \frac{e^{(-0.001*(x-10)*46)} - 1}{e^{(-0.02950*46)} - 1} + 81$$

$$Speed = 61.02 \frac{e^{(-0.001*(x-10)*46)} - 1}{e^{(-0.06102*46)} - 1}$$

The differences in these control algorithms can be seen in Figures 10 and 11 below. The control value sent to the car computed for both speed and steering. The control box communicated with the car by using a pair of Xbee wireless communication chips. This communication stream was unidirectional, from the control box to the car only. The communication speed was set to a baud rate of 9600bps.

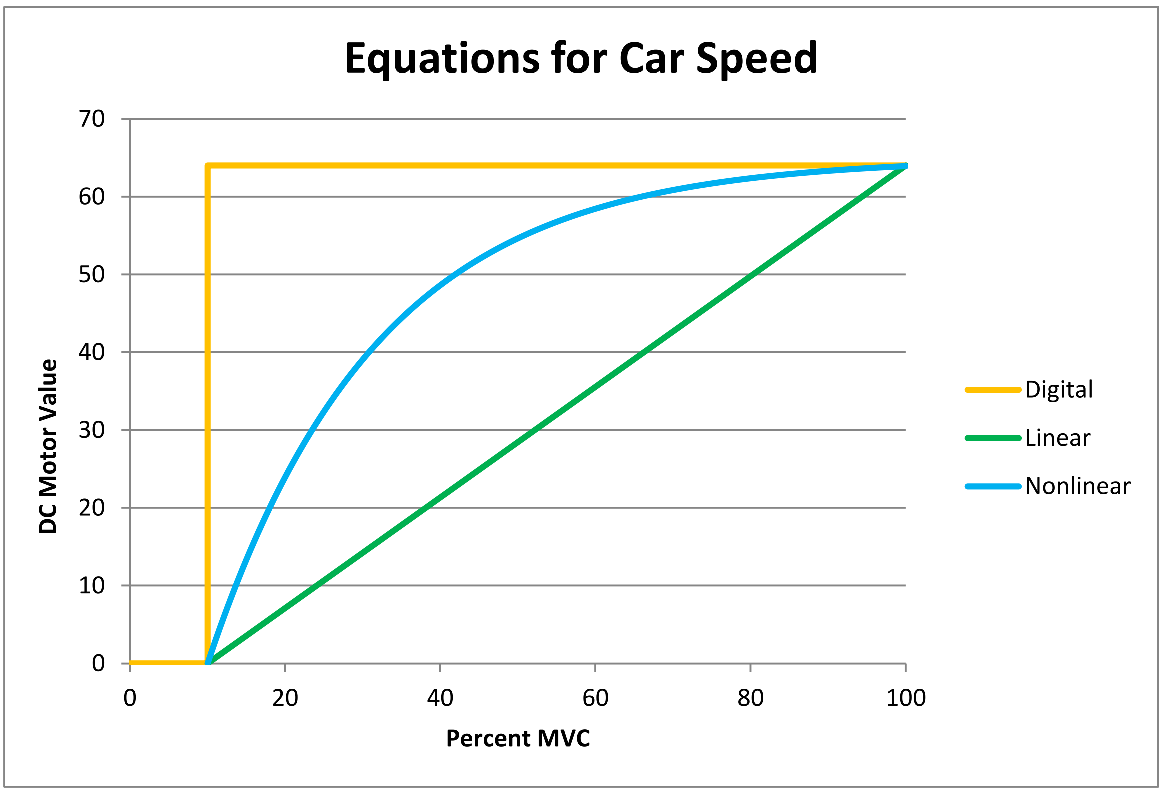

Figure 10: Digital, linear, and non-linear equations used for the speed of the car.

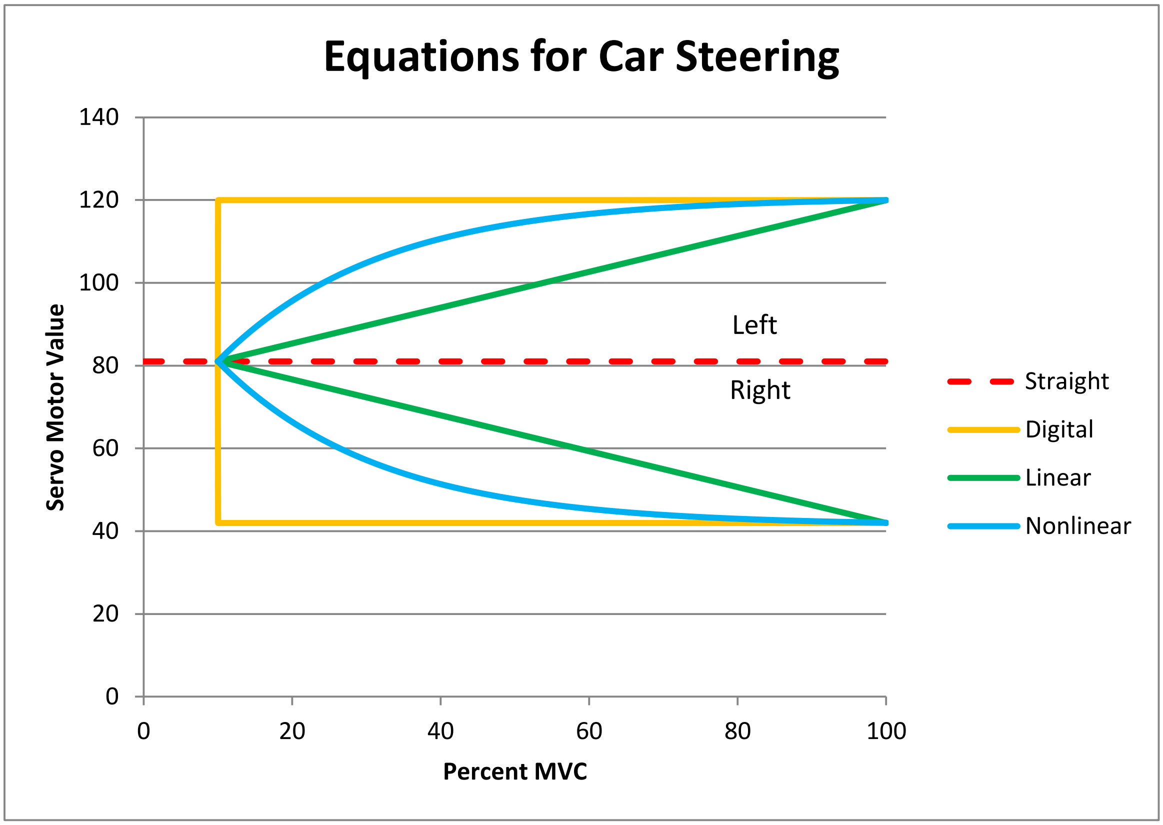

Figure 11: Digital, linear, and non-linear equations used for the steering of the car.

Chapter 3: Results

A Generalized Estimated Equations (GEE) test was run using IBM SPSS Statistics v23 to compare the means of time, total errors, and overall workload of each control algorithm across day 1 and day 2. The GEE test was also used to compare the means of time, total errors, and overall workload between the three algorithms on day 2. Tables 1-3 below show a summary of the data. A significance value ($p<0.05$) indicates that there is statistical significance between the data. The full set of data can be found in Appendices A, B, and C.

3.1 Time and Error Data: Day 1 vs. Day 2

Figure 12 below shows the average time per trial for each of the three algorithms (Digital (D), Proportional Linear (PL) and Proportional Non-Linear (PNL)) across both days. Trial number seven was the beginning of day 2, which is represented by the vertical dashed line. A GEE test showed that the mean time difference between day 1 and day 2 for each algorithm was statistically significant ($p < 0.05$). The times for all three algorithms showed a progressive decrease from the first trial on day 1 to the last trial on day 2. Note that D started out with the highest average start time and PNL was the lowest. Although the average times by trial 12 were relatively close to each other, D and PL remained with the highest and lowest average time, respectively. The improvement from the end of day 1 to the start of day 2 is due to memory consolidation, which is defined as “the progressive post acquisition stabilization of long-term memory” (8). This means that there won’t be a decrease in performance from the last trial in day 1 to the first trial in day 2 because subjects retained the strategy of operating the toy car.

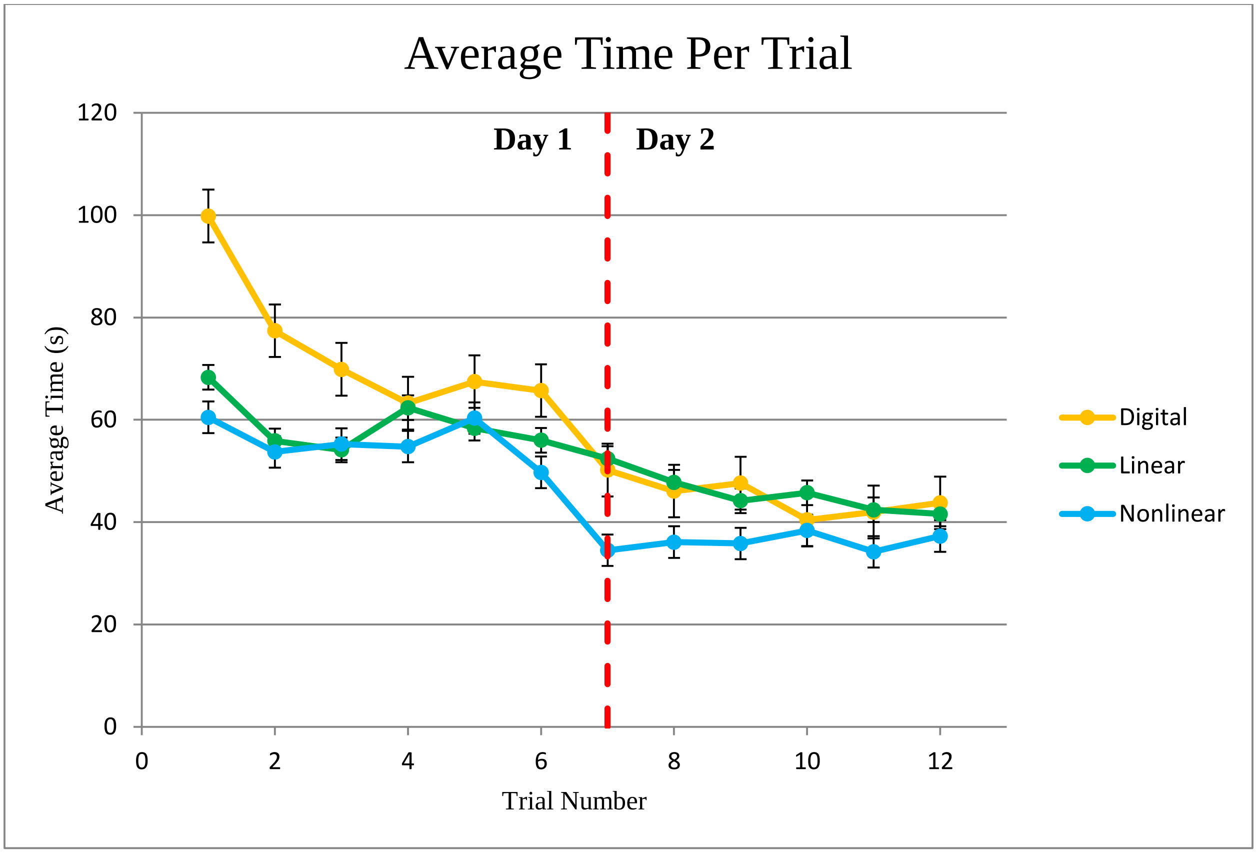

Figure 12: Graph of average course completion time per trial for all three equations on day 1 and day 2. Day 2 begins at trial number 7 and is represented by the red, vertical, dashed line.

Figure 13 below represents the average total errors (reversals, wall hits, cone hits) per trial for each of the three algorithms across both days. Average total errors per trial also steadily decreased like average time per trial. D again started with the highest average total errors, similar to average time per trial. However, PL began with the lowest average total errors. By trial 12, the average total errors decreased significantly for all three algorithms, and although PNL was not much different from PL, the original ranking remained the same. Statistical significance ($p < 0.05$) between both days was again seen by the GEE test that was performed.

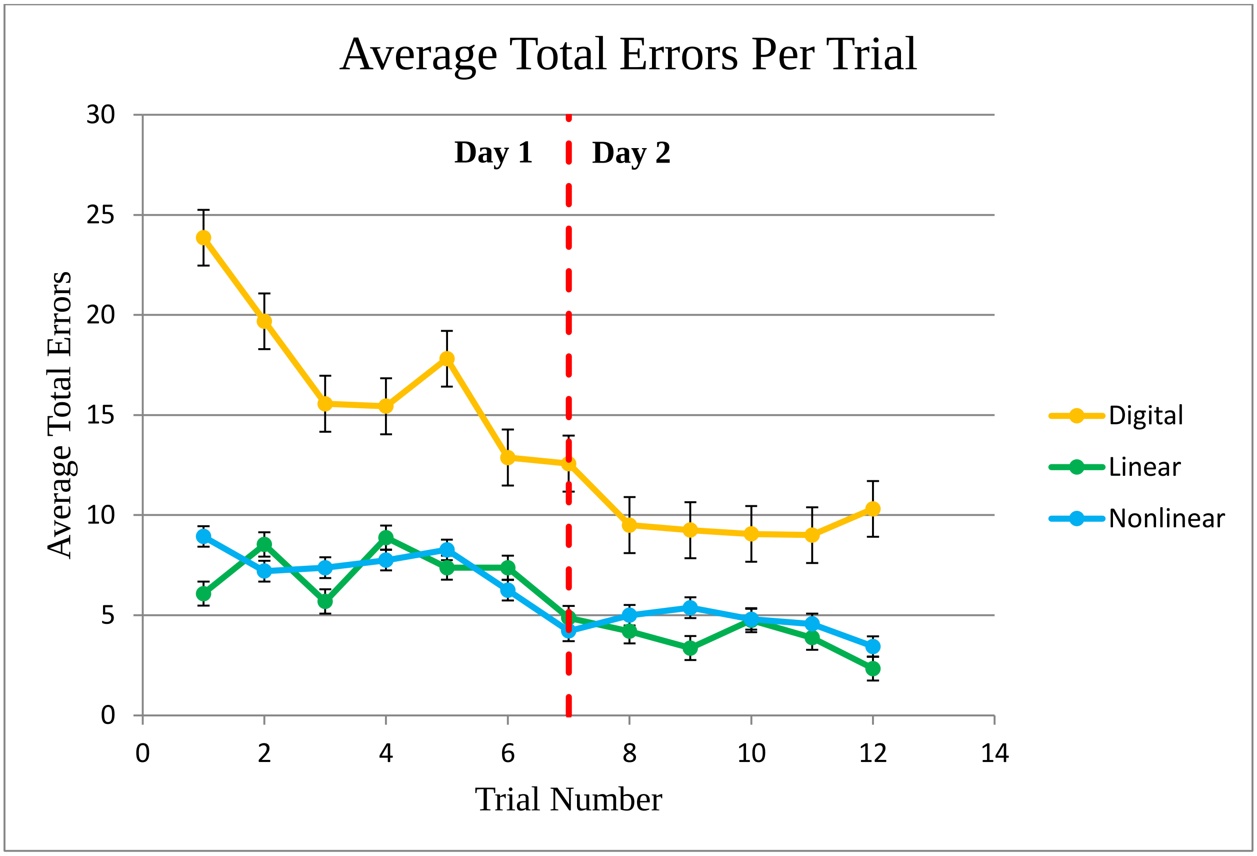

Figure 13: Graph of average total errors per trial for all three algorithms on day 1 and day 2. Day 2 begins at trial number 7 and is represented by the red, vertical, dashed line.

The average time and error difference per day for each algorithm is represented by the bar graph in Figure 14 below. D shows the highest differences for both time and error with 39.30% and 43.61% decreases, respectively. PL has a 22.83% decrease in time and PNL has a 40.32% decrease in errors, both of which are the lowest in their respective categories.

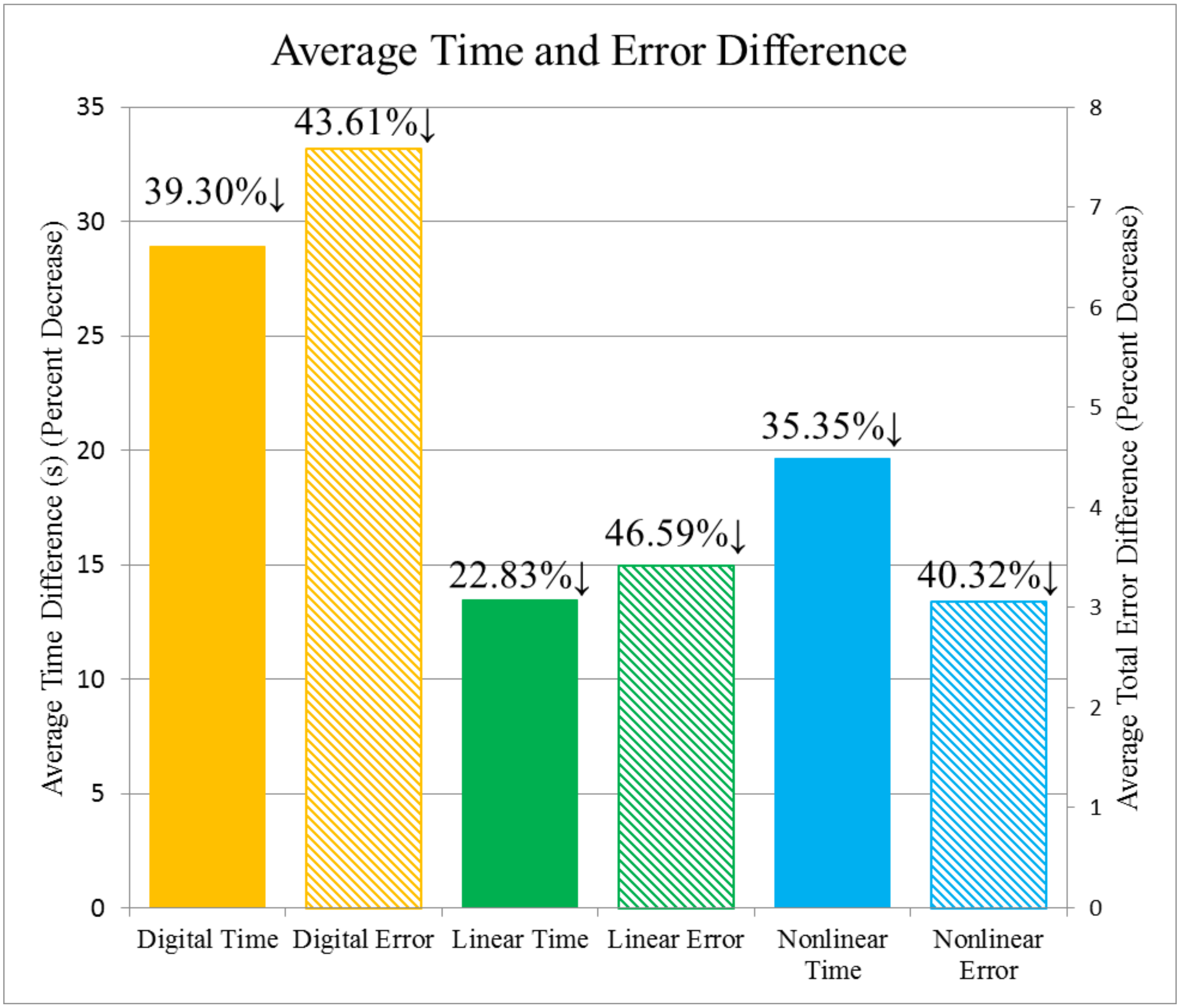

Figure 14: Average time and error differences between day 1 and day 2 for each algorithm. Percentages represent a percent decrease in time and error.

3.2 NASA TLX: Day 1 vs. Day 2

Figures 15-17 below show the results from the NASA TLX survey for the three algorithms on both days. As with the average time and total errors per trial, the majority of the averages for day 2 were lower than day 1, with temporal demand and effort for PL being the only two exceptions. The variances for all three algorithms also decreased. Categories that had a statistical significant ($p < 0.05$) difference between day 1 and day 2 are marked with an asterisk. The only categories that were statistically significant between day 1 and day 2 for all three algorithms were mental demand and overall workload.

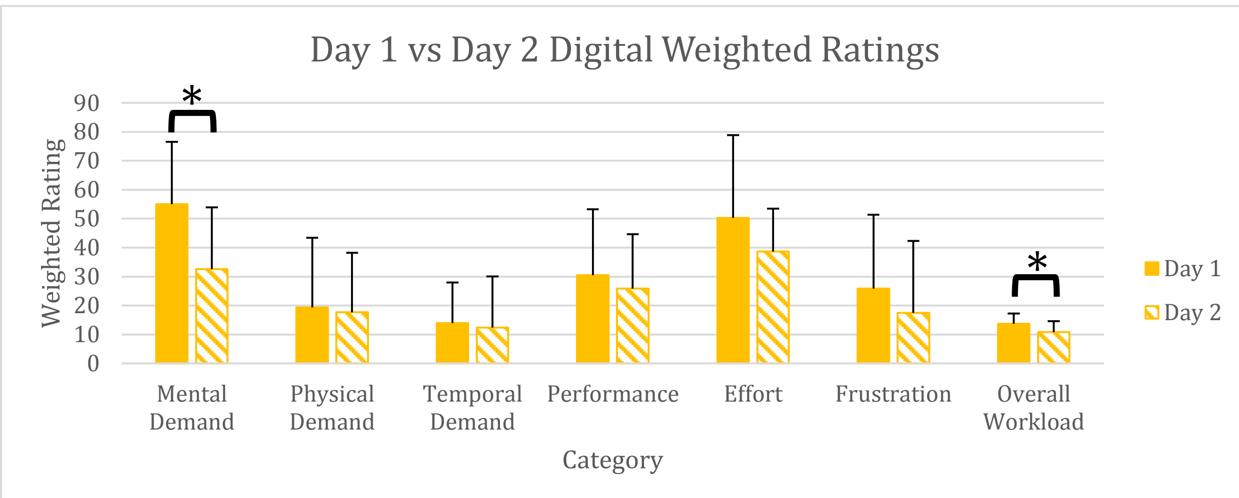

Figure 15: Average weighted ratings of NASA TLX for the digital algorithm on day 1 and day 2. Asterisk denotes statistical significance ($p < 0.05$).

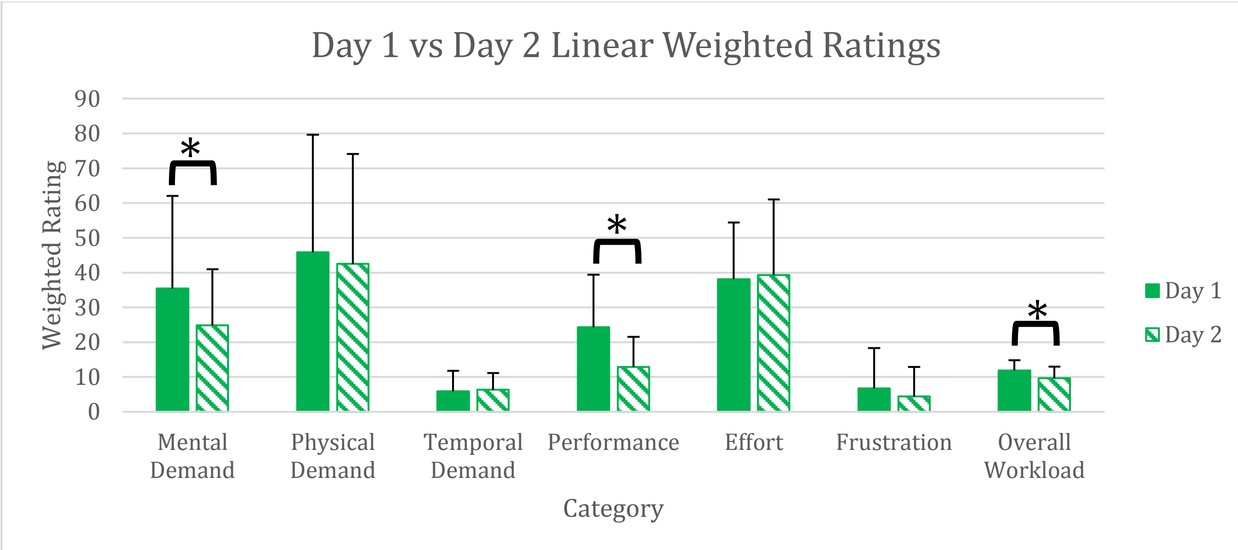

Figure 16: Average weighted ratings of NASA TLX for the linear algorithm on day 1 and day 2. Asterisk denotes statistical significance ($p < 0.05$).

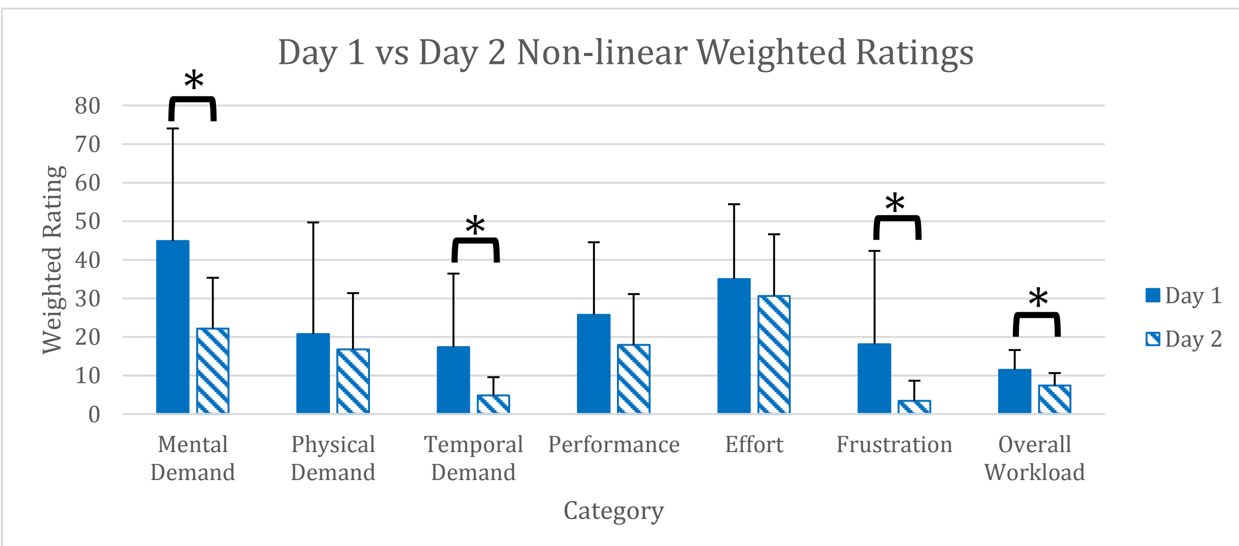

Figure 17: Average weighted ratings of NASA TLX for the non-linear algorithm on day 1 and day 2. Asterisk denotes statistical significance ($p < 0.05$).

3.3 Time and Error: Day 2 only

Since there was a significant difference for each algorithm between day 1 and day 2, only data from day 2 was analyzed to determine if there was a difference between the three algorithms. Figure 18 below shows the average course completion time per trial for day 2. The PNL time seems to have reached a plateau, but the PL and D times are still decreasing. There is a statistical significance ($p < 0.05$) between PNL and both PL and D, which is marked by an asterisk on the graph.

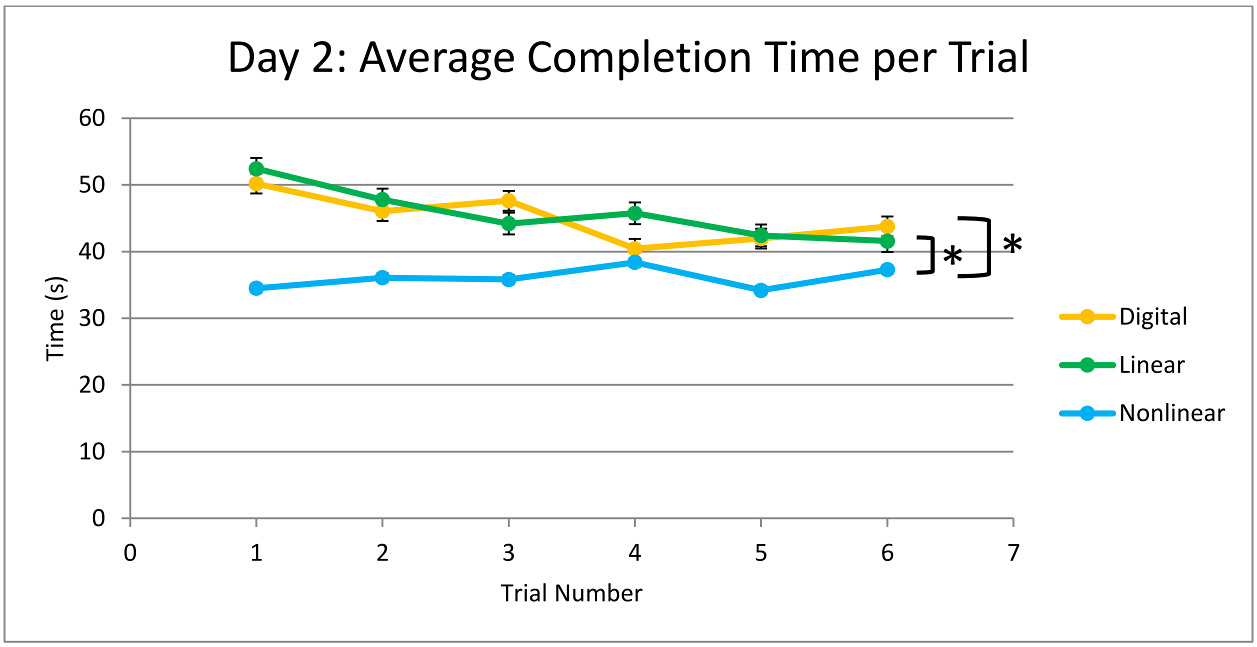

Figure 18: Average course completion time per trial on day 2 for all three algorithms. Asterisk denotes statistical significance ($p < 0.05$).

Figure 19 below shows the average total errors per trial for all three algorithms on day 2. None of these metrics appear to plateau within this timeframe. There is statistical significance ($p < 0.05$) between D and both PNL and PL, which is marked by an asterisk.

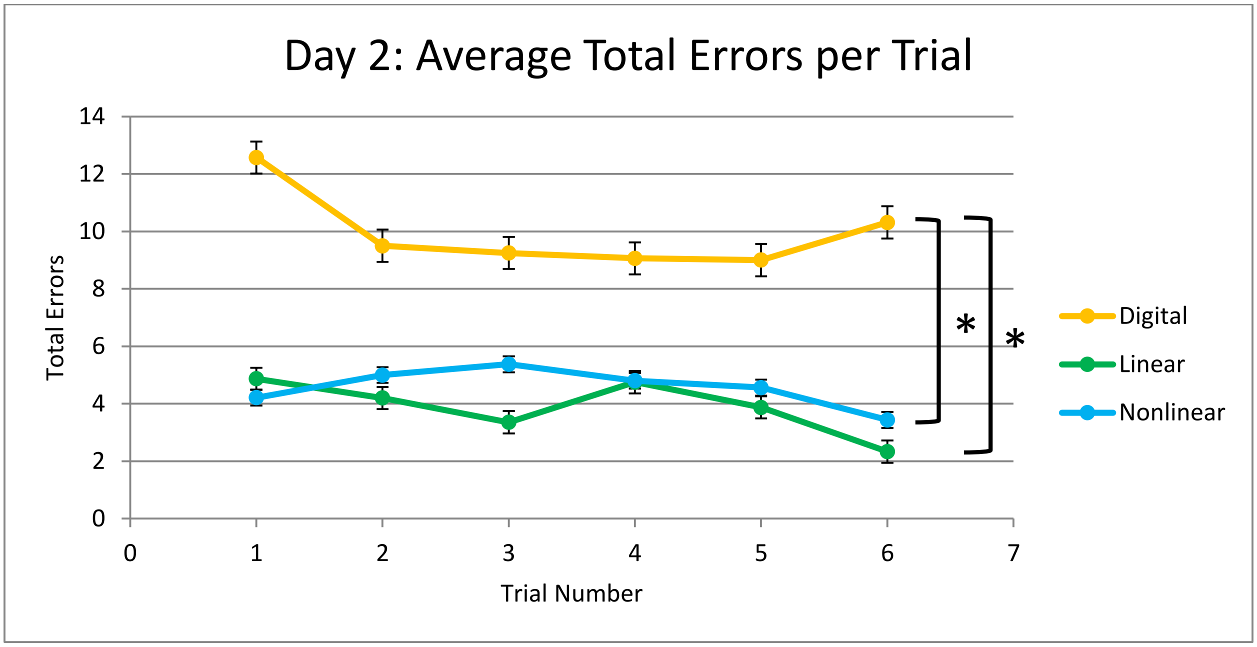

Figure 19: Average total errors per trial on day 2 for all three algorithms. Asterisk denotes statistical significance ($p < 0.05$).

3.4 NASA TLX: Day 2 only

Figure 20 shows the average weighted ratings on the NASA TLX for day 2. There is statistical significance ($p < 0.05$) between D and PNL for mental demand. The difference in physical demand was statistically significant ($p < 0.05$) between PL and both D and PNL. Performance showed statistical significance ($p < 0.05$) between D and PL. There was statistical significance ($p < 0.05$) between D and PNL when looking at frustration, with PNL having the lowest value. Overall workload showed a statistical significance ($p < 0.05$) between PNL and both D and PL.

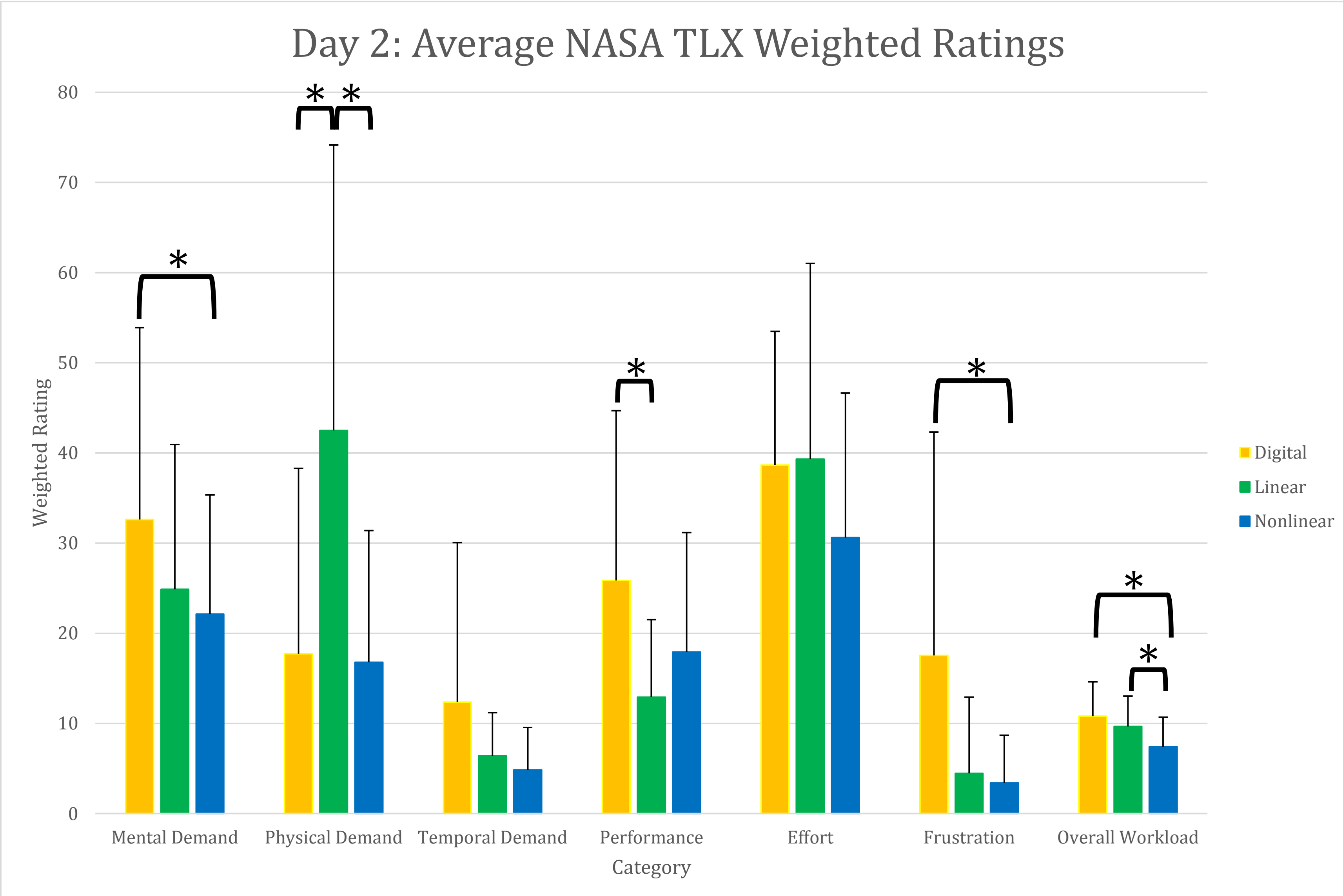

Figure 20: Average NASA TLX weighted ratings for all three algorithms on day 2. Asterisk denotes statistical significance ($p < 0.05$).

3.5 Regression Equations

A graphical regression analysis was done to determine how many days it would take a given measurement metric reach a stable value. Figure 21 shows the course completion time regression for each of the three algorithms. The red dashed line represents the fastest theoretical time the car could complete the course if it were to go in a straight line at its fastest speed. The purple, vertical dashed lines represent the beginning of a new day, which are spaced every seven trials. Note that PNL has the fastest completion time on day 1. D and PNL are the first algorithms to reach the fastest time possible for the course by the end of day 4. L reaches the fastest time possible about a day after D and PNL.

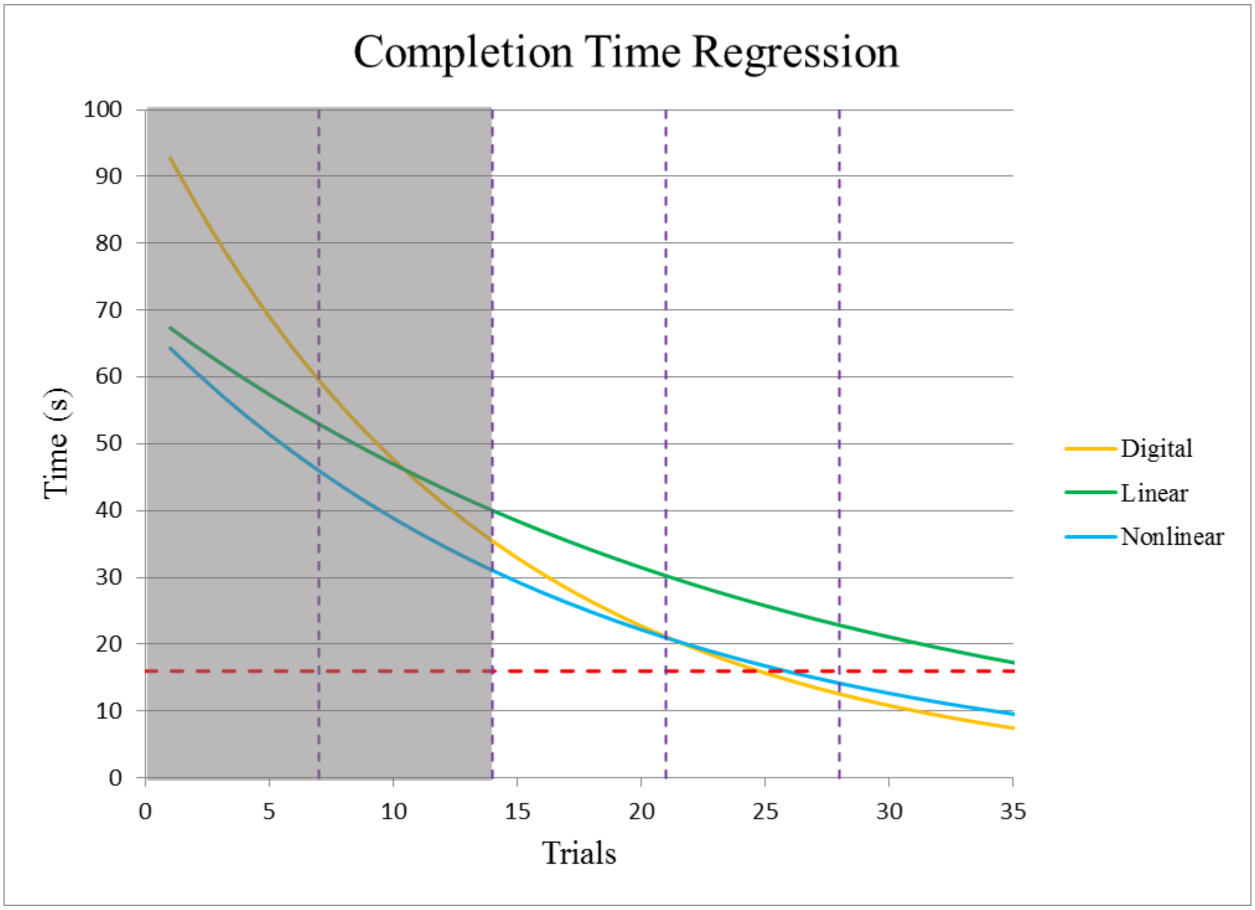

Figure 21: Regression graphs for completion time. The horizontal, red, dashed line represents the fastest theoretical completion time if the car were to travel in a straight line down the course. The purple, vertical dashed lines represent the beginning of a new day (every 7 trials).

Figure 22 shows the total errors regression for each of the three algorithms. Note that both PL and PNL start out around the same value on day 1 and D starts at a much higher value. All three algorithms eventually converge to no errors, but PL is the first to reach it by the end of day 6. However, the pattern stays consistent throughout the plot, with PL improving slightly faster than PNL and D trailing behind both of them.

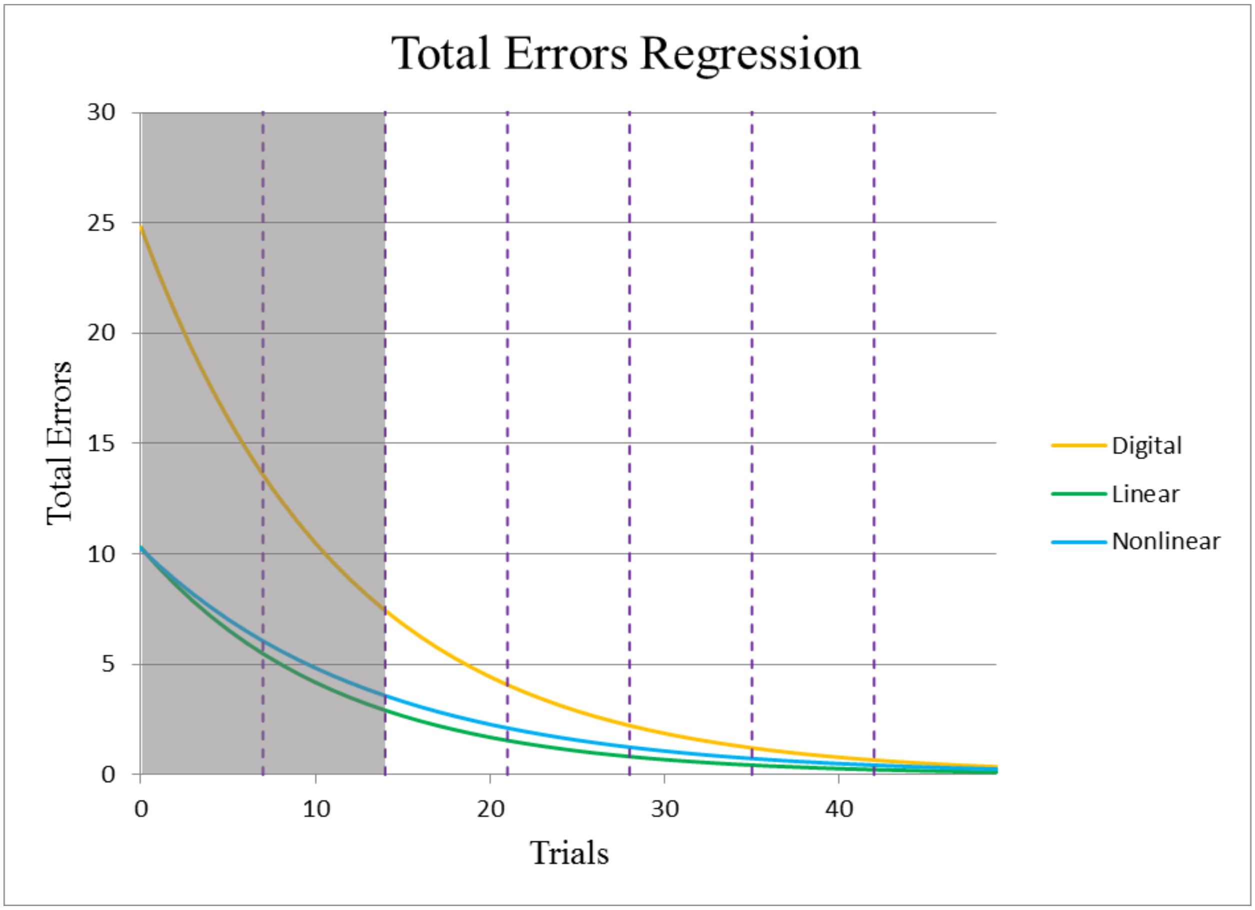

Figure 22: Regression graphs for total errors. The purple, vertical dashed lines represent the beginning of a new day (every 7 trials).

Figure 23 below shows the overall workload regression for each of the three algorithms. Note that the x-axis is labeled represented as days and not trials. Since a modified NASA TLX survey was used, 1 was the lowest possible number that could be obtained for overall workload. This is represented by the horizontal, red, dashed line and will be referred to as “zero overall workload.” Although PNL starts out with the highest overall workload on day 1, it dramatically decreases and is the first algorithm to reach zero overall workload. D and PL do not reach zero overall workload until much later than PNL.

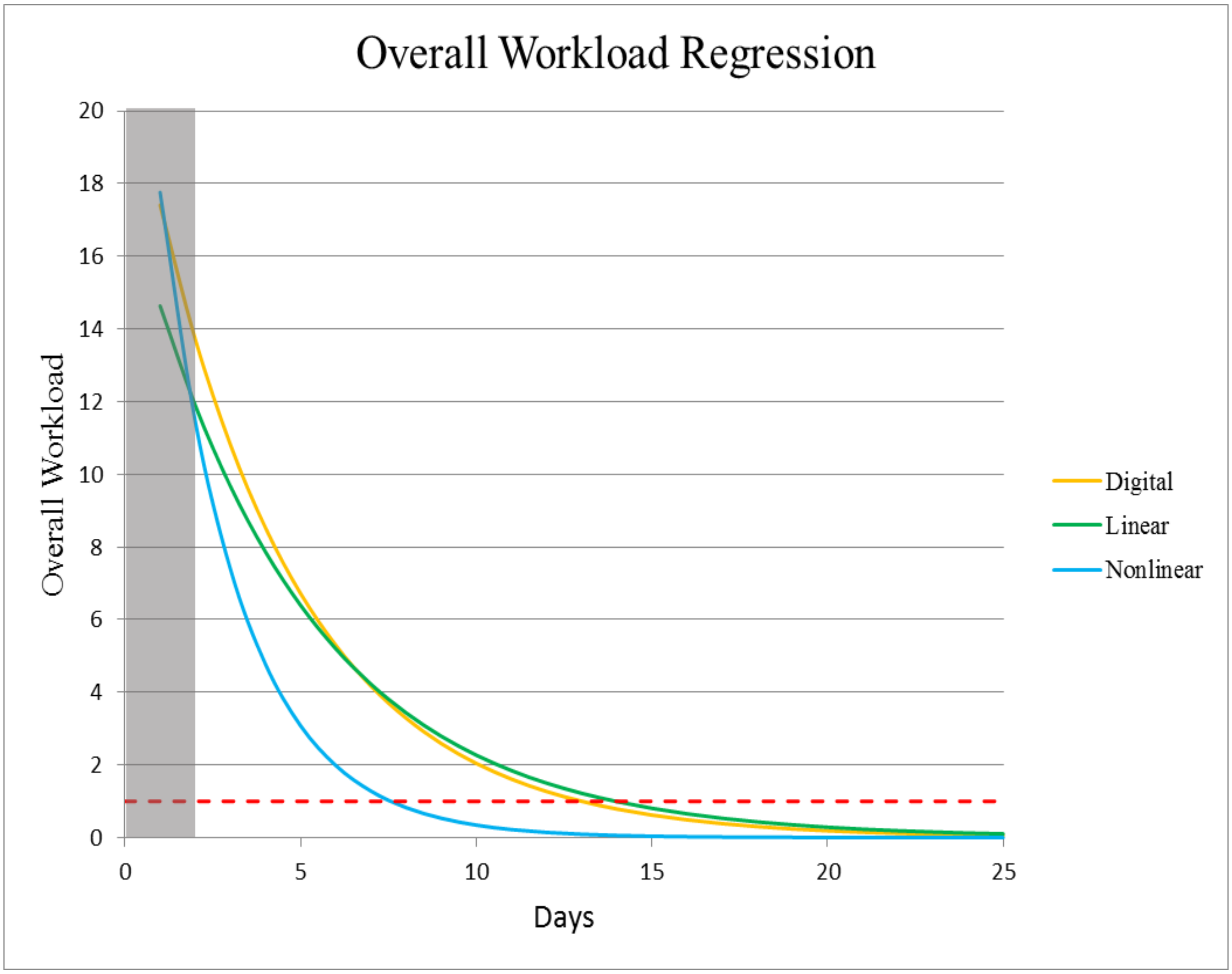

Figure 23: Regression graphs for overall workload. Note the x-axis is in days and not trials.

3.6 Learning: Time vs. Total Errors Correlation

To further evaluate the performance of each subject, it was assumed that if the subject truly learned the full capabilities of each control algorithm, they would commit the least amount of errors during their fastest completion times and commit the largest number of errors during their slowest completion times (3). Regression lines were calculated for each subject based on the correlation of time and total errors for each control algorithm on day 2. Based on the average slope of the regression lines, subjects were split into two groups. If a subject had an above average slope for all three control algorithms, they were classified as a high-capacity learner. If a subject had a below average slope for all three control algorithms, they were classified as a low-capacity learner (3). Figure 24 illustrates a hypothetical example of both a high-capacity and low-capacity learner using the same control algorithm.

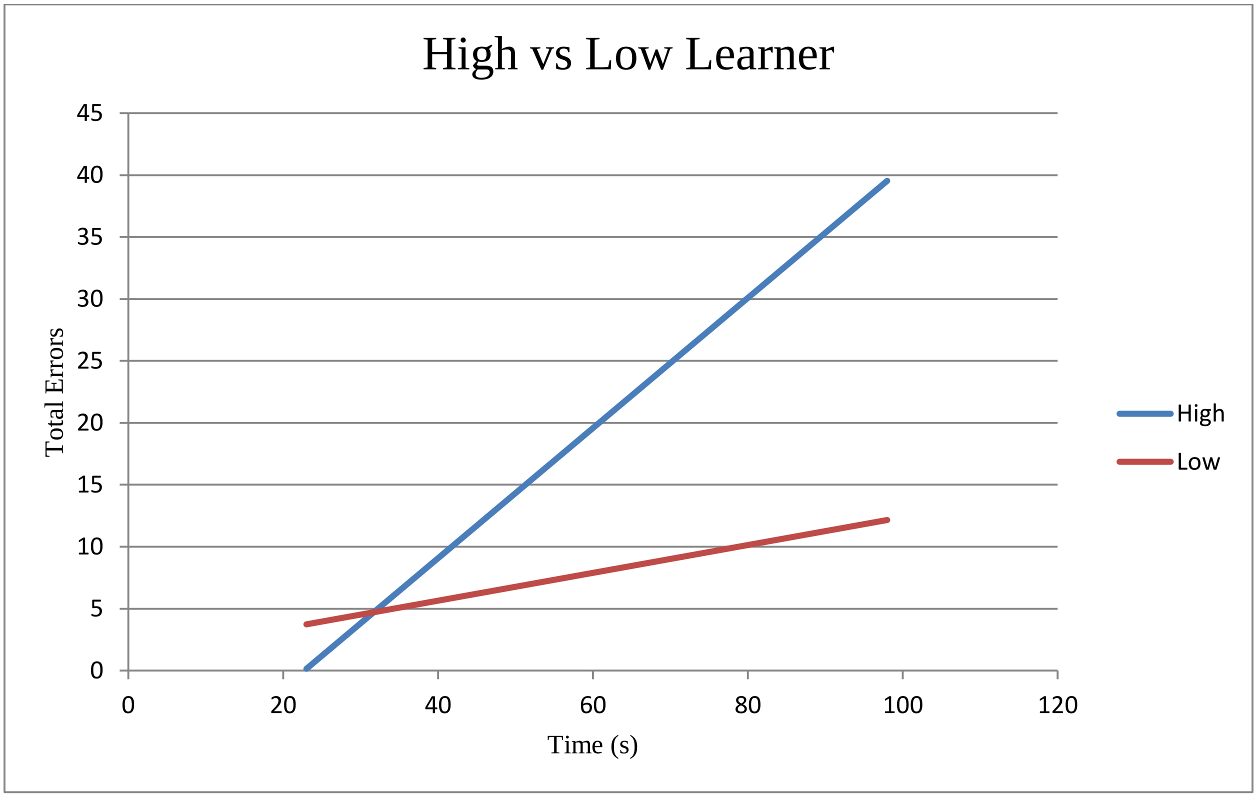

Figure 24: High-capacity learner vs. low-capacity learner. Note that the high-capacity learner has a steeper slope than the low-capacity learner.

High Learners

Figures 25-27 show the time vs. total error correlation graphs of high capacity learners performing with all three control algorithms. Note that D has the steepest slope of the three algorithms. However, of the two proportional control algorithms, PNL has the steepest slope.

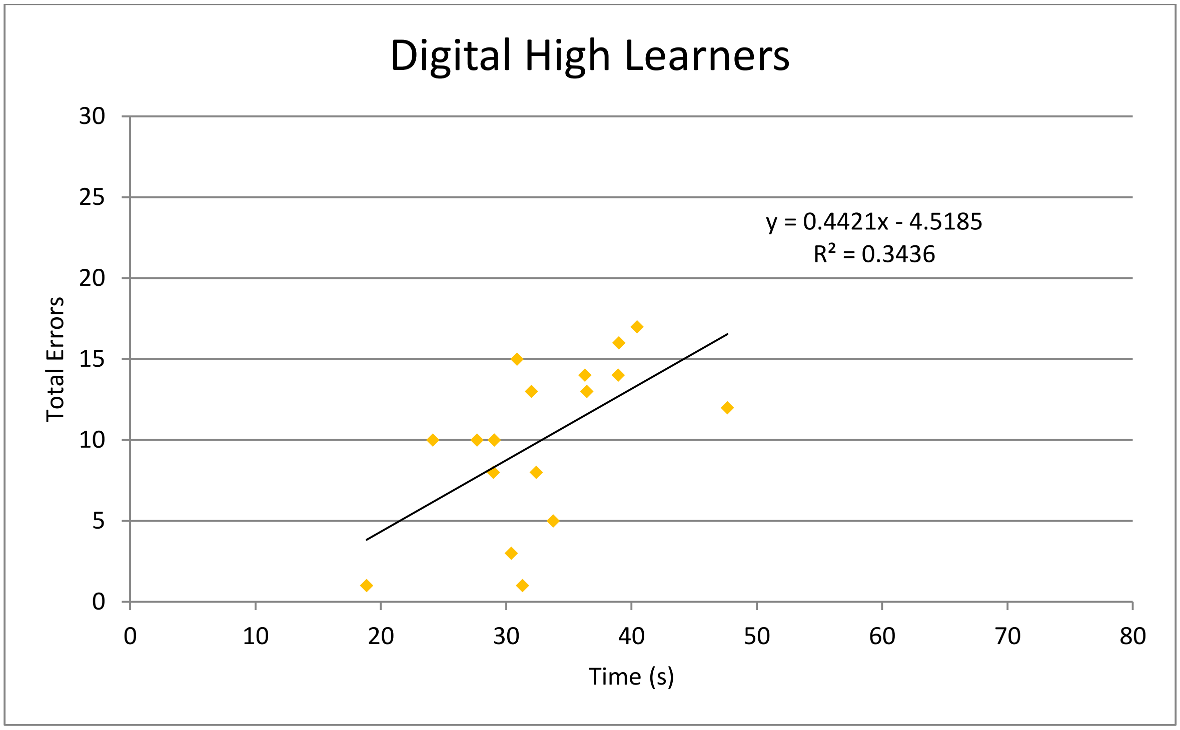

Figure 25: Time vs. Total Errors correlation for high-capacity learners with the digital control algorithm.

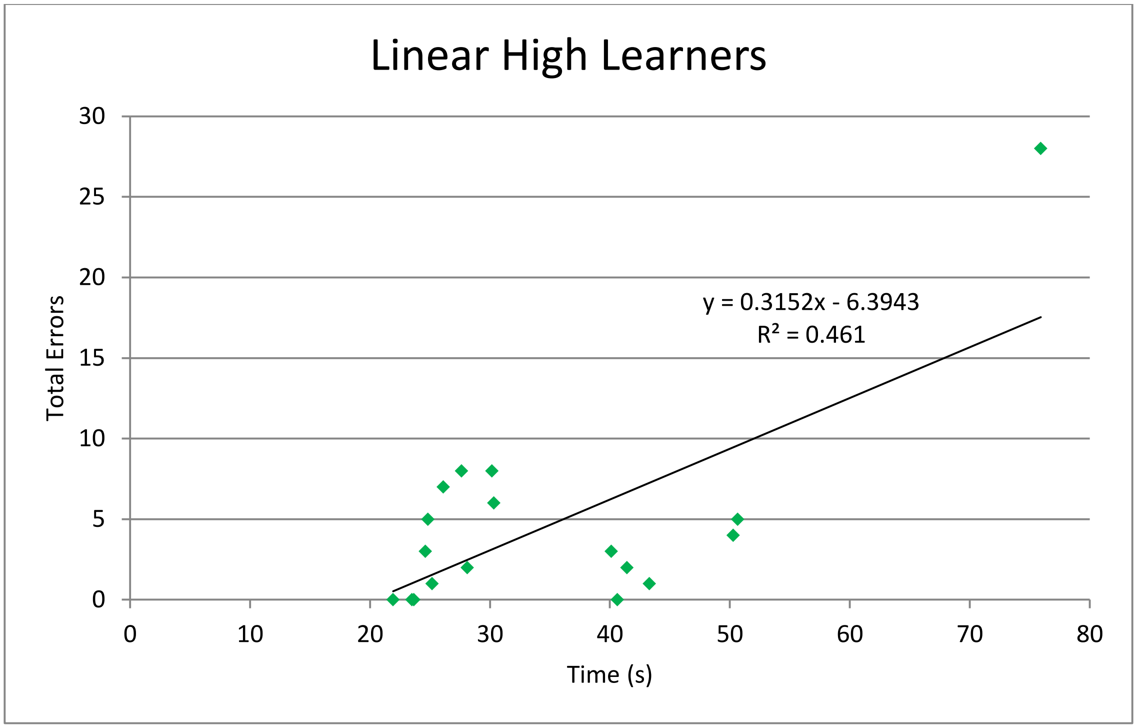

Figure 26: Time vs. Total Errors correlation for high capacity learners with the linear control algorithm.

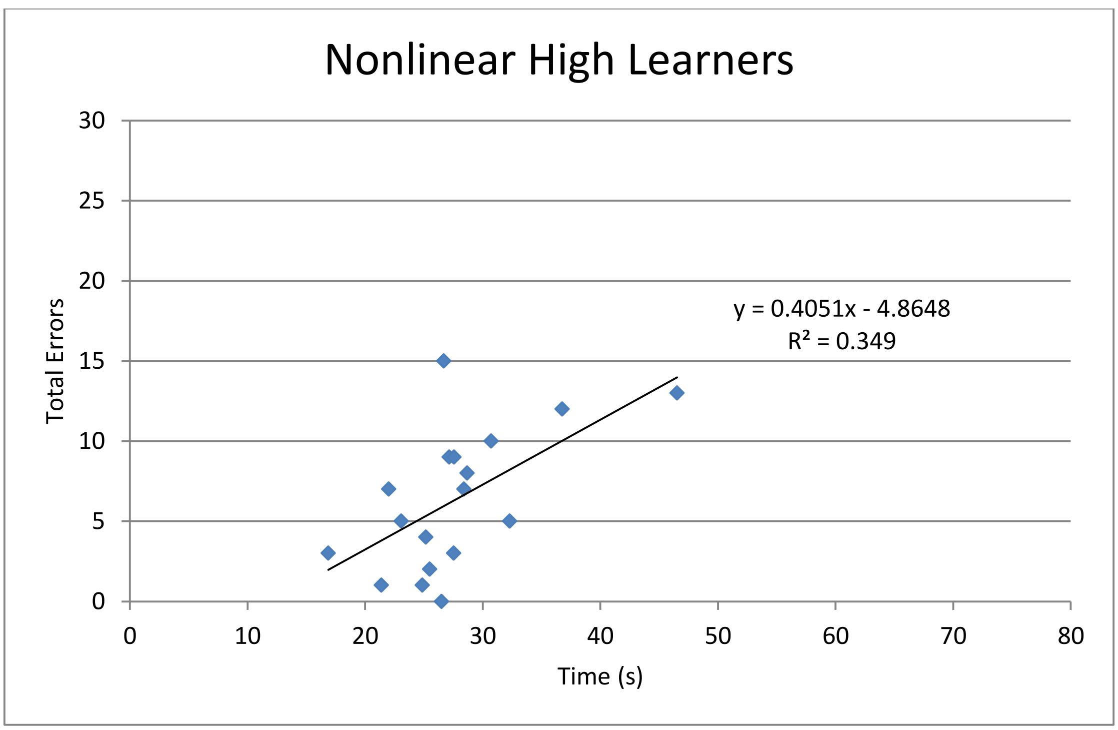

Figure 27: Time vs. Total Errors correlation for high capacity learners with the non-linear control algorithm.

Low Learners

Figures 28-30 show the time vs. total error correlation graphs of high capacity learners in all three control algorithms. Note that PL has the steepest slope and PNL has the flattest slope out of the three algorithms.

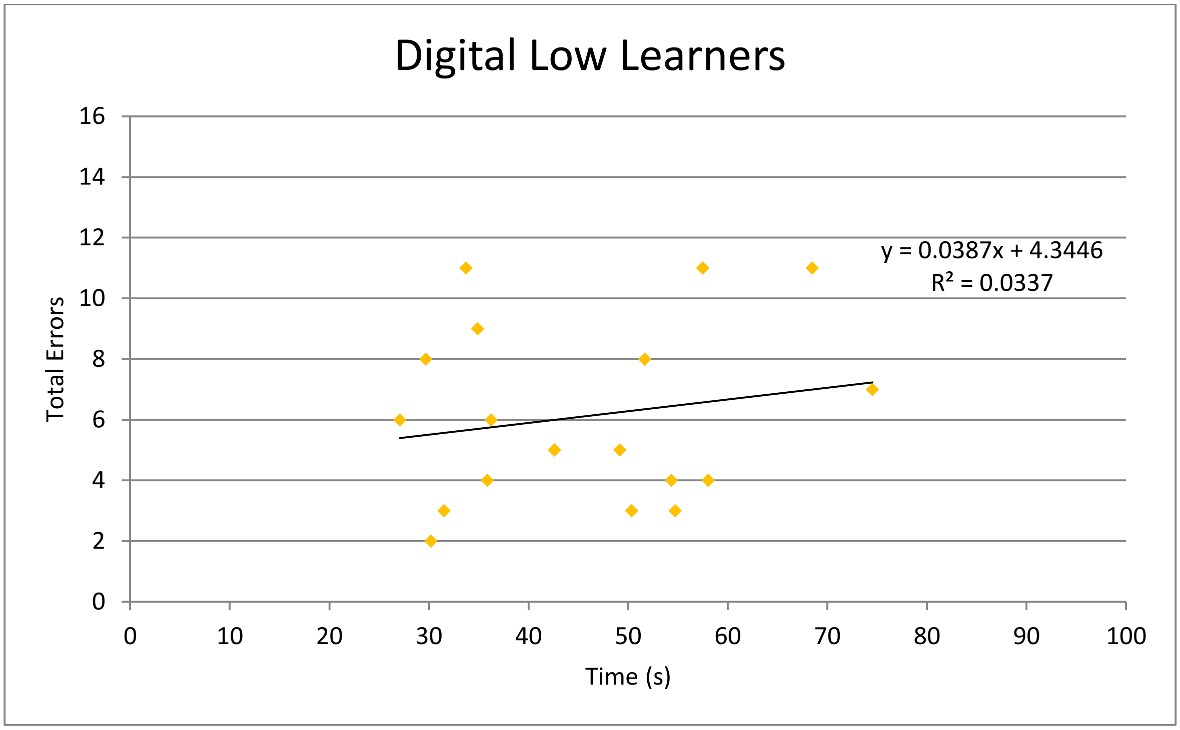

Figure 28: Time vs. Total Errors correlation for low capacity learners with the digital control algorithm.

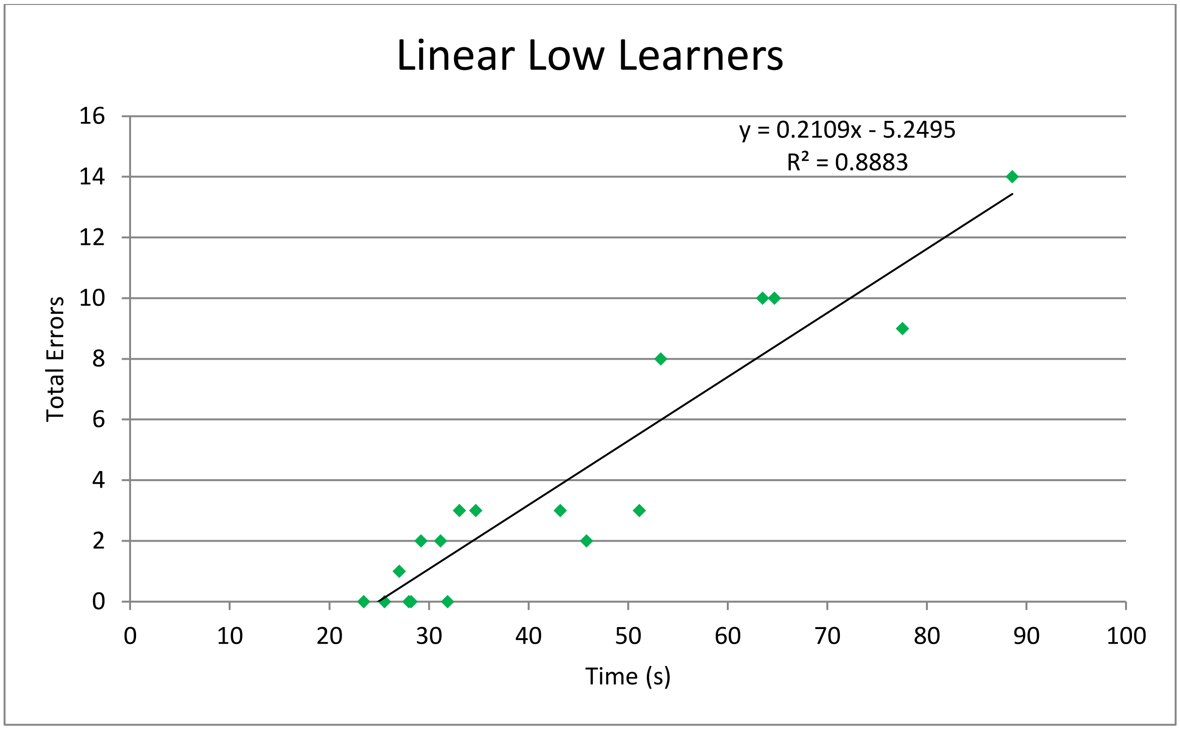

Figure 29: Time vs. Total Errors correlation for low capacity learners with the linear control algorithm.

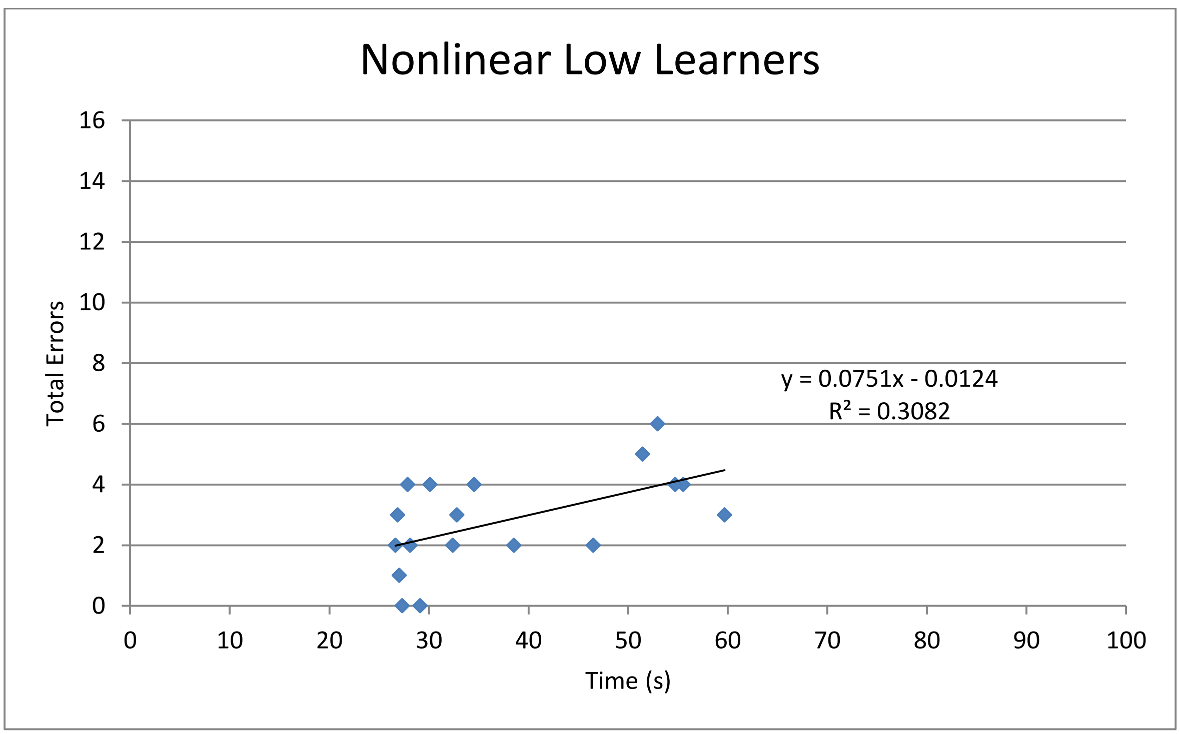

Figure 30: Time vs. Total Errors correlation for low capacity learners with the non-linear control algorithm.

Chapter 4: Discussion

The overall goal of this research was to investigate the performance of three different man-machine interface algorithms linking EMG to external device control. These algorithms range from the simple on/off control strategy (D) to a more complex non-linear proportional (PNL) control that mimics the physiological relationship that exists between muscle electrical potential and muscle force generation. Each algorithm was introduced to subjects over the course of two days in a randomized fashion. Subjects were given adequate time to train and then tested by measuring time to task completion and errors during task performance. Psychometrics were also assessed using the NASA TLX to assess perceptions of mental demand, physical demand, frustration level, and overall workload. Three hypotheses were tested. Each is listed and discussed below.

4.1 Hypothesis 1

"Hypothesis 1: A man-machine control interface that more closely mimics the EMG-muscle force generation relationship will provide more robust control."

Course completion time and total errors for all three algorithms had statistically significant differences when comparing day 1 results with day 2 results (Figures 12 and 13). This demonstrates subject learning. The smaller variances from day 1 to day 2 showed that the subjects were becoming more consistent with how long it took them to finish and the amount of errors they made, which is also indicative learning. Further evidence of learning is demonstrated by the large average time and error differences per day (Figure 14). D had the largest percent decrease for both time and errors, while PL had the lowest percent decrease in time and PNL the lowest percent decrease in errors. Therefore, day 1 was considered training and it was assumed that subjects were fully trained on day 2. All subsequent analysis was performed on day 2 data only.

On day 2, PNL had a significantly faster time than D and PL (Figure 18) demonstrating that subjects were able to complete the course fastest using PNL. When looking at total errors, PL and PNL had a significantly lower amount of errors than D (Figure 19). This demonstrates that subjects were able to complete the course more accurately with PL and PNL. Although PL has a fewer amount of errors than PNL, the result is not statistically significant. The oscillatory shape that can be seen by PNL and PL in both time and errors can be attributed to overconfidence. Subjects performed well in the beginning and then stated they became overconfident, resulting in a spike of time and errors before continuing the decreasing trend. This artifact has been documented in similar research (3). The hypothesis was proven correct by the results, which demonstrated that D performed the worst compared to PL and PNL.

4.2 Hypothesis 2

"Hypothesis 2: A man-machine control interface that more closely mimics the EMG-muscle force generation relationship will appear more natural, have the quickest acclimation time, result in the least frustration, and have the least overall workload for the user."

Evidence of learning was supported when comparing the NASA TLX data between day 1 and day 2 (Figures 15-17). The test elements assessing Overall Workload and Mental Demand showed a statistically significant difference between all three algorithms when comparing results from day 1 to day 2. This suggests that on day 2, all three algorithms were easier to use overall and required lower cognitive demand. PL showed a significant difference in performance from day 1 to day 2, demonstrating subjects felt they performed better on day 2 than on day 1. PNL had a significant difference in temporal demand and frustration, meaning subjects felt less rushed and less irritated/annoyed on day 2 than on day 1.

Day 2 NASA TLX data (Figure 20) revealed subjects felt the D algorithm was the most mentally demanding and frustrating out of the three. These results were also shown to be significantly higher than PNL. This meant they felt D required the most thinking. PL demonstrated a significantly higher physical demand than both D and PNL, indicating subjects felt PL required them to flex and extend their hardest, when compared to D and PNL. PNL had a significantly lower overall workload than D and PL. Subjects felt PNL required the least amount of work to control.

When looking at the average times and total errors per trial for both days (Figures 12 and 13), it can be seen that there is no clear plateau for any of the algorithms. All still show decreasing trends towards the end of day 2, indicating that the subjects were still learning and suggesting that they were not yet fully trained. If the subjects were to continue for multiple days, the average time and total errors per trial would be expected to eventually level out for each algorithm. This would likely affect overall workload for each algorithm and cause it to decrease over time as well. Learning is defined as an exponential improvement in metrics. A regression analysis was performed to determine how many days it would take for the subjects to reach the minimum value possible using each algorithm for average course completion time, average total errors, and average overall workload (Figures 21-23). By definition, the steepness of the negative slope indicates how fast the subjects were learning with that algorithm.

D had the largest negative slope out of all three algorithms, indicating subjects learned fastest with this algorithm. However, this assessment may be biased since D also began with the highest values out of the three algorithms in all categories. The regression graphs demonstrated that multiple days were required for all three algorithms to reach the minimum values possible in each category. A minimum of five days would be required for all three algorithms to reach the fastest completion time possible for the course, six to seven days for total errors to reach zero, and about 14 days for overall workload to reach the absolute minimum.

Although it appears that it would take multiple days for the three algorithms to converge to the same minimum value, the rank order of the algorithms does not change from the day 1 assessment to the final plateau day when looking at performance. PNL begins with the lowest average course completion time and, along with D, is the first to reach the fastest time to complete the course, with PL finishing about a day later. PL begins with the lowest value on day 1, with PNL beginning at about the same value. PL is the first equation to reach zero total errors, with PNL and D reaching the same value 1-2 days later. When looking at overall workload, PNL is the first equation to reach the minimum value. Although the data obtained did not reach a plateau, the regression analysis validates the primary objective of determining if there's a difference between the three equations. From this, it was concluded that the hypothesis was confirmed. PNL, which more closely matches the EMG-muscle force generation relationship, had the least amount of frustration and overall workload compared to D and PL. It also had the quickest acclimation time in terms of average course completion time as well as overall workload.

4.3 Hypothesis 3

"Hypothesis 3: Subject capacity to learn, as elucidated by errors committed per unit time, will impact which control algorithm will produce the best results."

When looking at learning capacity (Figures 25-30), all three control algorithms had steeper regression slopes for high-capacity learners than low-capacity learners, indicating that high-capacity learners were able to learn faster than low-capacity learners. The steeper regression slope of D for high-capacity learners (Figures 25-27), demonstrated they were able to learn this control algorithm fastest out of the three. This is likely due to the fact they were able to realize this was an on/off type control algorithm and had no further capabilities. Out of the two proportional algorithms, PNL had the steepest regression slope indicating they learned how to take full advantage of the proportional capabilities of this control algorithm.

Low-capacity learners (Figures 28-30) had a faster learning rate with PL than the other two algorithms. It seems that low-capacity learners weren't able to fully learn how to operate the D and PNL control algorithms, unlike the high-capacity learners. One explanation for low-capacity learners being unable to operate D despite its relatively simple control activation is that D is not as physiologic as PL or PNL. PNL may model the EMG-muscle force relationship so well that low-capacity learners weren't challenged enough and weren't as actively engaged in the learning process. However, this doesn't mean that low-capacity can't learn the D and PNL algorithms, or that it was more difficult. Over time, subjects could indeed learn how to operate the D and PNL algorithms, but it would take longer than the two days used in this study. This proves hypothesis 3 correct since high-capacity learners and low-capacity learned faster with different control algorithms.

A training study found that some subjects were not able to fully "use the available options of the proportional control." The study went on to explain that if differences in learning capacity actually exist, this should be taken into account when determining the most appropriate control algorithm for a patient to increase the chances of acceptance. Their findings showed that a digital control algorithm may be more appropriate for those less proficient in myoelectric control (low-capacity learner) and a proportional algorithm would be more appropriate for high-capacity learners (3). Although the results in Figures 25-27 are in agreement with differences in learning capacity, the specific control algorithms suitable for each group are inconsistent with previous research.

4.4 Summary

Although subjects learned quickest with the D and PL algorithms, as seen by the steeper slopes in the correlation between time and errors (Figures 32-37), the NASA TLX data (Figure 27) shows that these two equations had significantly ($p < 0.05$) higher overall workloads than PNL. D was also significantly ($p < 0.05$) more frustrating and mentally demanding than PNL. PL was significantly ($p < 0.05$) more physically demanding than PNL. In context of application, despite the difference in learning capacity, PNL would be more suitable than D or PL because of the lower overall workload. It would be inappropriate to assign a control algorithm to a patient that would require a high physical demand, workload, or frustration level. This would likely deter the patient from using the prosthesis and cause them to reject it altogether.

4.5 Future Work

A potential application of this study is to test the algorithms using a prosthetic hand. It is clear that D had the poorest overall performance out of the three. However, the results showed that subjects perform better using a proportional algorithm. The next steps in this line of research could be to develop a prosthetic hand that is controlled by the PL and PNL algorithms and have subjects perform tasks, such as object manipulation, to further evaluate differences between the two proportional algorithms in a more real-world setting.

Chapter 5: Conclusion

The primary objective of this experiment was to evaluate differences between D, PL, and PNL control during the performance of a novel task. A training device was modified to have proportional control capabilities. Hypotheses were constructed and tested revealing that a man-machine control interface that more closely mimics the EMG-muscle force relationship provides more robust control and appears more natural despite a longer rate of learning. There was statistical difference between the two days of trials, indicating that subjects learned over time with all of the algorithms. Analysis of day 2 data demonstrated PNL to be significantly different in course completion time, being faster than D and PL. D was shown to be significantly different in terms of total errors, having the most out of the three. PNL showed lower values that were statistically significant in physical demand, frustration, and overall workload. A regression analysis showed that even though subjects would be able to eventually achieve the same performance for all three algorithms, they would reach peak performance faster with PNL. Although there may be differences in learning capacity, the lower cognitive load gives evidence that a PNL algorithm is most appropriate for myoelectric control in prosthetic hands. Further work needs to be done in order to determine the efficacy of both the proportional algorithms when it comes to functional tasks using a prosthetic limb. In conclusion, there were differences found between the three control algorithms. A D equation does not match the EMG-force relationship of muscle and results in a higher mental demand and frustration for the user. Although PNL requires more time to fully learn, it has a significantly lower physical demand and overall workload than PL. Therefore, a PNL algorithm is more suitable for myoelectric control.

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Appendices

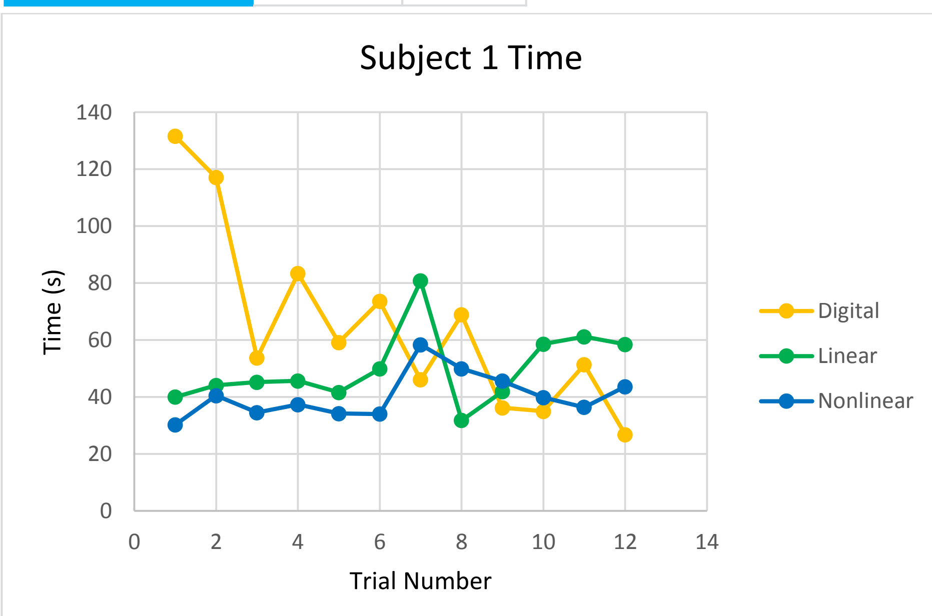
Appendix A

Individual Subject Time and Error Data

Subject 1							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
dig 1	2m 5.63s	125.63	22	9	2	33	131.63
dig 2	1m 45.09s	105.09	14	12	4	30	117.09
dig 3	0m 47.72s	47.72	8	9	2	19	53.72
dig 4	1m 11.40s	71.4	11	8	4	23	83.4
dig 5	0m 56.18s	56.18	8	6	1	15	59.18
dig 6	1m 7.60s	67.6	11	11	2	24	73.6
average		78.93667	12.33333	9.166667	2.5	24	86.43666667
lin 1	0m 40s	40	0	0	0	0	40
lin 2	0m 44.13s	44.13	0	0	0	0	44.13
lin 3	0m 45.22s	45.22	0	0	0	0	45.22
lin 4	0m 45.72s	45.72	0	0	0	0	45.72
lin 5	0m 41.62s	41.62	0	0	0	0	41.62
lin 6	0m 49.91	49.91	0	0	0	0	49.91
average		44.43333	0	0	0	0	44.43333333
non 1	0m 30.22s	30.22	0	1	0	1	30.22
non 2	0m 37.53s	37.53	0	0	1	1	40.53
non 3	0m 34.56s	34.56	0	0	0	0	34.56
non 4	0m 37.37s	37.37	0	0	0	0	37.37
non 5	0m 34.22s	34.22	0	0	0	0	34.22
non 6	0m 34.06s	34.06	0	0	0	0	34.06
average		34.66	0	0.166667	0.166667	0.33333333	35.16

Day2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
non 1	0m 58.41s	58.41	0	0	0	0	58.41
non 2	0m 49.97s	49.97	0	0	0	0	49.97
non 3	0m 45.62s	45.62	0	0	0	0	45.62
non 4	0m 39.84s	39.84	0	0	0	0	39.84
non 5	0m 36.44s	36.44	0	0	0	0	36.44
non 6	0m 43.66s	43.66	0	0	0	0	43.66
average		45.6567	0	0	0	0	45.65666667
lin 1	1m 20.78s	80.78	4	4	0	8	80.78
lin 2	0m 31.81s	31.81	0	0	0	0	31.81
lin 3	0m 41.94s	41.94	1	0	0	1	41.94
lin 4	0m 58.64s	58.64	4	4	0	8	58.64
lin 5	0m 55.19s	55.19	0	0	2	2	61.19
lin 6	0m 58.50s	58.5	0	0	0	0	58.5
average		54.4767	1.5	1.333333	0.3333333	3.16666667	55.47666667
dig 1	0m 40.09s	40.09	5	5	2	12	46.09
dig 2	1m 5.88s	65.88	13	11	1	25	68.88
dig 3	0m 27.28s	27.28	4	4	3	11	36.28
dig 4	0m 29s	29	5	6	2	13	35
dig 5	0m 42.37s	42.37	7	7	3	17	51.37
dig 6	0m 20.81s	20.81	2	3	2	7	26.81
average		37.5717	6	6	2.1666667	14.1666667	44.07166667

Total Averages	Time (s)	Errors
Digital	58.2541667	19.08333
Linear	49.455	1.583333
Nonlinear	40.1583333	0.166667

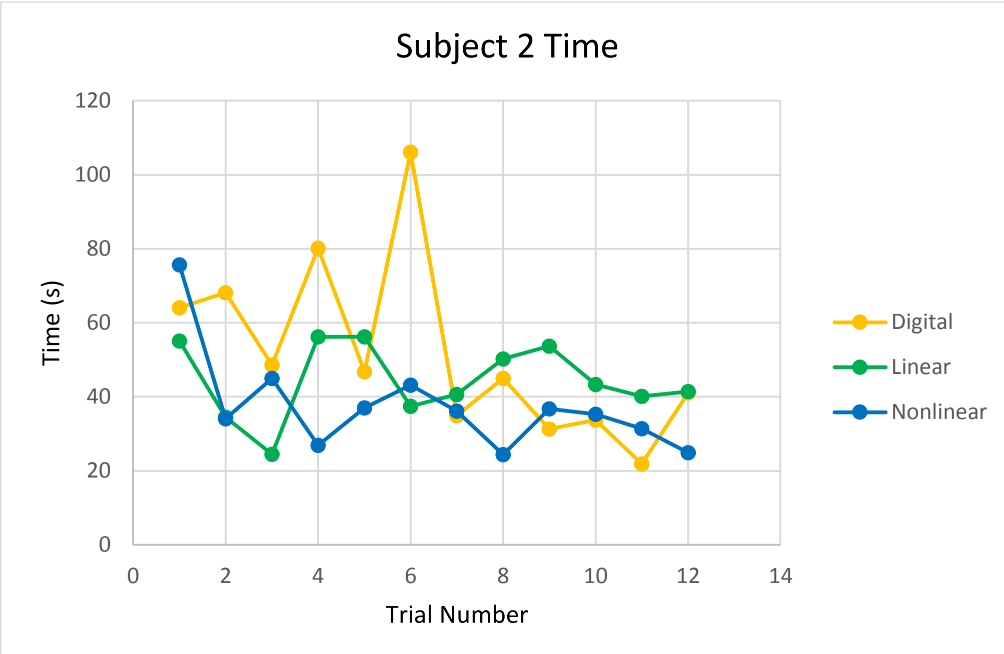


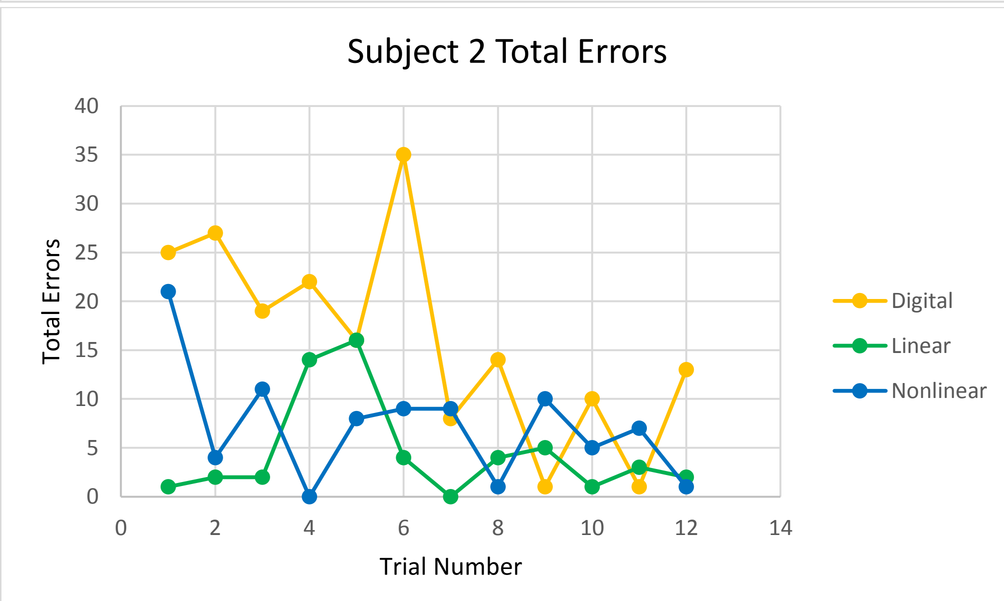
Subject 1 Total Errors
Total Errors
35
30
25
20
15
10
5
0
0
2
4
6
8
10
12
14
Trial Number
Digital
Linear
Nonlinear

Subject 2							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
lin 1	0m 55.08s	55.08	1	0	0	1	55.08
lin 2	0m 34.53s	34.53	1	1	0	2	34.53
lin 3	0m 21.43s	21.43	0	1	1	2	24.43
lin 4	0m 56.25s	56.25	8	6	0	14	56.25
lin 5	0m 50.22s	50.22	8	6	2	16	56.22
lin 6	0m 31.43s	31.43	1	1	2	4	37.43
average		41.49	3.166667	2.5	0.833333	6.5	43.99
dig 1	0m 55.04s	55.04	11	11	3	25	64.04
dig 2	0m 53.16s	53.16	18	4	5	27	68.16
dig 3	0m 42.56s	42.56	12	5	2	19	48.56
dig 4	1m 5.19s	65.19	11	6	5	22	80.19
dig 5	0m 43.80s	43.8	9	6	1	16	46.8
dig 6	1m 40.09s	100.09	22	11	2	35	106.09
average		59.97333	13.83333	7.166667	3	24	68.97333333
non 1	1m 6.69s	66.69	14	4	3	21	75.69
non 2	0m 28.07s	28.07	2	0	2	4	34.07
non 3	0m 32.97s	32.97	4	3	4	11	44.97
non 4	0m 26.88s	26.88	0	0	0	0	26.88
non 5	0m 28.03s	28.03	4	1	3	8	37.03
non 6	0m 34.19s	34.19	4	2	3	9	43.19
average		36.13833	4.666667	1.666667	2.5	8.83333333	43.63833333

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
non 1	0m 27.16s	27.16	3	3	3	9	36.16
non 2	0m 21.37s	21.37	0	0	1	1	24.37
non 3	0m 30.71s	30.71	4	4	2	10	36.71
non 4	0m 32.28s	32.28	3	1	1	5	35.28
non 5	0m 28.41s	28.41	3	3	1	7	31.41
non 6	0m 24.87s	24.87	0	1	0	1	24.87
average		27.4667	2.166666667	2	1.3333333	5.5	31.46666667
dig 1	0m 28.97s	28.97	4	2	2	8	34.97
dig 2	0m 38.94s	38.94	7	5	2	14	44.94
dig 3	0m 31.31s	31.31	1	0	0	1	31.31
dig 4	0m 27.69s	27.69	4	4	2	10	33.69
dig 5	0m 18.87s	18.87	0	0	1	1	21.87
dig 6	0m 32.03s	32.03	5	5	3	13	41.03
average		29.635	3.5	2.666667	1.6666667	7.83333333	34.635
lin 1	0m 40.62s	40.62	0	0	0	0	40.62
lin 2	0m 50.28s	50.28	4	0	0	4	50.28
lin 3	0m 50.66s	50.66	3	1	1	5	53.66
lin 4	0m 43.31s	43.31	1	0	0	1	43.31
lin 5	0m 40.13s	40.13	3	0	0	3	40.13
lin 6	0m 41.44s	41.44	2	0	0	2	41.44
average		44.4067	2.166666667	0.166667	0.1666667	2.5	44.90666667

Total Averages	Time (s)	Errors
Digital	44.8041667	15.91667
Linear	42.9483333	4.5
Nonlinear	31.8025	7.166667

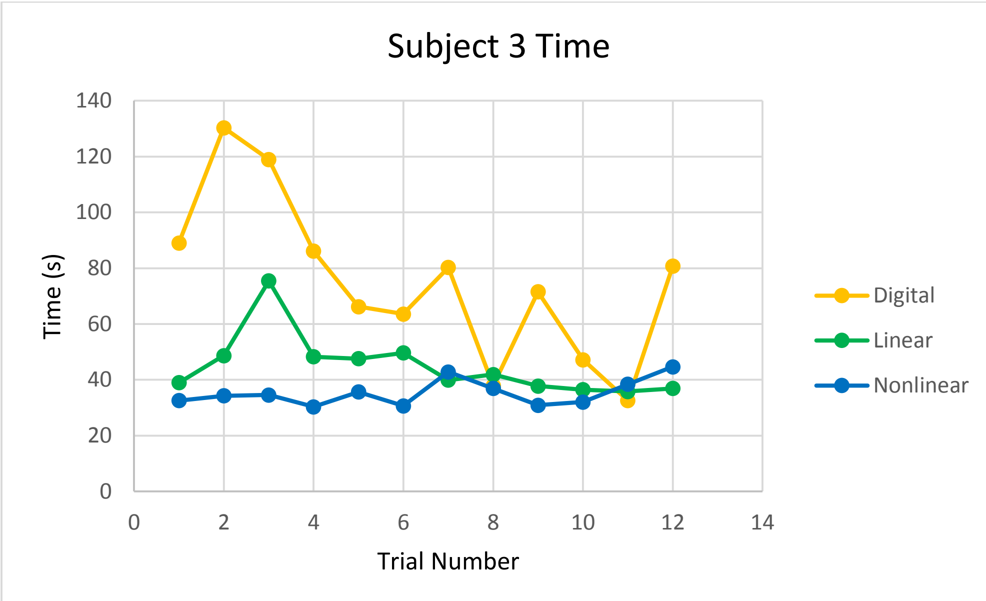


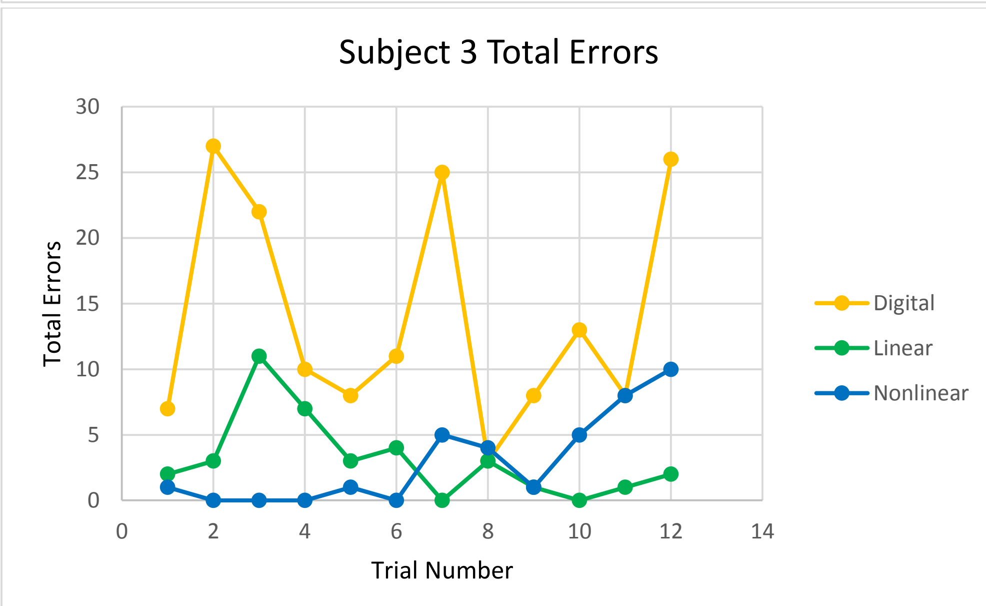


Subject 3							
Day1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
dig 1	1m 17.07s	77.07	2	1	4	7	89.07
dig 2	2m 10.34s	130.34	16	11	0	27	130.34
dig 3	1m 56s	116	14	7	1	22	119
dig 4	1m 23.09s	83.09	5	4	1	10	86.09
dig 5	1m 3.25s	63.25	4	3	1	8	66.25
dig 6	1m 0.56s	60.56	6	4	1	11	63.56
average		88.385	7.833333	5	1.333333	14.1666667	92.385
lin 1	0m 39s	39	1	1	0	2	39
lin 2	0m 45.65s	45.65	1	1	1	3	48.65
lin 3	1m 9.44s	69.44	8	1	2	11	75.44
lin 4	0m 48.28s	48.28	4	3	0	7	48.28
lin 5	0m 47.60s	47.6	2	1	0	3	47.6
lin 6	0m 46.66s	46.66	2	1	1	4	49.66
average		49.43833	3	1.333333	0.666667	5	51.43833333
non 1	0m 32.59s	32.59	0	1	0	1	32.59
non 2	0m 34.28s	34.28	0	0	0	0	34.28
non 3	0m 34.60s	34.6	0	0	0	0	34.6
non 4	0m 30.34s	30.34	0	0	0	0	30.34
non 5	0m 32.65s	32.65	0	0	1	1	35.65
non 6	0m 30.69s	30.69	0	0	0	0	30.69
average		32.525	0	0.166667	0.166667	0.33333333	33.025

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
lin 1	0m 39.88s	39.88	0	0	0	0	39.88
lin 2	0m 38.93s	38.93	1	1	1	3	41.93
lin 3	0m 34.81	34.81	0	0	1	1	37.81
lin 4	0m 36.46s	36.46	0	0	0	0	36.46
lin 5	0m 35.81s	35.81	1	0	0	1	35.81
lin 6	0m 36.91s	36.91	1	1	0	2	36.91
average		37.1333	0.5	0.333333	0.3333333	1.16666667	38.13333333
non 1	0m 36.82s	36.82	2	1	2	5	42.82
non 2	0m 30.94s	30.94	1	1	2	4	36.94
non 3	0m 27.90s	27.9	0	0	1	1	30.9
non 4	0m 29.07s	29.07	2	2	1	5	32.07
non 5	0m 32.41s	32.41	4	2	2	8	38.41
non 6	0m 41.66s	41.66	5	4	1	10	44.66
average		33.1333	2.333333333	1.666667	1.5	5.5	37.63333333
dig 1	1m 8.25s	68.25	11	10	4	25	80.25
dig 2	0m 34.88s	34.88	1	1	1	3	37.88
dig 3	1m 8.53s	68.53	5	2	1	8	71.53
dig 4	0m 41.19s	41.19	6	5	2	13	47.19
dig 5	0m 29.57s	29.57	3	4	1	8	32.57
dig 6	1m 8.72s	68.72	11	11	4	26	80.72
average		51.8567	6.166666667	5.5	2.1666667	13.8333333	58.35666667

Total Averages	Time (s)	Errors
Digital	70.1208333	14
Linear	43.2858333	3.083333
Nonlinear	32.8291667	2.916667

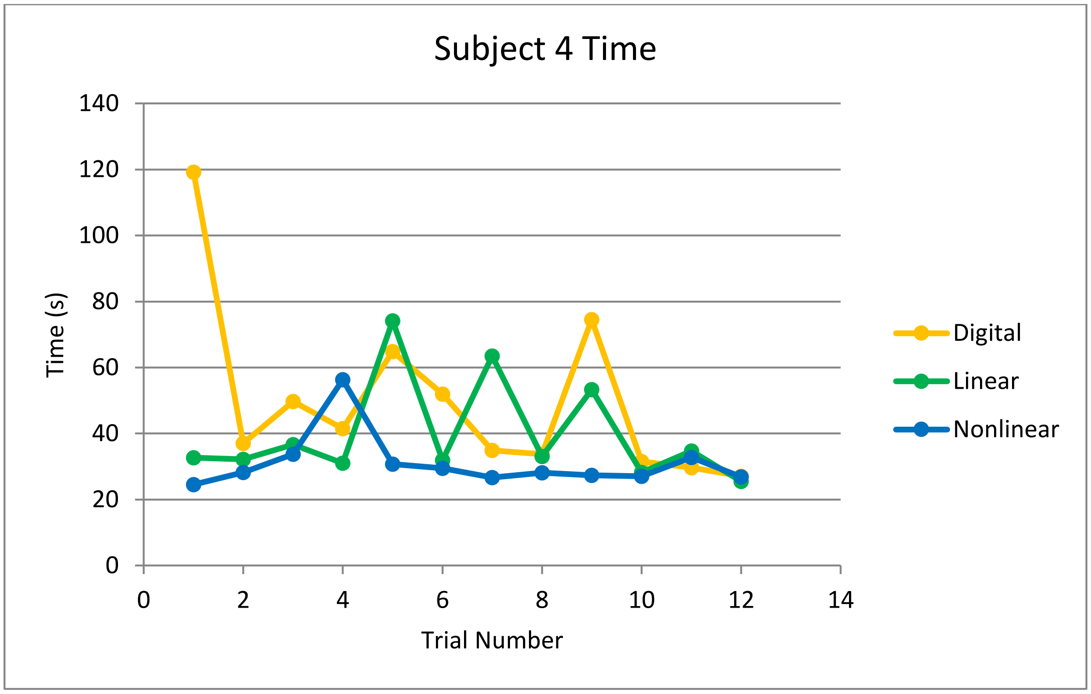


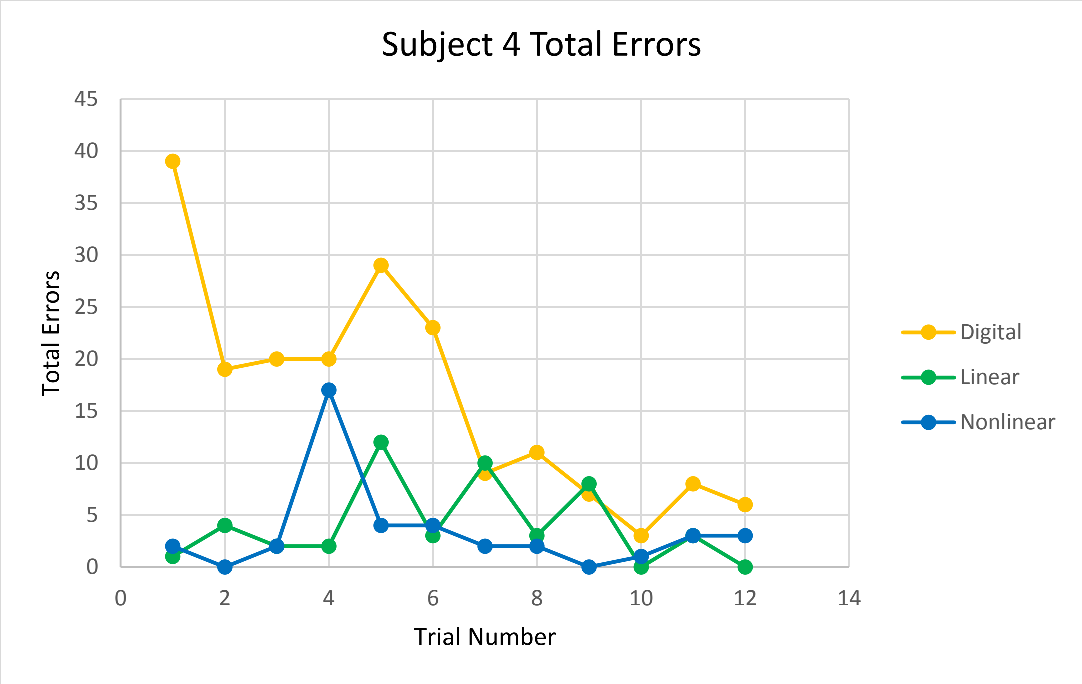


Subject 4							
Day1							
Trial	**Time (min)**	**Time (s)**	**Reversals**	**Hits**	**Cones**	**Total Errors**	**Final Time (s)**
dig 1	1 m 59.19 s	119.19	21	12	6	39	137.19
dig 2	0m 37.04s	37.04	7	6	6	19	55.04
dig 3	0m 49.68s	49.68	8	8	4	20	61.68
dig 4	0m 41.53s	41.53	8	5	7	20	62.53
dig 5	1m 4.87s	64.87	14	11	4	29	76.87
dig 6	0m 51.97s	51.97	9	9	5	23	66.97
average		60.71333	11.16667	8.5	5.333333	25	76.71333333
non 1	0m 24.56s	24.56	0	0	2	2	30.56
non 2	0m 28.19s	28.19	0	0	0	0	28.19
non 3	0m 33.72s	33.72	1	1	0	2	33.72
non 4	0m 56.34s	56.34	7	8	2	17	62.34
non 5	0m 30.75s	30.75	2	1	1	4	33.75
non 6	0m 29.43s	29.43	2	2	0	4	29.43
average		33.83167	2	2	0.833333	4.83333333	36.33166667
lin 1	0m 32.63s	32.63	0	0	1	1	35.63
lin 2	0m 32.16s	32.16	1	1	2	4	38.16
lin 3	0m 36.69s	36.69	1	1	0	2	36.69
lin 4	0m 31.07s	31.07	0	0	2	2	37.07
lin 5	1m 14.16s	74.16	7	2	3	12	83.16
lin 6	0m 31.88s	31.88	1	0	2	3	37.88
average		39.765	1.666667	0.666667	1.666667	4	44.765

Day 2							
Trial	**Time (min)**	**Time (s)**	**Reversals**	**Hits**	**Cones**	**Total Errors**	**Final Time (s)**
lin 1	1m 3.50s	63.5	6	3	1	10	66.5
lin 2	0m 33.06s	33.06	1	1	1	3	36.06
lin 3	0m 53.28s	53.28	5	2	1	8	56.28
lin 4	0m 28.22s	28.22	0	0	0	0	28.22
lin 5	0m 34.72s	34.72	2	0	1	3	37.72
lin 6	0m 25.54s	25.54	0	0	0	0	25.54
average		39.72	2.333333333	1	0.6666667	4	41.72
non 1	0m 26.65s	26.65	0	0	2	2	32.65
non 2	0m 28.13s	28.13	1	1	0	2	28.13
non 3	0m 27.31s	27.31	0	0	0	0	27.31
non 4	0m 27.03s	27.03	0	1	0	1	27.03
non 5	0m 32.81s	32.81	2	0	1	3	35.81
non 6	0m 26.87s	26.87	1	1	1	3	29.87
average		28.1333	0.666666667	0.5	0.6666667	1.83333333	30.13333333
dig 1	0m 34.90s	34.9	4	3	2	9	40.9
dig 2	0m 33.72s	33.72	4	4	3	11	42.72
dig 3	1m 14.53s	74.53	4	3	0	7	74.53
dig 4	0m 31.53s	31.53	1	1	1	3	34.53
dig 5	0m 29.69s	29.69	3	4	1	8	32.69
dig 6	0m 27.10s	27.1	1	3	2	6	33.1
average		38.5783	2.833333333	3	1.5	7.33333333	43.07833333

Total Averages	Time (s)	Errors
Digital	49.6458333	16.16667
Linear	39.7425	4
Nonlinear	30.9825	3.333333

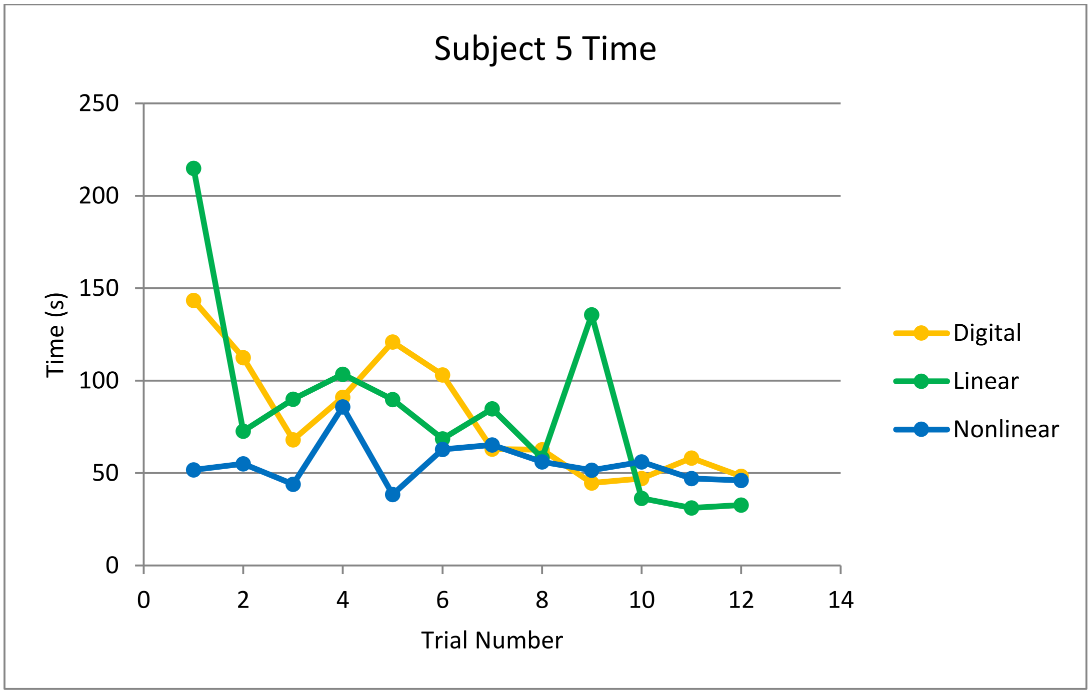


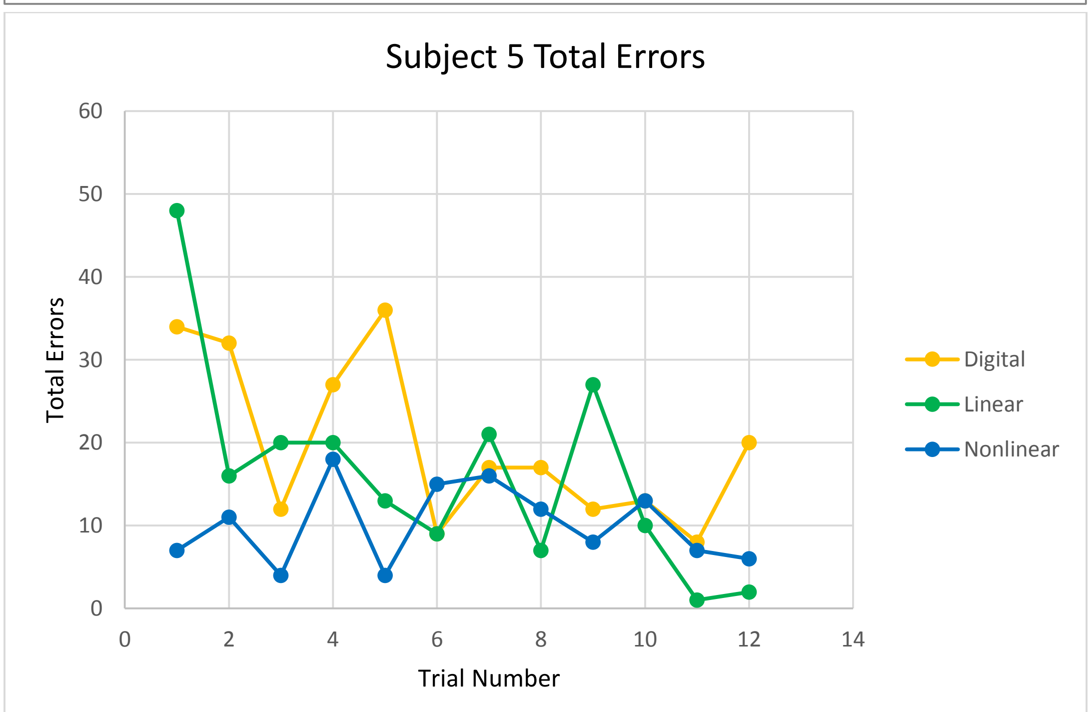


Subject 5							
Day1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
lin 1	3m 34.90s	214.9	25	22	1	48	217.9
lin 2	1m 12.63s	72.63	8	8	0	16	72.63
lin 3	1m 30s	90	11	7	2	20	96
lin 4	1m 43.53s	103.53	12	7	1	20	106.53
lin 5	1m 29.75s	89.75	10	2	1	13	92.75
lin 6	1m 8.53s	68.53	5	3	1	9	71.53
average		106.5567	11.83333	8.166667	1	21	109.5566667
dig 1	2m 23.50s	143.5	17	15	2	34	149.5
dig 2	1m 52.54s	112.54	16	15	1	32	115.54
dig 3	1m 7.97s	67.97	6	4	2	12	73.97
dig 4	1m 30.97s	90.97	15	11	1	27	93.97
dig 5	2m 1s	121	18	15	3	36	130
dig 6	1m 43.10s	103.1	6	1	2	9	109.1
average		106.5133	13	10.16667	1.833333	25	112.0133333
non 1	0m 51.79s	51.79	4	2	1	7	54.79
non 2	0m 55.07s	55.07	7	4	0	11	55.07
non 3	0m 43.93s	43.93	2	2	0	4	43.93
non 4	1m 25.87s	85.87	11	5	2	18	91.87
non 5	0m 38.44s	38.44	2	1	1	4	41.44
non 6	1m 2.78s	62.78	9	5	1	15	65.78
average		56.31333	5.833333	3.166667	0.833333	9.83333333	58.81333333

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
non 1	1m 5.18s	65.18	8	7	1	16	68.18
non 2	0m 56.09s	56.09	7	5	0	12	56.09
non 3	0m 51.59s	51.59	6	2	0	8	51.59
non 4	0m 56.09s	56.09	7	4	2	13	62.09
non 5	0m 47.10s	47.1	4	3	0	7	47.1
non 6	0m 46.06s	46.06	5	1	0	6	46.06
average		53.685	6.166666667	3.666667	0.5	10.3333333	55.185
dig 1	1m 3.03s	63.03	11	4	2	17	69.03
dig 2	1m 2.65s	62.65	8	6	3	17	71.65
dig 3	0m 44.60s	44.6	7	5	0	12	44.6
dig 4	0m 47.09s	47.09	6	2	5	13	62.09
dig 5	0m 58.18s	58.18	7	1	0	8	58.18
dig 6	0m 48.31s	48.31	8	8	4	20	60.31
average		53.9767	7.833333333	4.333333	2.3333333	14.5	60.97666667
lin 1	1m 24.88s	84.88	12	8	1	21	87.88
lin 2	0m 58.22s	58.22	4	2	1	7	61.22
lin 3	2m 15.63s	135.63	19	4	4	27	147.63
lin 4	0m 36.31s	36.31	4	5	1	10	39.31
lin 5	0m 31.19s	31.19	1	0	0	1	31.19
lin 6	0m 32.69s	32.69	2	0	0	2	32.69
average		63.1533	7	3.166667	1.1666667	11.3333333	66.65333333

Total Averages	Time (s)	Errors
Digital	80.245	19.75
Linear	84.855	16.16667
Nonlinear	54.9991667	10.08333

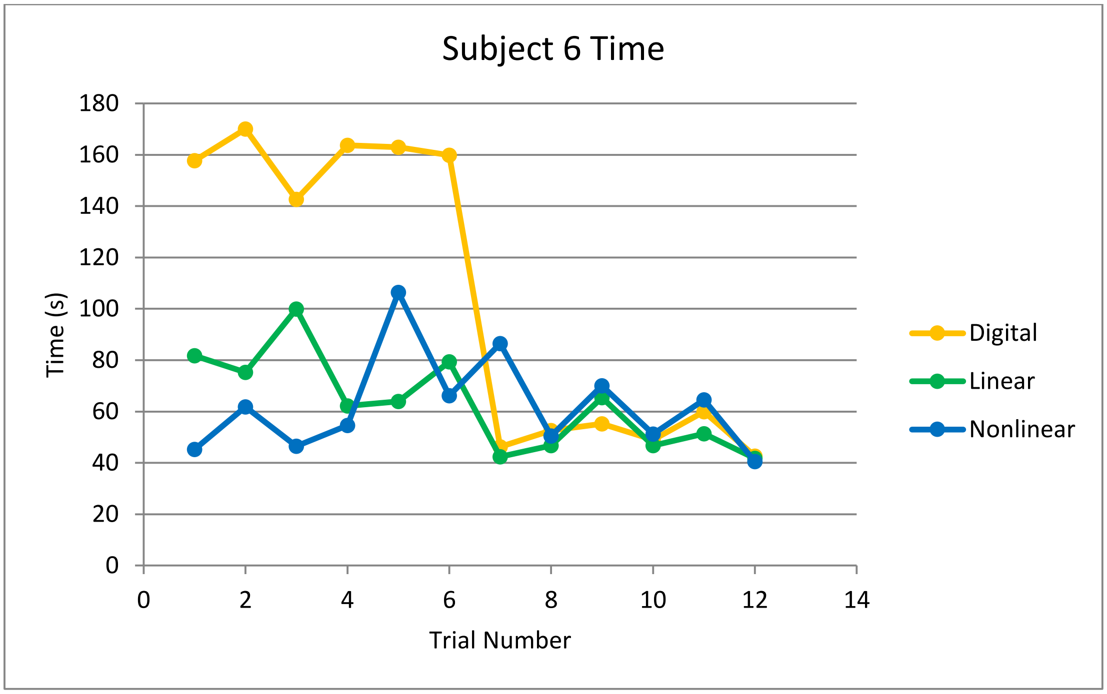


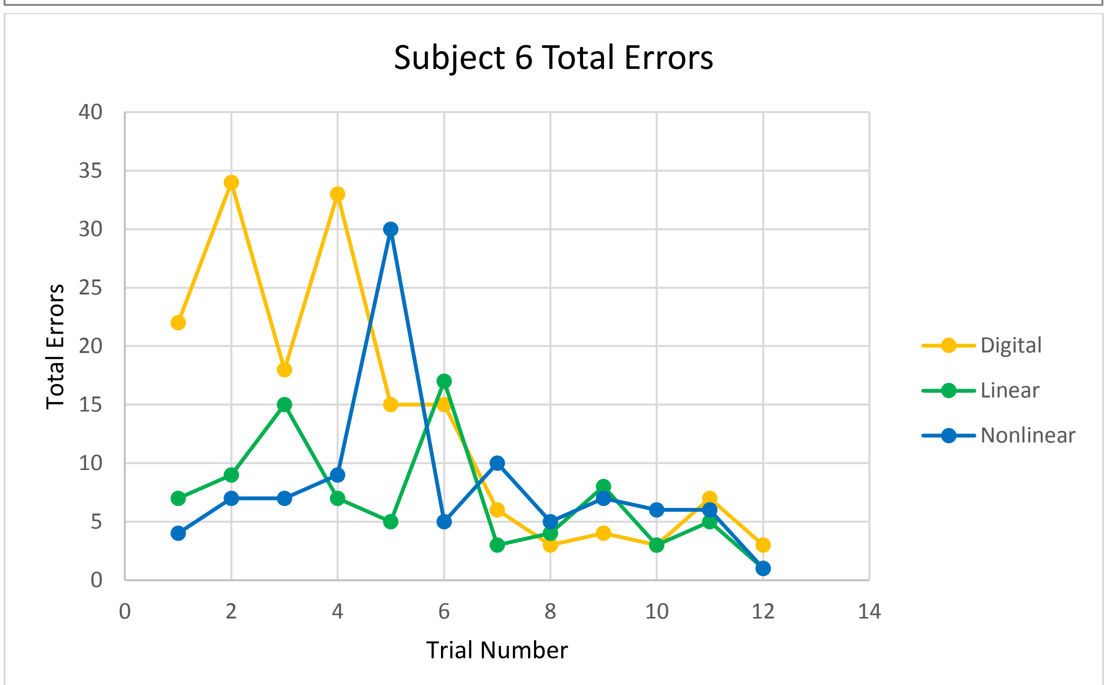


Subject 6							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
dig 1	2m 37.68s	157.68	16	5	1	22	160.68
dig 2	2m 50.07s	170.07	21	11	2	34	176.07
dig 3	2m 22.69s	142.69	14	2	2	18	148.69
dig 4	2m 43.68s	163.68	18	11	4	33	175.68
dig 5	1m 42.97s	162.97	13	1	1	15	165.97
dig 6	1m 39.90s	159.9	11	4	0	15	159.9
average		159.4983	15.5	5.666667	1.666667	22.8333333	164.4983333
non 1	0m 45.22s	45.22	2	0	2	4	51.22
non 2	1m 1.87s	61.87	6	0	1	7	64.87
non 3	0m 46.44s	46.44	4	2	1	7	49.44
non 4	0m 54.62s	54.62	5	4	0	9	54.62
non 5	1m 46.47s	106.47	18	11	1	30	109.47
non 6	1m 6.19s	66.19	3	0	2	5	72.19
average		63.46833	6.333333	2.833333	1.166667	10.3333333	66.96833333
lin 1	1m 21.72s	81.72	7	0	0	7	81.72
lin 2	1m 15.25s	75.25	7	2	0	9	75.25
lin 3	1m 39.88s	99.88	10	4	1	15	102.88
lin 4	1m 2.13s	62.13	6	1	0	7	62.13
lin 5	1m 3.97s	63.97	5	0	0	5	63.97
lin 6	1m 19.43s	79.43	11	6	0	17	79.43
average		77.06333	7.666667	2.166667	0.166667	10	77.56333333

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
non 1	1m 26.50s	86.5	9	1	0	10	86.5
non 2	0m 50.47s	50.47	3	1	1	5	53.47
non 3	1m 10.09s	70.09	5	2	0	7	70.09
non 4	0m 51.17s	51.17	3	3	0	6	51.17
non 5	1m 4.59s	64.59	4	1	1	6	67.59
non 6	0m 40.50s	40.5	1	0	0	1	40.5
average		60.5533	4.166666667	1.333333	0.3333333	5.83333333	61.55333333
lin 1	0m 42.35s	42.35	3	0	0	3	42.35
lin 2	0m 46.78s	46.78	3	0	1	4	49.78
lin 3	1m 5.44s	65.44	6	1	1	8	68.44
lin 4	0m 46.68s	46.68	2	1	0	3	46.68
lin 5	0m 51.34s	51.34	3	2	0	5	51.34
lin 6	0m 41.81s	41.81	1	0	0	1	41.81
average		49.0667	3	0.666667	0.3333333	4	50.06666667
dig 1	0m 46.22s	46.22	2	2	2	6	52.22
dig 2	0m 52.56s	52.56	2	0	1	3	55.56
dig 3	0m 55.19s	55.19	2	0	2	4	61.19
dig 4	0m 49.03s	49.03	3	0	0	3	49.03
dig 5	1m 0s	60	6	1	0	7	60
dig 6	0m 42.68s	42.68	2	1	0	3	42.68
average		50.9467	2.833333333	0.666667	0.8333333	4.33333333	53.44666667

Total Averages	Time (s)	Errors
Digital	105.2225	13.58333
Linear	63.065	7
Nonlinear	62.0108333	8.083333

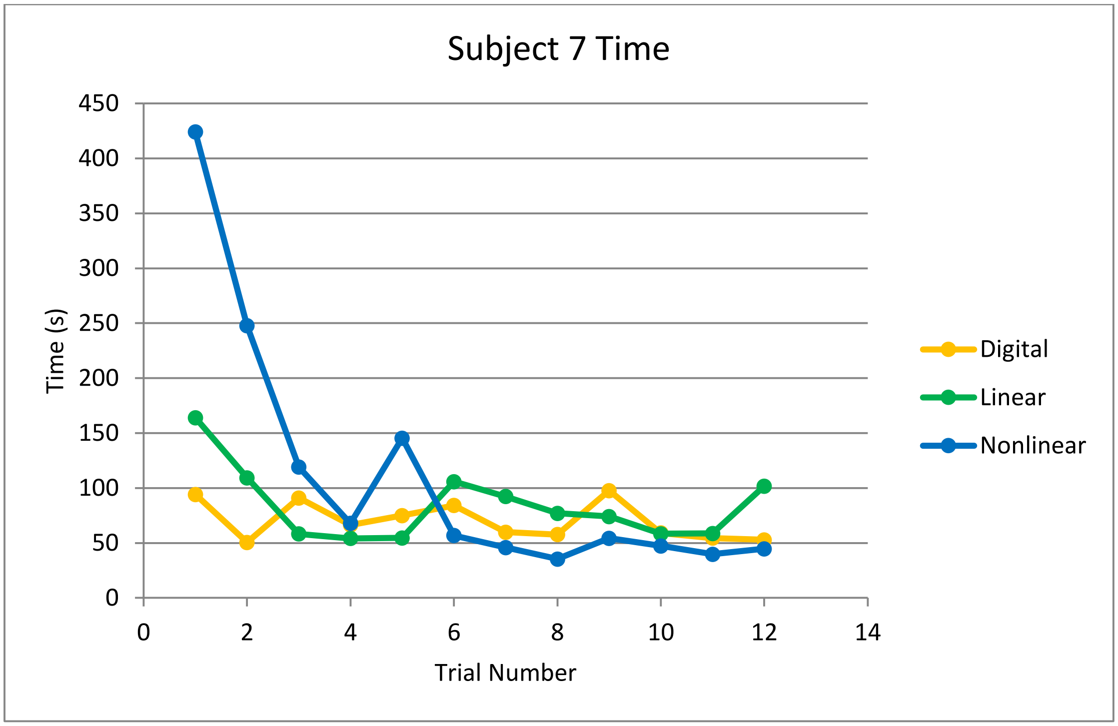


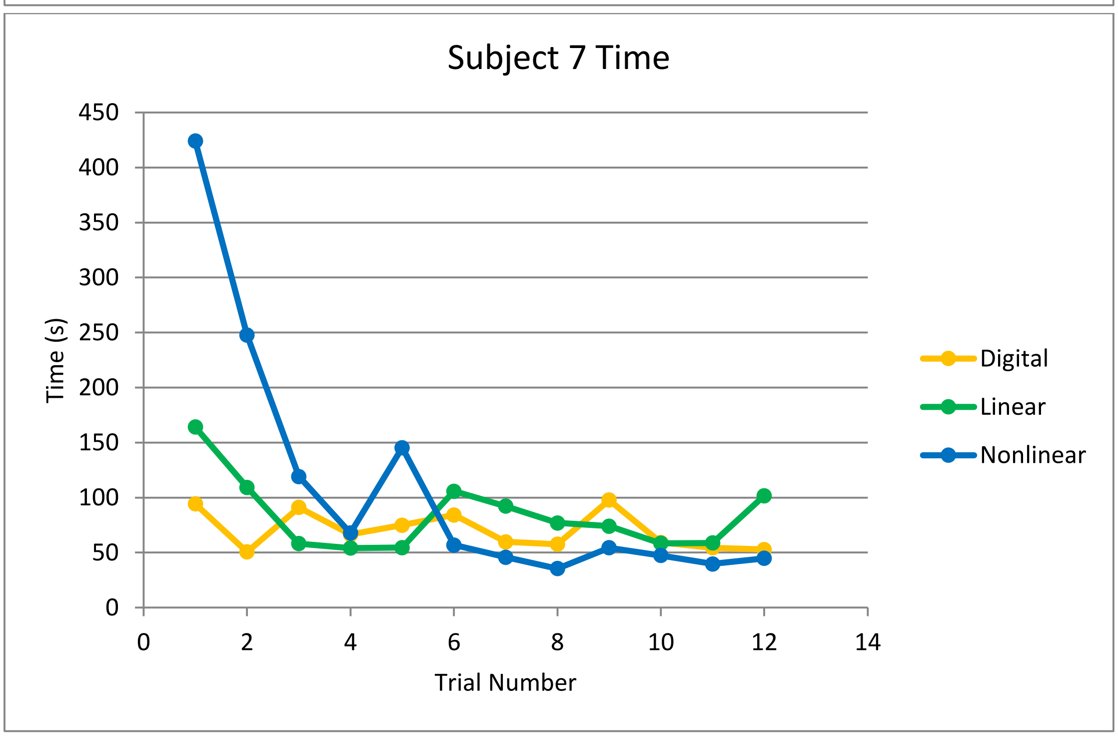


Subject 7							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
non 1	7m 4.09s	424.09	49	25	4	78	436.09
non 2	4m 7.66s	247.66	26	14	1	41	250.66
non 3	1m 59.13s	119.13	13	9	0	22	119.13
non 4	1m 7.84s	67.84	5	5	1	11	70.84
non 5	2m 25.44s	145.44	20	18	2	40	151.44
non 6	0m 56.88s	56.88	0	0	1	1	59.88
average		176.84	18.83333	11.83333	1.5	32.1666667	181.34
lin 1	2m 44.09s	164.09	17	12	3	32	173.09
lin 2	1m 49.31s	109.31	13	11	0	24	109.31
lin 3	0m 58.25s	58.25	4	4	0	8	58.25
lin 4	0m 54.16s	54.16	2	2	0	4	54.16
lin 5	0m 54.60s	54.6	2	2	0	4	54.6
lin 6	1m 45.85s	105.85	10	5	2	17	111.85
average		91.04333	8	6	0.833333	14.8333333	93.54333333
dig 1	1m 34.28s	94.28	11	7	1	19	97.28
dig 2	0m 50.60s	50.6	2	3	3	8	59.6
dig 3	1m 31.03s	91.03	12	9	4	25	103.03
dig 4	1m 6.48s	66.48	6	3	0	9	66.48
dig 5	1m 15.00s	75	10	8	3	21	84
dig 6	1m 24.19s	84.19	9	13	1	23	87.19
average		76.93	8.333333	7.166667	2	17.5	82.93

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
lin 1	1m 32.28s	92.28	2	3	0	5	92.28
lin 2	1m 17.02s	77.02	2	2	0	4	77.02
lin 3	1m 14.09s	74.09	3	2	0	5	74.09
lin 4	0m 58.44s	58.44	0	0	0	0	58.44
lin 5	0m 58.78s	58.78	0	0	0	0	58.78
lin 6	1m 41.75s	101.75	0	0	0	0	101.75
average		77.06	1.166666667	1.166667	0	2.33333333	77.06
non 1	0m 45.84s	45.84	0	0	1	1	48.84
non 2	0m 35.44	35.44	0	0	0	0	35.44
non 3	0m 54.40s	54.4	7	5	1	13	57.4
non 4	0m 47.38s	47.38	1	1	0	2	47.38
non 5	0m 39.78s	39.78	1	1	3	5	48.78
non 6	0m 44.75s	44.75	0	0	0	0	44.75
average		44.5983	1.5	1.166667	0.8333333	3.5	47.09833333
dig 1	0m 59.88s	59.88	5	1	4	10	71.88
dig 2	0m 57.63s	57.63	3	3	1	7	60.63
dig 3	1m 37.75s	97.75	7	8	1	16	100.75
dig 4	0m 59.16s	59.16	4	3	2	9	65.16
dig 5	0m 54.44s	54.44	2	2	0	4	54.44
dig 6	0m 52.84s	52.84	1	2	1	4	55.84
average		63.6167	3.666666667	3.166667	1.5	8.33333333	68.11666667

Total Averages	Time (s)	Errors
Digital	70.2733333	12.91667
Linear	84.0516667	8.583333
Nonlinear	110.719167	17.83333

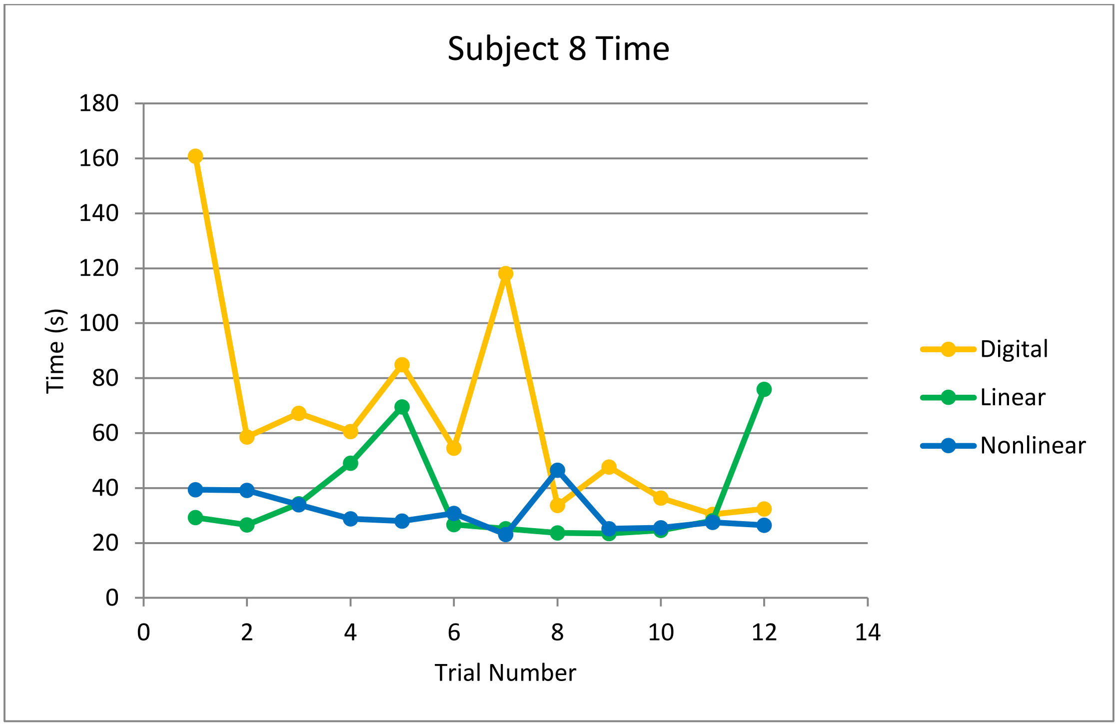


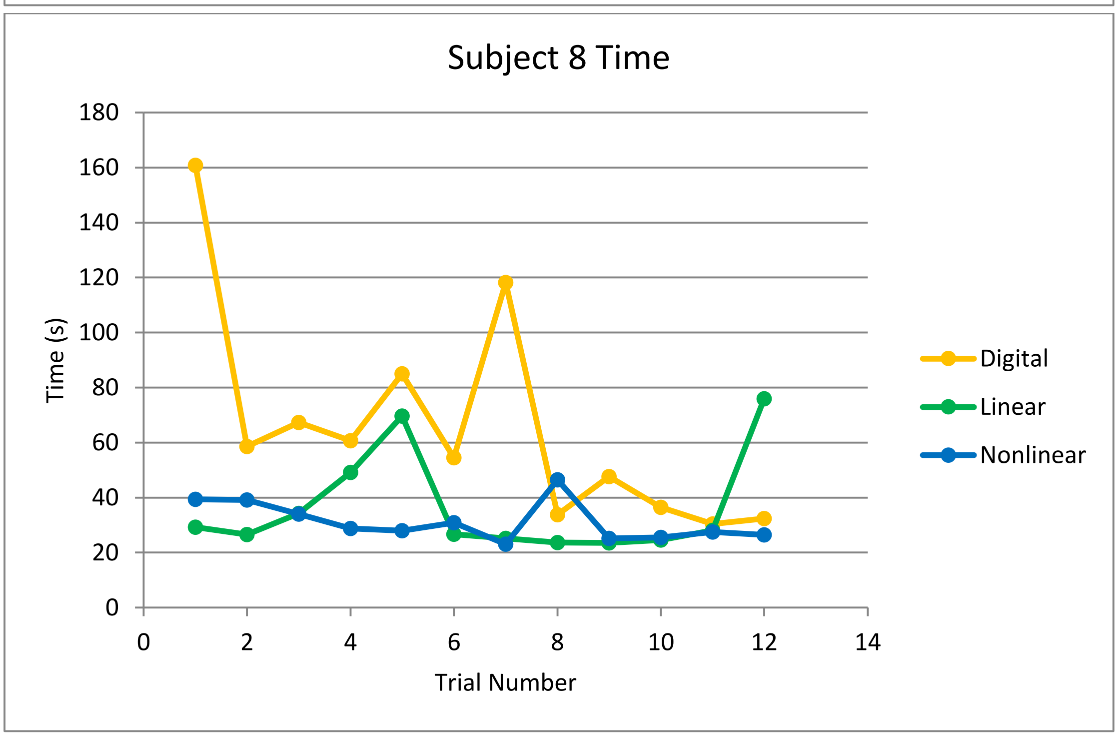


Subject 8							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
dig 1	2m 40.84s	160.84	18	16	3	37	169.84
dig 2	0m 58.56s	58.56	5	1	2	8	64.56
dig 3	1m 7.28s	67.28	8	4	2	14	73.28
dig 4	1m 0.63s	60.63	8	4	1	13	63.63
dig 5	1m 24.97s	84.97	17	9	2	28	90.97
dig 6	0m 54.56s	54.56	5	5	2	12	60.56
average		81.14	10.16667	6.5	2	18.6666667	87.14
non 1	0m 39.43s	39.43	0	0	1	1	42.43
non 2	0m 39.18s	39.18	2	2	0	4	39.18
non 3	0m 33.97s	33.97	2	2	1	5	36.97
non 4	0m 28.78s	28.78	0	1	1	2	31.78
non 5	0m 27.94s	27.94	0	0	1	1	30.94
non 6	0m 30.84s	30.84	0	1	2	3	36.84
average		33.35667	0.666667	1	1	2.66666667	36.35666667
lin 1	0m 29.25s	29.25	0	0	0	0	29.25
lin 2	0m 26.62s	26.62	0	1	0	1	26.62
lin 3	0m 34.31s	34.31	3	3	1	7	37.31
lin 4	0m 49.12s	49.12	5	4	1	10	52.12
lin 5	1m 9.59s	69.59	11	9	0	20	69.59
lin 6	0m 26.72s	26.72	0	0	3	3	35.72
average		39.26833	3.166667	2.833333	0.833333	6.83333333	41.76833333

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
lin 1	0m 25.19s	25.19	0	1	0	1	25.19
lin 2	0m 23.65s	23.65	0	0	0	0	23.65
lin 3	0m 23.50s	23.5	0	0	0	0	23.5
lin 4	0m 24.63s	24.63	1	1	1	3	27.63
lin 5	0m 28.12s	28.12	1	1	0	2	28.12
lin 6	1m 15.94s	75.94	14	13	1	28	78.94
average		33.505	2.666666667	2.666667	0.3333333	5.66666667	34.505
non 1	0m 23.06s	23.06	1	1	3	5	32.06
non 2	0m 46.53s	46.53	6	6	1	13	49.53
non 3	0m 25.15s	25.15	1	2	1	4	28.15
non 4	0m 25.50s	25.5	1	1	0	2	25.5
non 5	0m 27.53s	27.53	1	1	1	3	30.53
non 6	0m 26.50s	26.5	0	0	0	0	26.5
average		29.045	1.666666667	1.833333	1	4.5	32.045
dig 1	1m 58.13s	118.13	20	16	6	42	136.13
dig 2	0m 33.75s	33.75	2	2	1	5	36.75
dig 3	0m 47.65s	47.65	5	5	2	12	53.65
dig 4	0m 36.43s	36.43	5	6	2	13	42.43
dig 5	0m 30.41s	30.41	0	1	2	3	36.41
dig 6	0m 32.40s	32.4	3	4	1	8	35.4
average		49.795	5.833333333	5.666667	2.3333333	13.8333333	56.795

Total Averages	Time (s)	Errors
Digital	65.4675	16.25
Linear	36.3866667	6.25
Nonlinear	31.2008333	3.583333

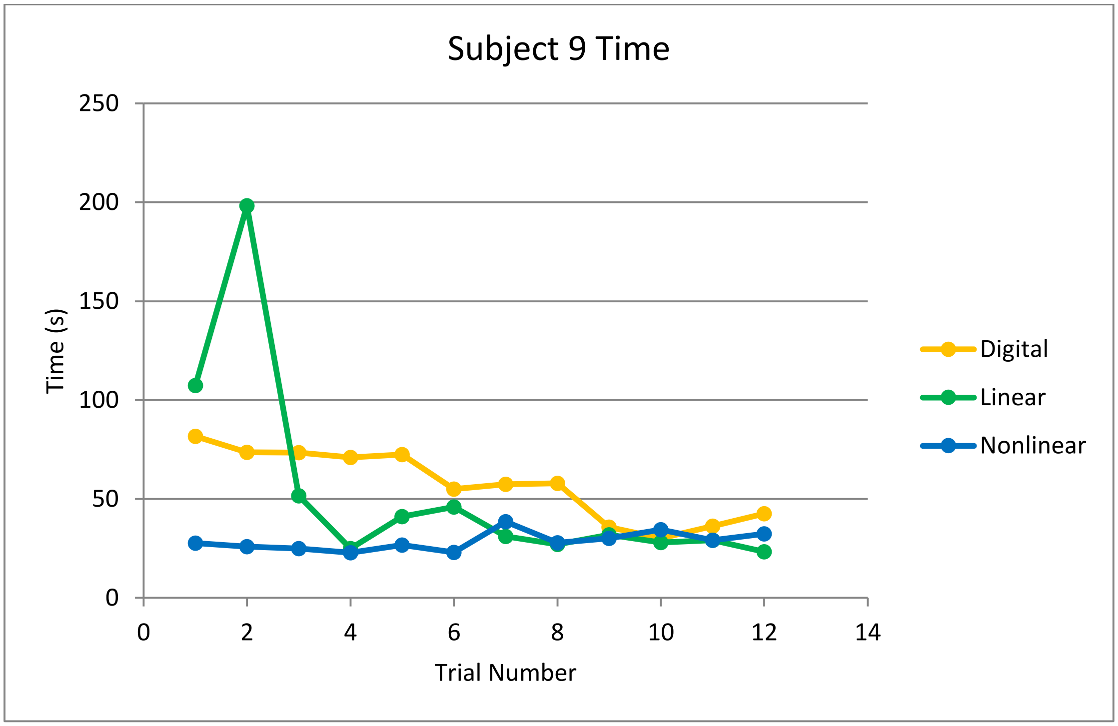


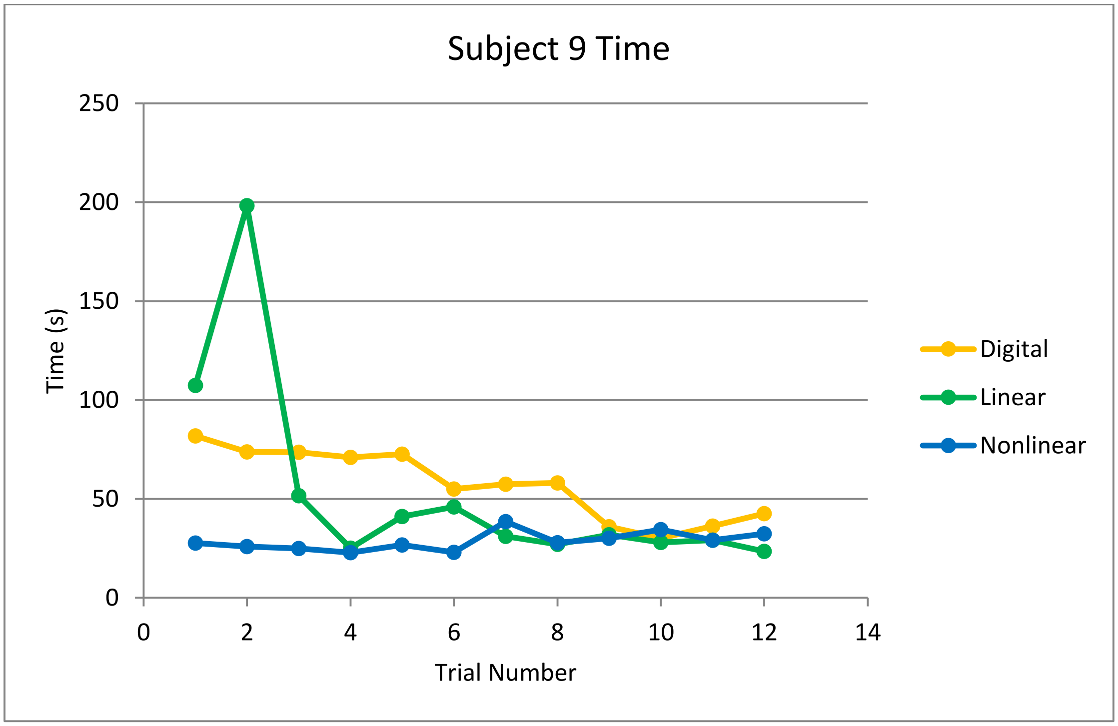


Subject 9							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
dig 1	1m 21.78s	81.78	1	0	0	1	81.78
dig 2	1m 13.69s	73.69	4	0	0	4	73.69
dig 3	1m 13.53s	73.53	6	1	0	7	73.53
dig 4	1m 11.06s	71.06	4	2	0	6	71.06
dig 5	1m 12.56s	72.56	2	0	0	2	72.56
dig 6	0m 55.07s	55.07	2	0	0	2	55.07
average		71.28167	3.166667	0.5	0	3.66666667	71.28166667
lin 1	1m 47.41s	107.41	9	4	1	14	110.41
lin 2	3m 18.28s	198.28	20	7	2	29	204.28
lin 3	0m 51.69s	51.69	2	2	1	5	54.69
lin 4	0m 25.04s	25.04	0	0	0	0	25.04
lin 5	0m 41.16s	41.16	4	3	0	7	41.16
lin 6	0m 45.94s	45.94	2	1	0	3	45.94
average		78.25333	6.166667	2.833333	0.666667	9.66666667	80.25333333
non 1	0m 27.69s	27.69	0	0	0	0	27.69
non 2	0m 25.96s	25.96	1	1	0	2	25.96
non 3	0m 24.91s	24.91	1	1	0	2	24.91
non 4	0m 22.81s	22.81	1	1	1	3	25.81
non 5	0m 26.72s	26.72	1	1	0	2	26.72
non 6	0m 23.03s	23.03	0	0	0	0	23.03
average		25.18667	0.666667	0.666667	0.166667	1.5	25.68666667

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
dig 1	0m 57.50s	57.5	5	2	4	11	69.5
dig 2	0m 58.03s	58.03	2	2	0	4	58.03
dig 3	0m 35.87s	35.87	2	1	1	4	38.87
dig 4	0m 30.19s	30.19	1	1	0	2	30.19
dig 5	0m 36.25s	36.25	3	2	1	6	39.25
dig 6	0m 42.62s	42.62	3	2	0	5	42.62
average		43.41	2.666666667	1.666667	1	5.33333333	46.41
non 1	0m 38.53s	38.53	1	0	1	2	41.53
non 2	0m 27.87s	27.87	2	2	0	4	27.87
non 3	0m 30.10s	30.1	2	1	1	4	33.1
non 4	0m 34.53s	34.53	2	2	0	4	34.53
non 5	0m 29.12s	29.12	0	0	0	0	29.12
non 6	0m 32.40s	32.4	1	1	0	2	32.4
average		32.0917	1.333333333	1	0.3333333	2.66666667	33.09166667
lin 1	0m 31.16s	31.16	1	1	0	2	31.16
lin 2	0m 27.03s	27.03	0	0	1	1	30.03
lin 3	0m 31.88s	31.88	0	0	0	0	31.88
lin 4	0m 28.00s	28	0	0	0	0	28
lin 5	0m 29.22s	29.22	1	1	0	2	29.22
lin 6	0m 23.44s	23.44	0	0	0	0	23.44
average		28.455	0.333333333	0.333333	0.1666667	0.83333333	28.955

Total Averages	Time (s)	Errors
Digital	57.3458333	4.5
Linear	53.3541667	5.25
Nonlinear	28.6391667	2.083333

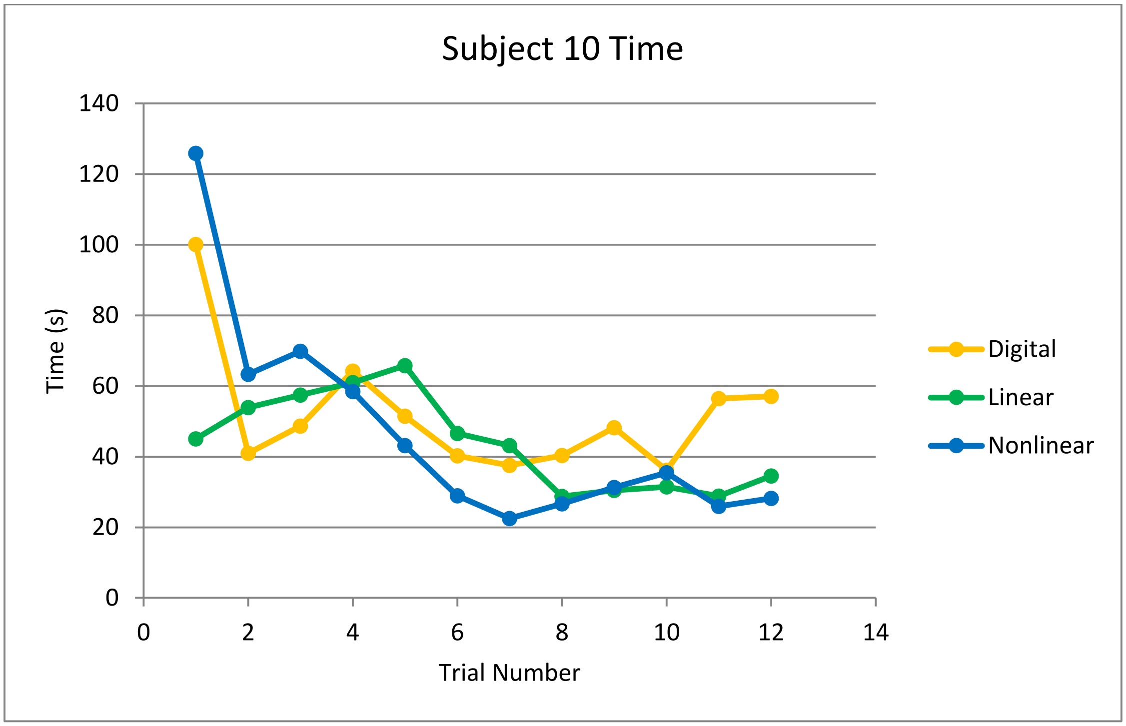


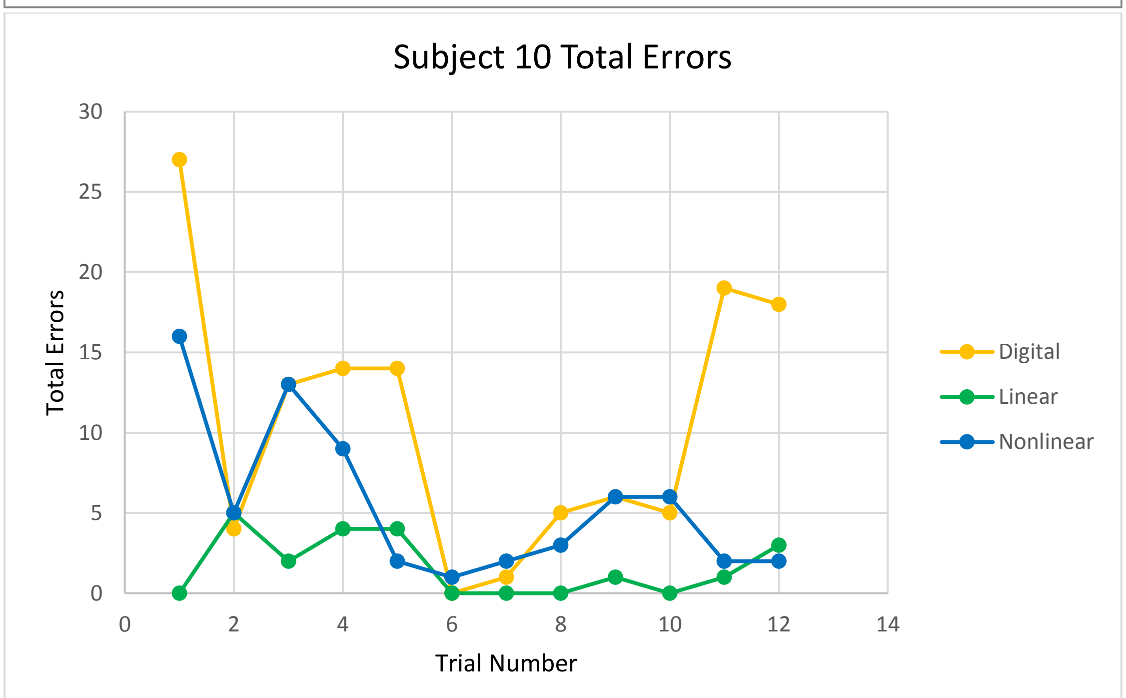


Subject 10							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
non 1	2m 5.87s	125.87	8	6	2	16	131.87
non 2	1m 3.35s	63.35	4	1	0	5	63.35
non 3	1m 9.87s	69.87	6	7	0	13	69.87
non 4	0m 58.41s	58.41	6	3	0	9	58.41
non 5	0m 43.13s	43.13	1	1	0	2	43.13
non 6	0m 28.94s	28.94	0	1	0	1	28.94
average		64.92833	4.166667	3.166667	0.333333	7.66666667	65.92833333
lin 1	0m 45.06s	45.06	0	0	0	0	45.06
lin 2	0m 53.93s	53.93	2	3	0	5	53.93
lin 3	0m 57.47s	57.47	1	1	0	2	57.47
lin 4	1m 0.97s	60.97	2	2	0	4	60.97
lin 5	1m 5.75s	65.75	2	2	0	4	65.75
lin 6	0m 46.59s	46.59	0	0	0	0	46.59
average		54.96167	1.166667	1.333333	0	2.5	54.96166667
dig 1	1m 40.13s	100.13	17	9	1	27	103.13
dig 2	0m 41.00s	41	1	2	1	4	44
dig 3	0m 48.63s	48.63	6	6	1	13	51.63
dig 4	1m 4.28s	64.28	8	4	2	14	70.28
dig 5	0m 51.43s	51.43	7	4	3	14	60.43
dig 6	0m 40.22s	40.22	0	0	0	0	40.22
average		57.615	6.5	4.166667	1.333333	12	61.615

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
lin 1	0m 43.13s	43.13	0	0	0	0	43.13
lin 2	0m 28.72s	28.72	0	0	0	0	28.72
lin 3	0m 30.47s	30.47	0	1	0	1	30.47
lin 4	0m 31.50s	31.5	0	0	0	0	31.5
lin 5	0m 28.85s	28.85	0	1	0	1	28.85
lin 6	0m 34.50s	34.5	1	1	1	3	37.5
average		32.8617	0.166666667	0.5	0.1666667	0.83333333	33.36166667
dig 1	0m 37.53s	37.53	0	1	0	1	37.53
dig 2	0m 40.37s	40.37	2	2	1	5	43.37
dig 3	0m 48.19s	48.19	3	3	0	6	48.19
dig 4	0m 36.15s	36.15	2	2	1	5	39.15
dig 5	0m 56.41s	56.41	11	7	1	19	59.41
dig 6	0m 57.09s	57.09	10	6	2	18	63.09
average		45.9567	4.666666667	3.5	0.8333333	9	48.45666667
non 1	0m 22.50s	22.5	0	1	1	2	25.5
non 2	0m 26.68s	26.68	1	1	1	3	29.68
non 3	0m 31.31s	31.31	3	3	0	6	31.31
non 4	0m 35.44s	35.44	3	2	1	6	38.44
non 5	0m 25.97s	25.97	1	1	0	2	25.97
non 6	0m 28.19s	28.19	1	1	0	2	28.19
average		28.3483	1.5	1.5	0.5	3.5	29.84833333

Total Averages	Time (s)	Errors
Digital	51.7858333	10.5
Linear	43.9116667	1.666667
Nonlinear	46.6383333	5.583333

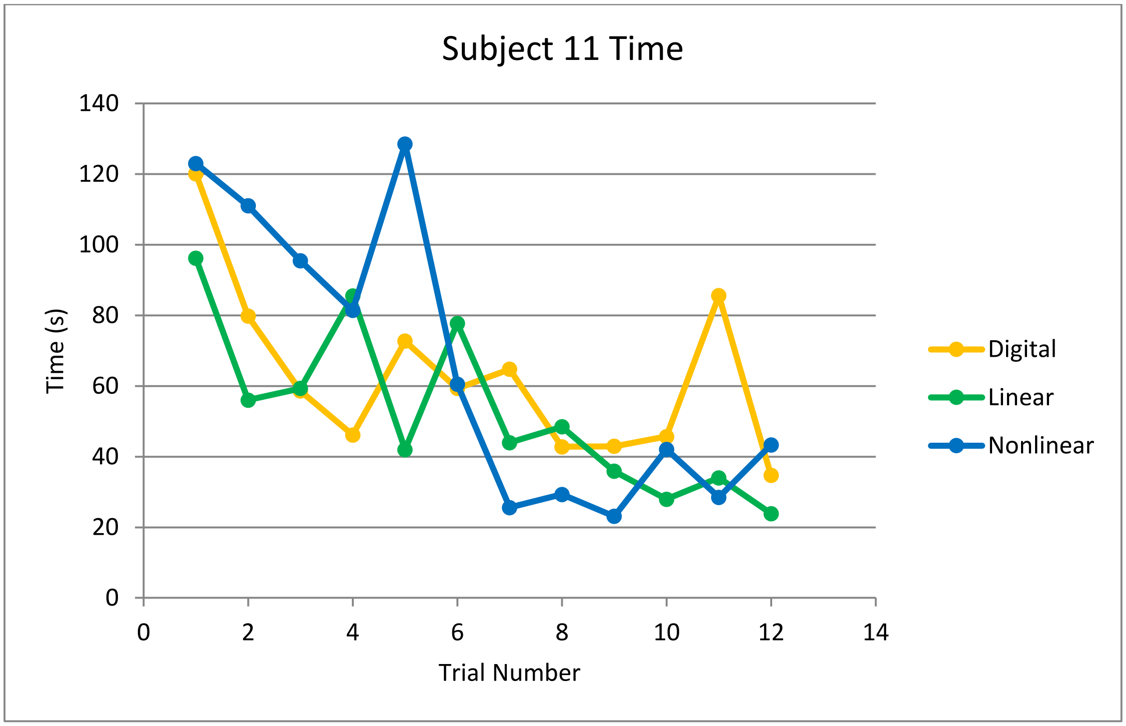


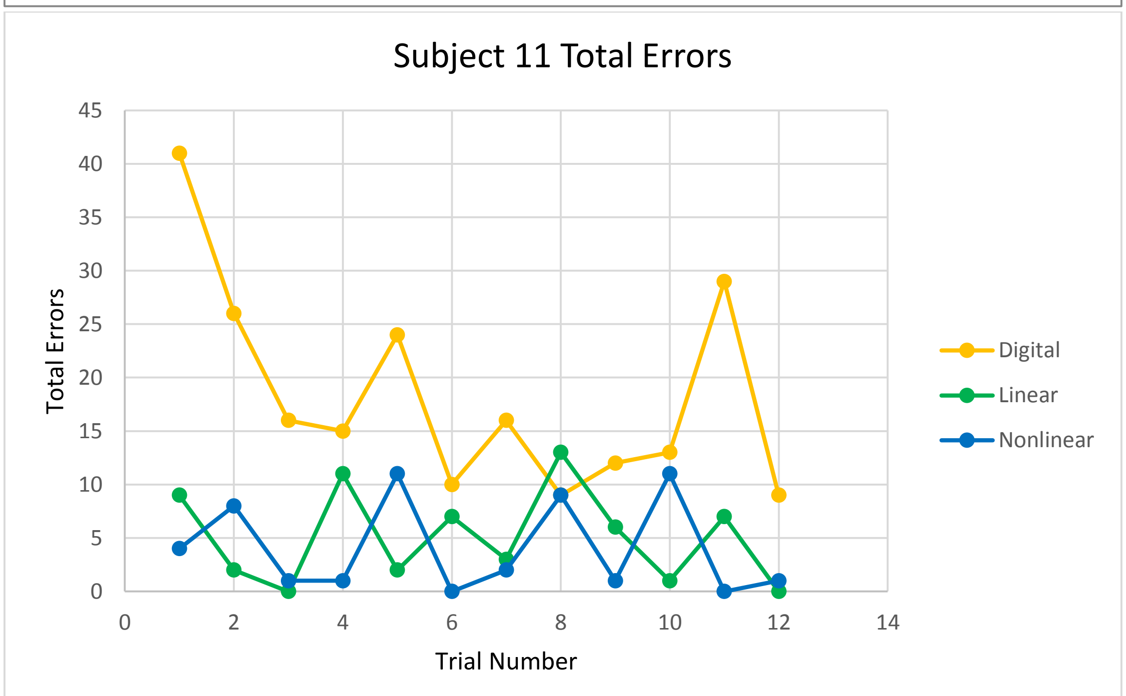


Subject 11							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
non 1	2m 3.03s	123.03	3	1	0	4	123.03
non 2	1m 51.04s	111.04	5	3	0	8	111.04
non 3	1m 35.44s	95.44	1	0	0	1	95.44
non 4	1m 21.41s	81.41	0	0	1	1	84.41
non 5	2m 8.53s	128.53	7	4	0	11	128.53
non 6	1m 0.57s	60.57	0	0	0	0	60.57
average		100.0033	2.666667	1.333333	0.166667	4.16666667	100.5033333
dig 1	2m 0.13s	120.13	26	12	3	41	129.13
dig 2	1m 19.78s	79.78	13	9	4	26	91.78
dig 3	0m 58.59s	58.59	7	6	3	16	67.59
dig 4	0m 46.15s	46.15	6	7	2	15	52.15
dig 5	1m 12.72s	72.72	12	10	2	24	78.72
dig 6	0m 59.34s	59.34	5	4	1	10	62.34
average		72.785	11.5	8	2.5	22	80.285
lin 1	1m 36.16s	96.16	6	3	0	9	96.16
lin 2	0m 56.00s	56	1	1	0	2	56
lin 3	0m 59.34s	59.34	0	0	0	0	59.34
lin 4	1m 25.47s	85.47	6	4	1	11	88.47
lin 5	0m 42.00s	42	1	1	0	2	42
lin 6	1m 17.75s	77.75	4	3	0	7	77.75
average		69.45333	3	2	0.166667	5.16666667	69.95333333

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
dig 1	1m 4.78s	64.78	8	4	4	16	76.78
dig 2	0m 42.81s	42.81	4	3	2	9	48.81
dig 3	0m 42.93s	42.93	6	5	1	12	45.93
dig 4	0m 45.68s	45.68	6	6	1	13	48.68
dig 5	1m 25.59s	85.59	16	11	2	29	91.59
dig 6	0m 34.72s	34.72	3	3	3	9	43.72
average		52.7517	7.166666667	5.333333	2.1666667	14.6666667	59.25166667
lin 1	0m 44.00s	44	1	1	1	3	47
lin 2	0m 48.47s	48.47	7	4	2	13	54.47
lin 3	0m 35.87s	35.87	3	3	0	6	35.87
lin 4	0m 27.94s	27.94	0	0	1	1	30.94
lin 5	0m 34.04s	34.04	3	3	1	7	37.04
lin 6	0m 23.90s	23.9	0	0	0	0	23.9
average		35.7033	2.333333333	1.833333	0.8333333	5	38.20333333
non 1	0m 25.60s	25.6	1	1	0	2	25.6
non 2	0m 29.31s	29.31	4	4	1	9	32.31
non 3	0m 23.09s	23.09	0	0	1	1	26.09
non 4	0m 42.06s	42.06	4	5	2	11	48.06
non 5	0m 28.50s	28.5	0	0	0	0	28.5
non 6	0m 43.34s	43.34	0	0	1	1	46.34
average		31.9833	1.5	1.666667	0.8333333	4	34.48333333

Total Averages	Time (s)	Errors
Digital	62.7683333	18.33333
Linear	52.5783333	5.083333
Nonlinear	65.9933333	4.083333

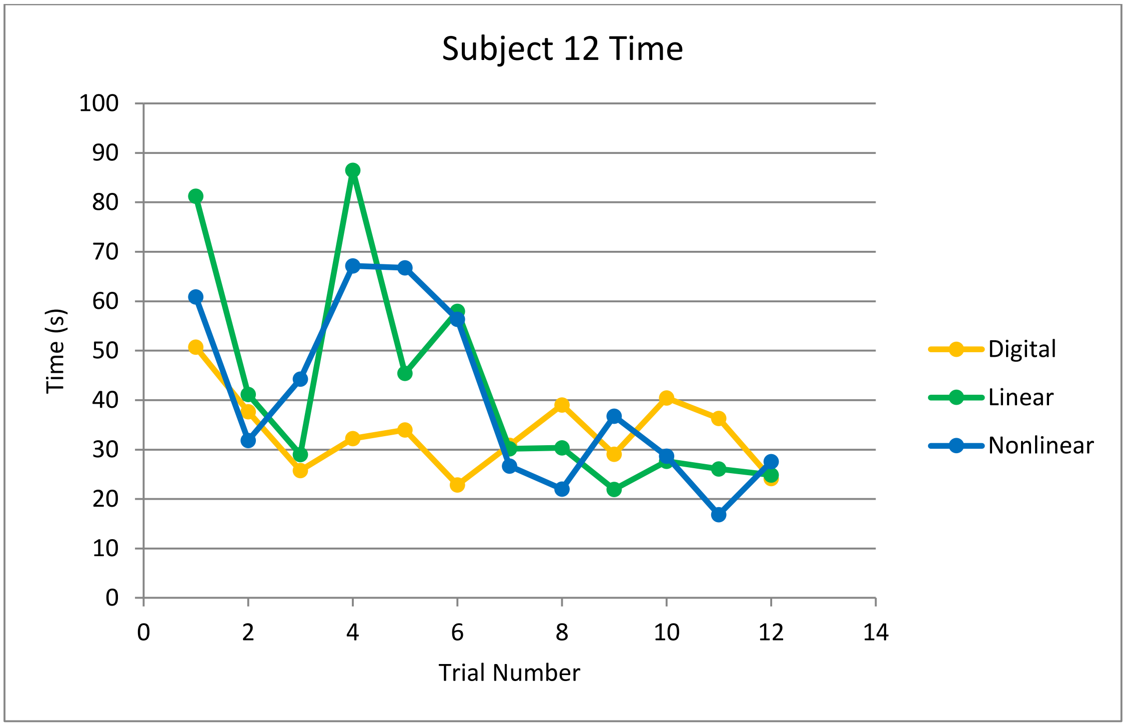


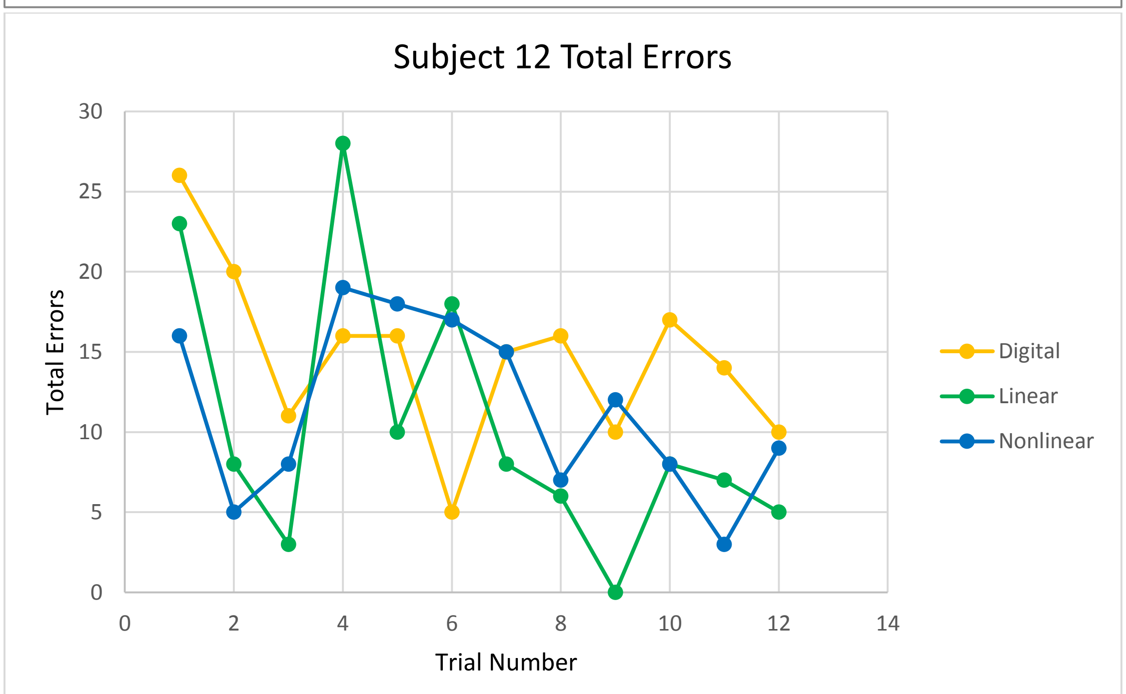


Subject 12							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
non 1	1m 0.88s	60.88	7	8	1	16	63.88
non 2	0m 31.87s	31.87	1	1	3	5	40.87
non 3	0m 44.25s	44.25	3	2	3	8	53.25
non 4	1m 7.19s	67.19	9	8	2	19	73.19
non 5	1m 6.75s	66.75	9	7	2	18	72.75
non 6	0m 56.35s	56.35	8	9	0	17	56.35
average		54.54833	6.166667	5.833333	1.833333	13.8333333	60.04833333
lin 1	1m 21.25s	81.25	13	7	3	23	90.25
lin 2	0m 41.15s	41.15	3	3	2	8	47.15
lin 3	0m 29.03s	29.03	1	1	1	3	32.03
lin 4	1m 26.53s	86.53	15	11	2	28	92.53
lin 5	0m 45.40s	45.4	5	4	1	10	48.4
lin 6	0m 58.00s	58	9	8	1	18	61
average		56.89333	7.666667	5.666667	1.666667	15	61.89333333
dig 1	0m 50.75s	50.75	12	11	3	26	59.75
dig 2	0m 37.69s	37.69	9	9	2	20	43.69
dig 3	0m 25.74s	25.74	4	4	3	11	34.74
dig 4	0m 32.22s	32.22	7	7	2	16	38.22
dig 5	0m 34.00s	34	7	7	2	16	40
dig 6	0m 22.84s	22.84	2	1	2	5	28.84
average		33.87333	6.833333	6.5	2.333333	15.6666667	40.87333333

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
dig 1	0m 30.87s	30.87	6	5	4	15	42.87
dig 2	0m 39.00s	39	8	7	1	16	42
dig 3	0m 29.06s	29.06	3	5	2	10	35.06
dig 4	0m 40.44s	40.44	8	7	2	17	46.44
dig 5	0m 36.29s	36.29	7	6	1	14	39.29
dig 6	0m 24.16s	24.16	3	3	4	10	36.16
average		33.3033	5.833333333	5.5	2.3333333	13.6666667	40.30333333
lin 1	0m 30.16s	30.16	3	3	2	8	36.16
lin 2	0m 30.34s	30.34	3	3	0	6	30.34
lin 3	0m 21.94s	21.94	0	0	0	0	21.94
lin 4	0m 27.65s	27.65	3	5	0	8	27.65
lin 5	0m 26.12s	26.12	3	4	0	7	26.12
lin 6	0m 24.84s	24.84	2	2	1	5	27.84
average		26.8417	2.333333333	2.833333	0.5	5.66666667	28.34166667
non 1	0m 26.69s	26.69	4	4	7	15	47.69
non 2	0m 22.00s	22	2	3	2	7	28
non 3	0m 36.75s	36.75	6	6	0	12	36.75
non 4	0m 28.66s	28.66	4	3	1	8	31.66
non 5	0m 16.85s	16.85	0	0	3	3	25.85
non 6	0m 27.56s	27.56	3	3	3	9	36.56
average		26.4183	3.166666667	3.166667	2.6666667	9	34.41833333

Total Averages	Time (s)	Errors
Digital	33.5883333	14.66667
Linear	41.8675	10.33333
Nonlinear	40.4833333	11.41667

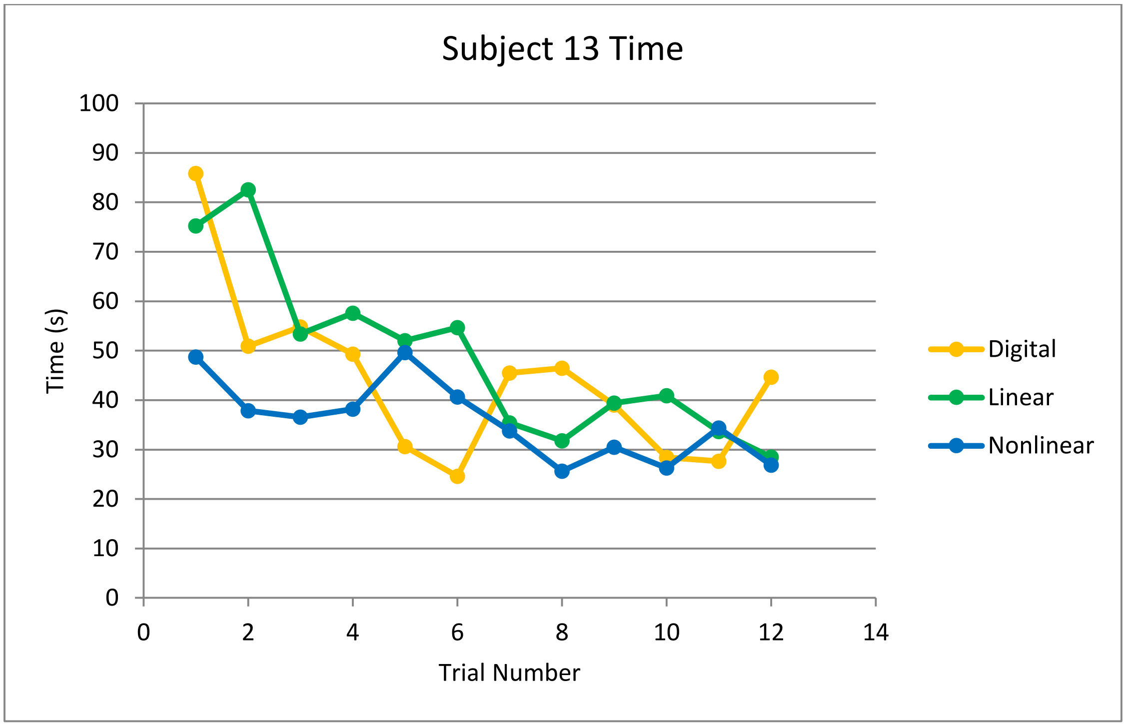


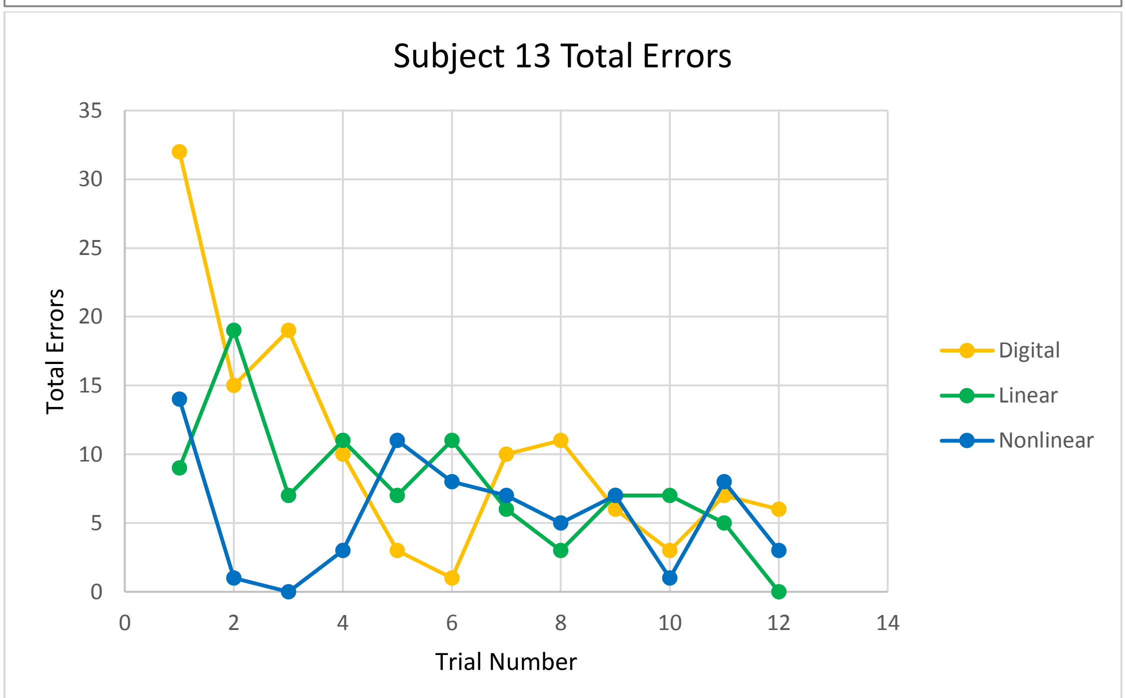


Subject 13							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
lin 1	1m 15.25s	75.25	7	2	0	9	75.25
lin 2	1m 22.56s	82.56	12	6	1	19	85.56
lin 3	0m 53.37s	53.37	5	1	1	7	56.37
lin 4	0m 57.59s	57.59	9	1	1	11	60.59
lin 5	0m 52.04s	52.04	6	0	1	7	55.04
lin 6	0m 54.71s	54.71	7	2	2	11	60.71
average		62.58667	7.666667	2	1	10.6666667	65.58666667
non 1	0m 48.75s	48.75	8	4	2	14	54.75
non 2	0m 37.85s	37.85	0	0	1	1	40.85
non 3	0m 36.60s	36.6	0	0	0	0	36.6
non 4	0m 38.16s	38.16	1	1	1	3	41.16
non 5	0m 49.62	49.62	7	4	0	11	49.62
non 6	0m 40.62s	40.62	5	3	0	8	40.62
average		41.93333	3.5	2	0.666667	6.16666667	43.93333333
dig 1	1m 25.88s	85.88	20	9	3	32	94.88
dig 2	0m 50.91s	50.91	6	5	4	15	62.91
dig 3	0m 54.78s	54.78	10	6	3	19	63.78
dig 4	0m 49.34s	49.34	5	3	2	10	55.34
dig 5	0m 30.59s	30.59	2	1	0	3	30.59
dig 6	0m 24.59s	24.59	1	0	0	1	24.59
average		49.34833	7.333333	4	2	13.3333333	55.34833333

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
dig 1	0m 45.50s	45.5	7	2	1	10	48.5
dig 2	0m 46.44s	46.44	5	5	1	11	49.44
dig 3	0m 39.06s	39.06	4	1	1	6	42.06
dig 4	0m 28.43s	28.43	1	1	1	3	31.43
dig 5	0m 27.62s	27.62	2	2	3	7	36.62
dig 6	0m 44.65s	44.65	6	0	0	6	44.65
average		38.6167	4.166666667	1.833333	1.1666667	7.16666667	42.11666667
non 1	0m 33.81s	33.81	4	1	2	7	39.81
non 2	0m 25.66s	25.66	2	1	2	5	31.66
non 3	0m 30.47s	30.47	4	2	1	7	33.47
non 4	0m 26.28s	26.28	0	0	1	1	29.28
non 5	0m 34.37s	34.37	4	3	1	8	37.37
non 6	0m 26.90s	26.9	3	0	0	3	26.9
average		29.5817	2.833333333	1.166667	1.1666667	5.16666667	33.08166667
lin 1	0m 35.38s	35.38	4	2	0	6	35.38
lin 2	0m 31.79s	31.79	1	0	2	3	37.79
lin 3	0m 39.44s	39.44	3	2	2	7	45.44
lin 4	0m 40.91s	40.91	5	2	0	7	40.91
lin 5	0m 33.66s	33.66	3	2	0	5	33.66
lin 6	0m 28.46s	28.46	0	0	0	0	28.46
average		34.94	2.666666667	1.333333	0.6666667	4.66666667	36.94

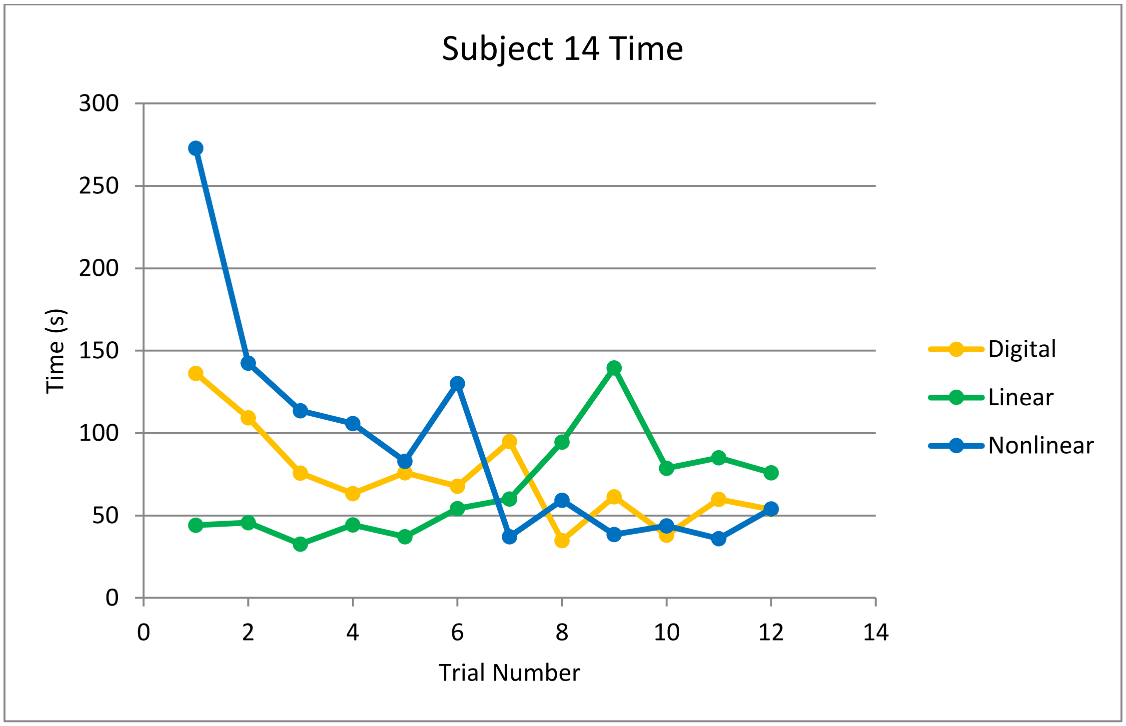
Total Averages	Time (s)	Errors
Digital	43.9825	10.25
Linear	48.7633333	7.666667
Nonlinear	35.7575	5.666667

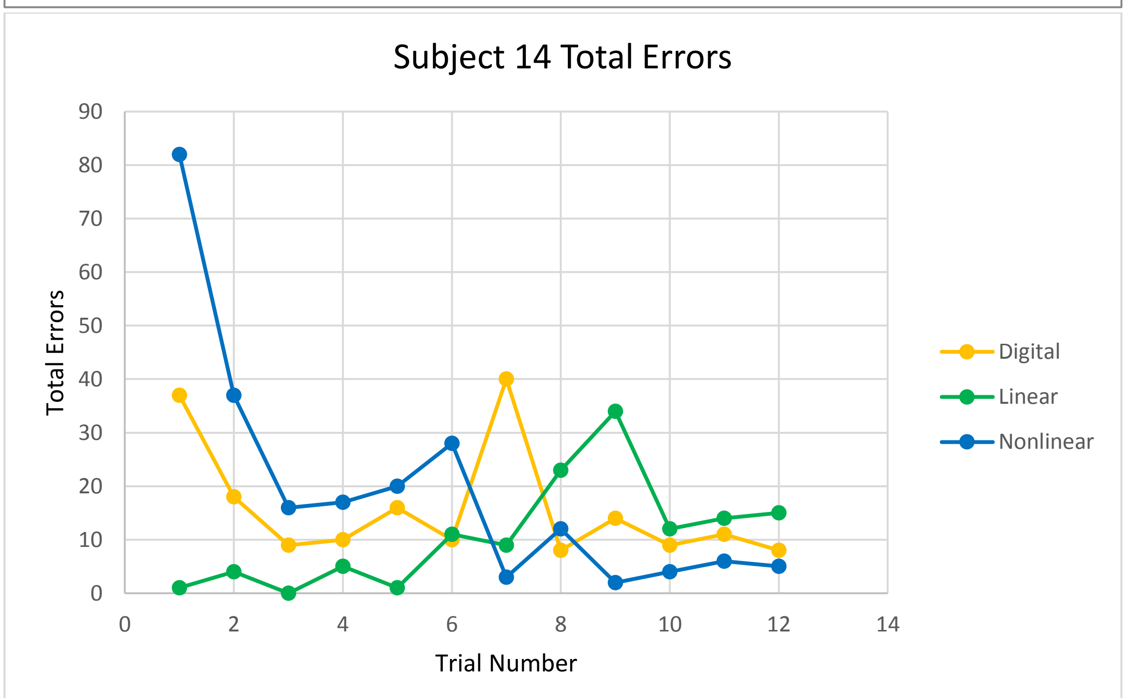




Subject 14							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
non 1	4m 32.94s	272.94	48	31	3	82	281.94
non 2	2m 22.50s	142.5	18	17	2	37	148.5
non 3	1m 53.57s	113.57	10	4	2	16	119.57
non 4	1m 45.84s	105.84	10	5	2	17	111.84
non 5	1m 22.94s	82.94	10	7	3	20	91.94
non 6	2m 10.18s	130.18	16	11	1	28	133.18
average		141.3283	18.66667	12.5	2.166667	33.3333333	147.8283333
dig 1	2m 16.34s	136.34	19	12	6	37	154.34
dig 2	1m 49.28s	109.28	12	5	1	18	112.28
dig 3	1m 15.68s	75.68	5	3	1	9	78.68
dig 4	1m 3.41s	63.41	4	5	1	10	66.41
dig 5	1m 15.87s	75.87	9	5	2	16	81.87
dig 6	1m 7.87s	67.87	3	4	3	10	76.87
average		88.075	8.666667	5.666667	2.333333	16.6666667	95.075
lin 1	0m 44.15s	44.15	1	0	0	1	44.15
lin 2	0m 45.66s	45.66	2	1	1	4	48.66
lin 3	0m 32.66s	32.66	0	0	0	0	32.66
lin 4	0m 43.34s	44.34	3	1	1	5	47.34
lin 5	0m 37.09s	37.09	0	0	1	1	40.09
lin 6	0m 54.22s	54.22	6	3	2	11	60.22
average		43.02	2	0.833333	0.833333	3.66666667	45.52
Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
non 1	0m 37.12s	37.12	1	1	1	3	40.12
non 2	0m 59.19s	59.19	7	3	2	12	65.19
non 3	0m 38.50s	38.5	2	0	0	2	38.5
non 4	0m 43.78s	43.78	2	1	1	4	46.78
non 5	0m 35.94s	35.94	2	2	2	6	41.94
non 6	0m 54.04s	54.04	3	1	1	5	57.04
average		44.7617	2.833333333	1.333333	1.1666667	5.33333333	48.26166667
lin 1	1m 0.06s	60.06	6	3	0	9	60.06
lin 2	1m 34.50s	94.5	14	7	2	23	100.5
lin 3	2m 19.59s	139.59	19	11	4	34	151.59
lin 4	1m 18.72s	78.72	7	3	2	12	84.72
lin 5	1m 25.06s	85.06	11	2	1	14	88.06
lin 6	1m 15.97s	75.97	11	3	1	15	78.97
average		88.9833	11.33333333	4.833333	1.6666667	17.8333333	93.98333333
dig 1	1m 34.93s	94.93	21	15	4	40	106.93
dig 2	0m 34.81s	34.81	3	2	3	8	43.81
dig 3	1m 1.31s	61.31	8	4	2	14	67.31
dig 4	0m 38.06s	38.06	2	5	2	9	44.06
dig 5	0m 59.90s	59.9	8	1	2	11	65.9
dig 6	0m 53.60s	53.6	5	2	1	8	56.6
average		57.1017	7.833333333	4.833333	2.3333333	15	64.10166667

Total Averages	Time (s)	Errors
Digital	72.5883333	15.83333
Linear	66.0016667	10.75
Nonlinear	93.045	19.33333

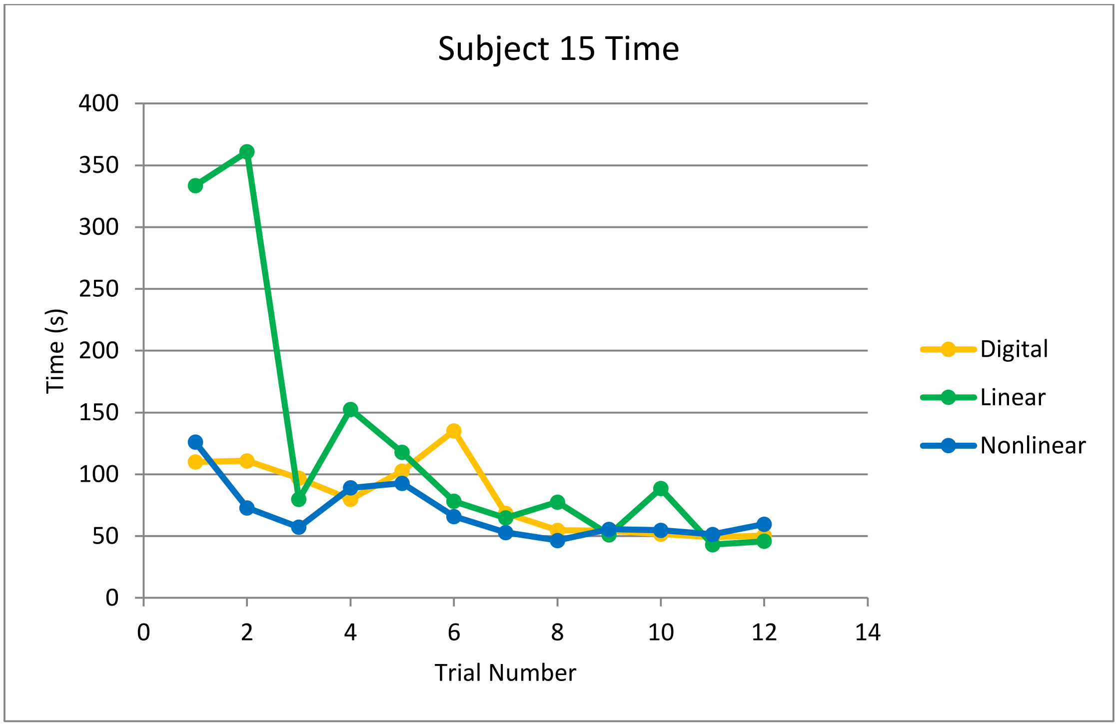


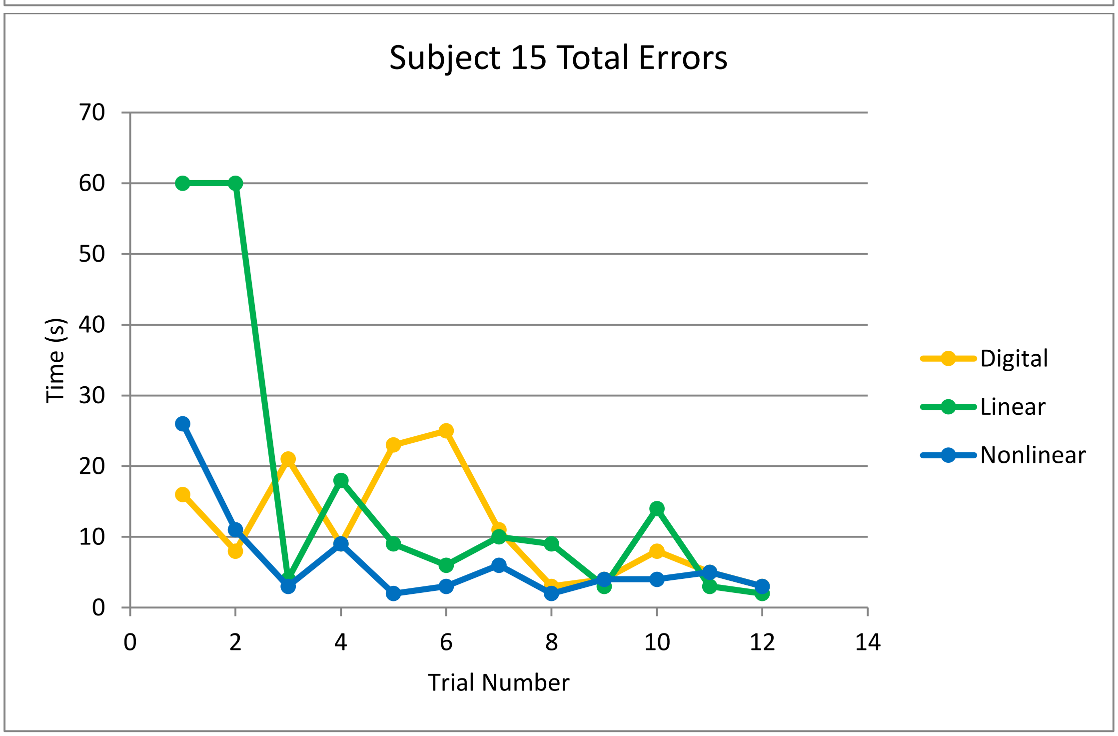


Subject 15							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
lin 1	5m 33.65s	333.65	42	14	4	60	345.65
lin 2	6m 0.87s	360.87	42	15	3	60	369.87
lin 3	1m 19.69s	79.69	2	1	1	4	82.69
lin 4	2m 32.56s	152.56	13	3	2	18	158.56
lin 5	1m 57.72s	117.72	7	1	1	9	120.72
lin 6	1m 18.13s	78.13	2	2	2	6	84.13
average		187.1033	18	6	2.166667	26.1666667	193.6033333
dig 1	1m 50.03s	110.03	8	6	2	16	116.03
dig 2	1m 50.91s	110.91	5	2	1	8	113.91
dig 3	1m 36.82s	96.82	15	4	2	21	102.82
dig 4	1m 19.72s	79.72	5	3	1	9	82.72
dig 5	1m 42.63s	102.63	14	6	3	23	111.63
dig 6	2m 15.19s	135.19	15	8	2	25	141.19
average		105.8833	10.33333	4.833333	1.833333	17	111.3833333
non 1	2m 6.03s	126.03	15	9	2	26	132.03
non 2	1m 12.87s	72.87	5	3	3	11	81.87
non 3	0m 57.28s	57.28	1	0	2	3	63.28
non 4	1m 29.00s	89	5	2	2	9	95
non 5	1m 32.78s	92.78	1	0	1	2	95.78
non 6	1m 5.85s	65.85	2	1	0	3	65.85
average		83.96833	4.833333	2.5	1.666667	9	88.96833333

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
lin 1	1m 4.69s	64.69	5	3	2	10	70.69
lin 2	1m 17.56s	77.56	5	4	0	9	77.56
lin 3	0m 51.12s	51.12	2	1	0	3	51.12
lin 4	1m 28.59s	88.59	10	4	0	14	88.59
lin 5	0m 43.19s	43.19	1	1	1	3	46.19
lin 6	0m 45.84s	45.84	1	1	0	2	45.84
average		61.8317	4	2.333333	0.5	6.83333333	63.33166667
non 1	0m 52.97s	52.97	2	3	1	6	55.97
non 2	0m 46.50s	46.5	0	0	2	2	52.5
non 3	0m 55.53s	55.53	2	1	1	4	58.53
non 4	0m 54.72s	54.72	3	1	0	4	54.72
non 5	0m 51.44s	51.44	2	2	1	5	54.44
non 6	0m 59.68s	59.68	3	0	0	3	59.68
average		53.4733	2	1.166667	0.8333333	4	55.97333333
dig 1	1m 8.50s	68.5	4	5	2	11	74.5
dig 2	0m 54.75s	54.75	2	1	0	3	54.75
dig 3	0m 54.35s	54.35	2	1	1	4	57.35
dig 4	0m 51.69s	51.69	2	3	3	8	60.69
dig 5	0m 49.16s	49.16	2	2	1	5	52.16
dig 6	0m 50.35s	50.35	1	1	1	3	53.35
average		54.8	2.166666667	2.166667	1.3333333	5.66666667	58.8

Total Averages	Time (s)	Errors
Digital	80.3416667	11.33333
Linear	124.4675	16.5
Nonlinear	68.7208333	6.5

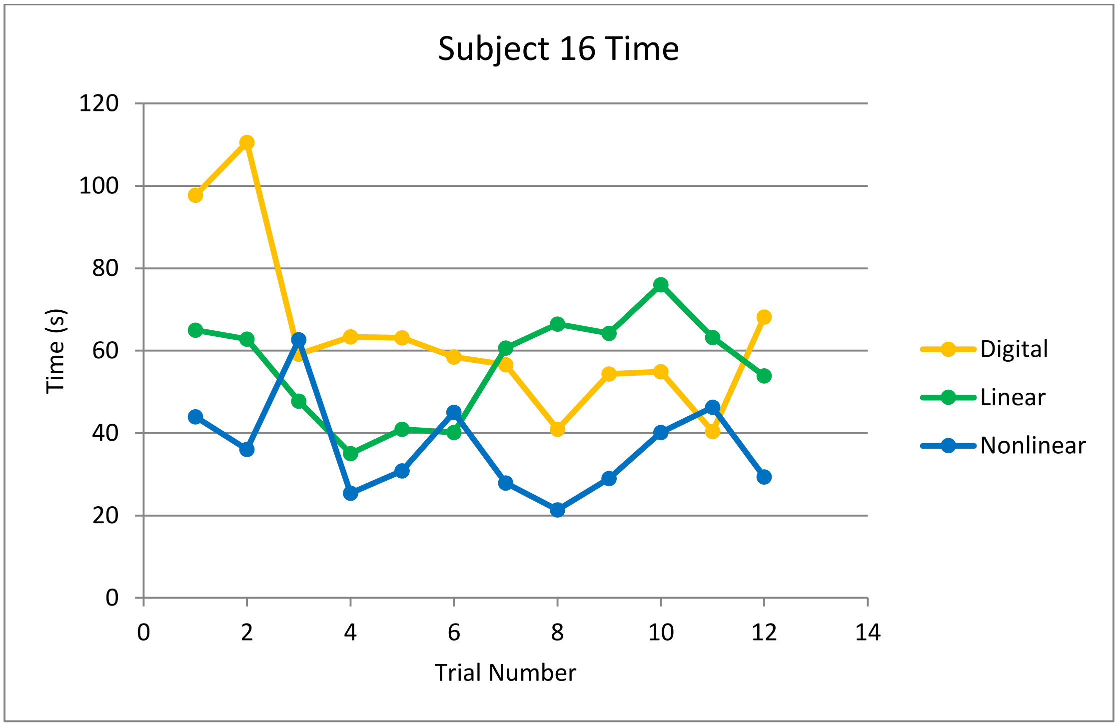


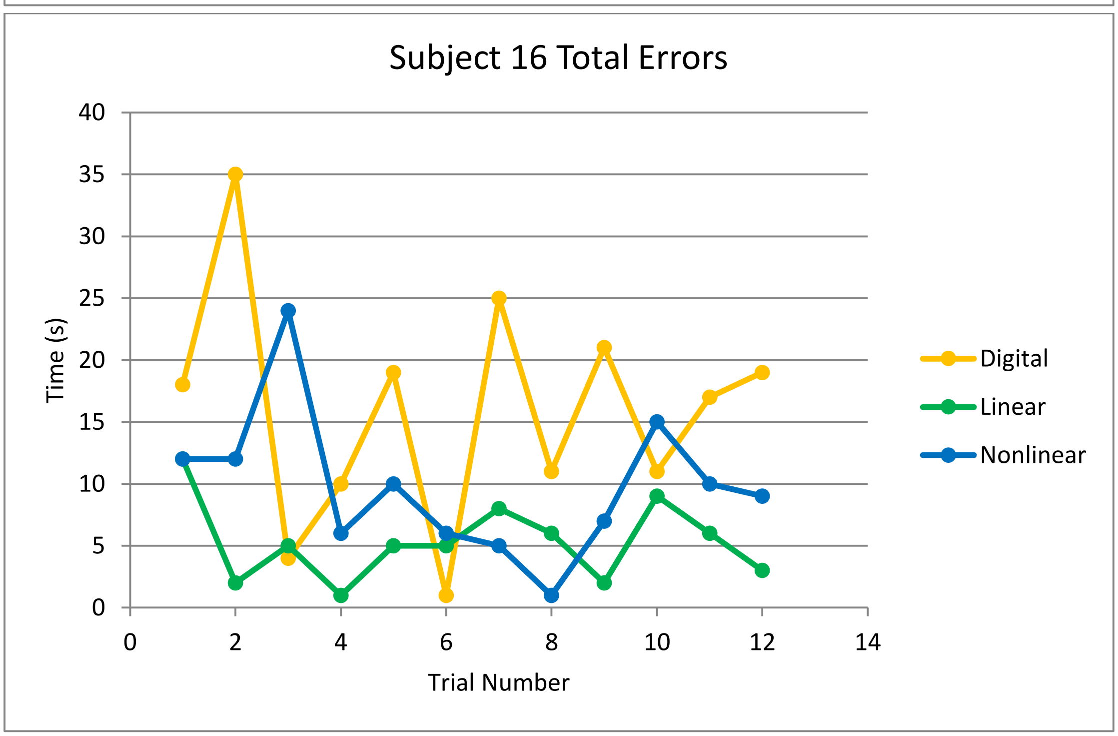


Subject 16							
Day 1							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
dig 1	1m 37.78s	97.78	10	6	2	18	103.78
dig 2	1m 50.54s	110.54	19	12	4	35	122.54
dig 3	0m 59.19s	59.19	2	1	1	4	62.19
dig 4	1m 3.37s	63.37	8	2	0	10	63.37
dig 5	1m 3.10s	63.1	10	8	1	19	66.1
dig 6	0m 58.44s	58.44	1	0	0	1	58.44
average		75.40333	8.333333	4.833333	1.333333	14.5	79.40333333
lin 1	1m 5.00s	65	8	2	2	12	71
lin 2	1m 2.81s	62.81	2	0	0	2	62.81
lin 3	0m 47.75s	47.75	3	2	0	5	47.75
lin 4	0m 35.03s	35.03	0	0	1	1	38.03
lin 5	0m 40.91s	40.91	3	2	0	5	40.91
lin 6	0m 40.19s	40.19	3	2	0	5	40.19
average		48.615	3.166667	1.333333	0.5	5	50.115
non 1	0m 43.97s	43.97	5	3	4	12	55.97
non 2	0m 36.07s	36.07	5	6	1	12	39.07
non 3	1m 2.63s	62.63	10	10	4	24	74.63
non 4	0m 25.44s	25.44	2	1	3	6	34.44
non 5	0m 30.87s	30.87	3	2	5	10	45.87
non 6	0m 45.03s	45.03	3	2	1	6	48.03
average		40.66833	4.666667	4	3	11.6666667	49.66833333

Day 2							
Trial	Time (min)	Time (s)	Reversals	Hits	Cones	Total Errors	Final Time (s)
lin 1	1m 0.66s	60.66	5	2	1	8	63.66
lin 2	1m 6.47s	66.47	4	2	0	6	66.47
lin 3	1m 4.19s	64.19	2	0	0	2	64.19
lin 4	1m 16.00s	76	4	3	2	9	82
lin 5	1m 3.22s	63.22	5	0	1	6	66.22
lin 6	0m 53.90s	53.9	3	0	0	3	53.9
average		64.0733	3.833333333	1.166667	0.6666667	5.66666667	66.07333333
dig 1	0m 56.59s	56.59	11	10	4	25	68.59
dig 2	0m 40.90s	40.9	5	2	4	11	52.9
dig 3	0m 54.35s	54.35	9	9	3	21	63.35
dig 4	0m 54.91s	54.91	5	3	3	11	63.91
dig 5	0m 40.37s	40.37	6	7	4	17	52.37
dig 6	1m 8.15s	68.15	6	7	6	19	86.15
average		52.545	7	6.333333	4	17.3333333	64.545
non 1	0m 27.91s	27.91	2	2	1	5	30.91
non 2	0m 21.35s	21.35	0	1	0	1	21.35
non 3	0m 29.00s	29	3	3	1	7	32
non 4	0m 40.19s	40.19	7	5	3	15	49.19
non 5	0m 46.28s	46.28	5	3	2	10	52.28
non 6	0m 29.34s	29.34	4	3	2	9	35.34
average		32.345	3.5	2.833333	1.5	7.83333333	36.845

Total Averages	Time (s)	Errors
Digital	63.9741667	15.91667
Linear	56.3441667	5.333333
Nonlinear	36.5066667	9.75





Appendix B

Individual Subject NASA TLX Data

Subject 1

Day 1

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	4	7	28
physical demand	1	7	7
temporal demand	4	4	16
performance	3	10	30
effort	3	7	21
frustration	0	4	0
		sum	102
		weighted rating	6.8

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	2	14	28
physical demand	3	10	30
temporal demand	1	3	3
performance	4	1	4
effort	5	5	25
frustration	0	2	0
		sum	90
		weighted rating	6

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	3	10	30
physical demand	1	4	4
temporal demand	2	4	8
performance	5	2	10
effort	4	4	16
frustration	0	2	0
		sum	68
		weighted rating	4.533333333

Day 2

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	3	4	12
physical demand	1	7	7
temporal demand	3	4	12
performance	4	1	4
effort	4	7	28
frustration	0	1	0
		sum	63
		weighted rating	4.2

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	1	10	10
physical demand	5	19	95
temporal demand	1	10	10
performance	3	2	6
effort	4	19	76
frustration	1	4	4
		sum	201
		weighted rating	13.4

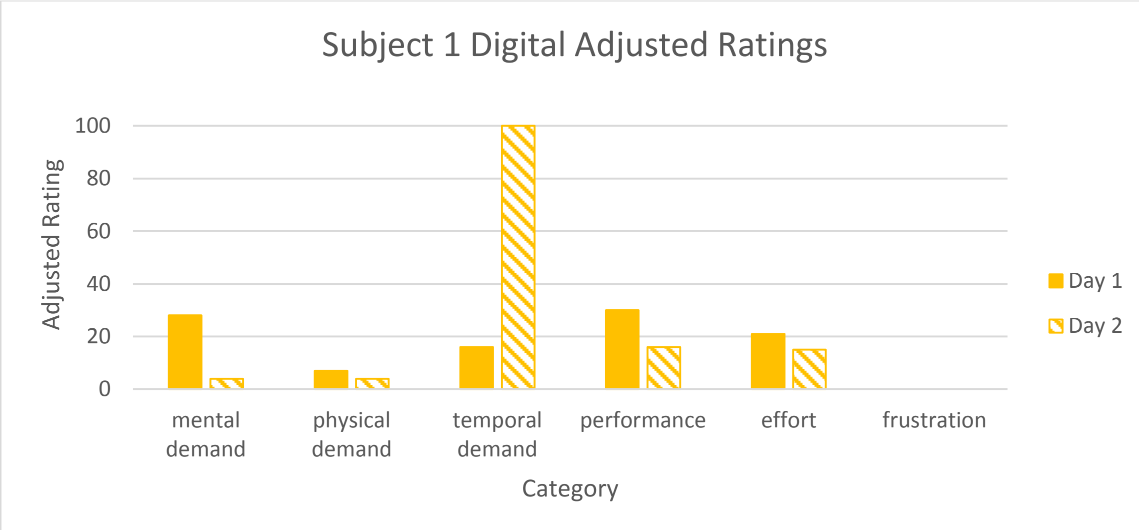
course digital			
scale title	weight	raw rating	adjusted rating
mental demand	2	2	4
physical demand	1	4	4
temporal demand	5	20	100
performance	4	4	16
effort	3	5	15
frustration	0	2	0
		sum	139
		weighted rating	9.266666667

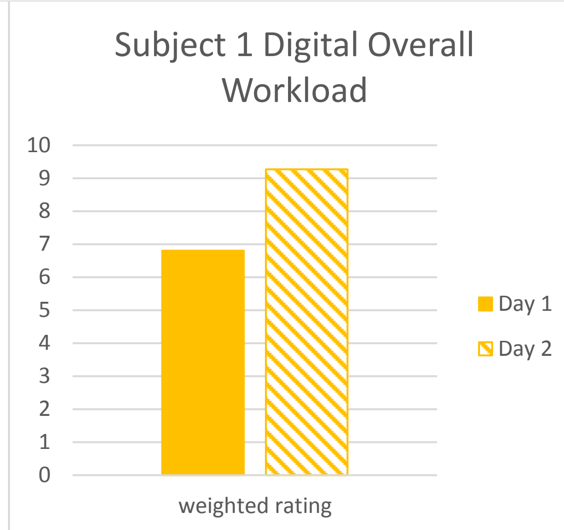
Averages

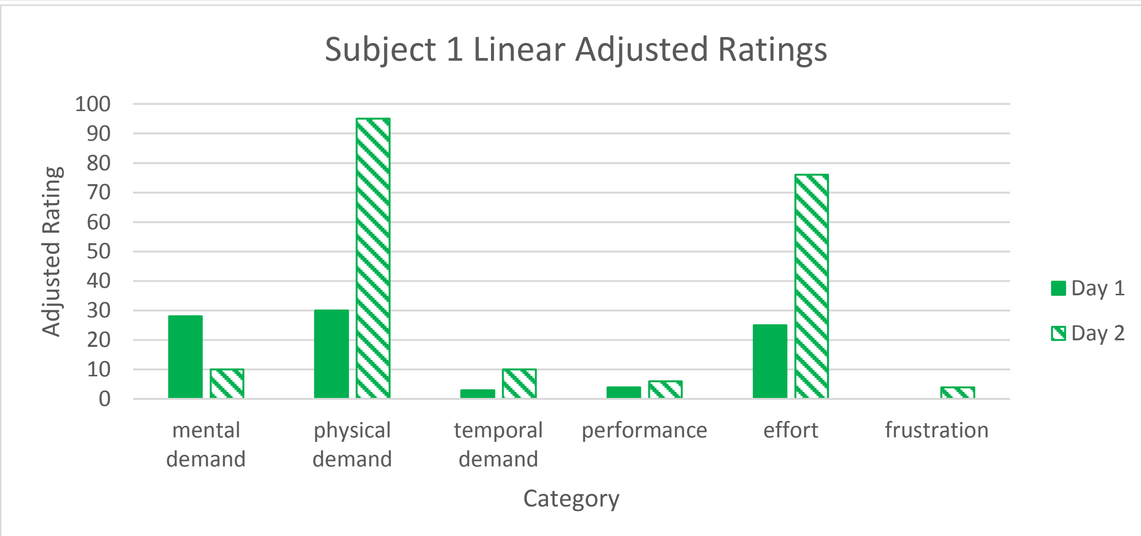
course digital	
scale title	adjusted rating
mental demand	16
physical demand	5.5
temporal demand	58
performance	23
effort	18
frustration	0
sum	120.5
weighted rating	8.033333333

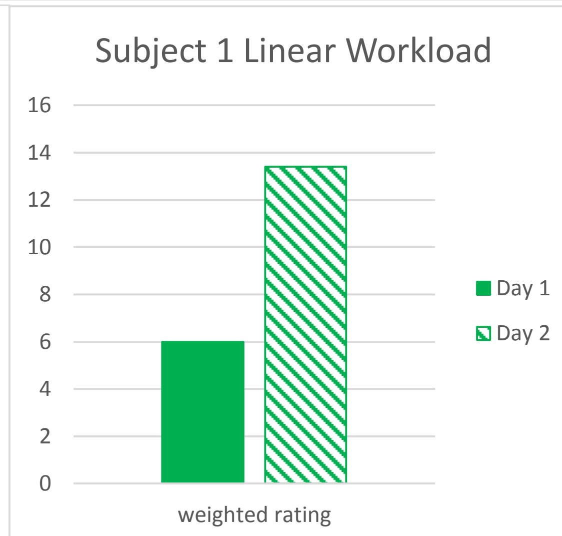
course linear	
scale title	adjusted rating
mental demand	19
physical demand	62.5
temporal demand	6.5
performance	5
effort	50.5
frustration	2
sum	145.5
weighted rating	9.7

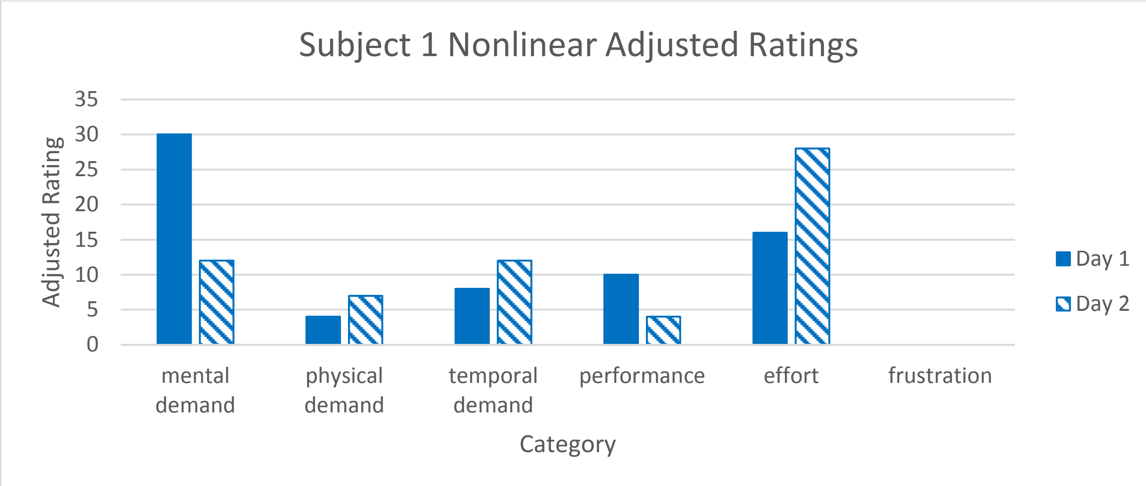
course nonlinear	
scale title	adjusted rating
mental demand	21
physical demand	5.5
temporal demand	10
performance	7
effort	22
frustration	0
sum	65.5
weighted rating	4.366666667

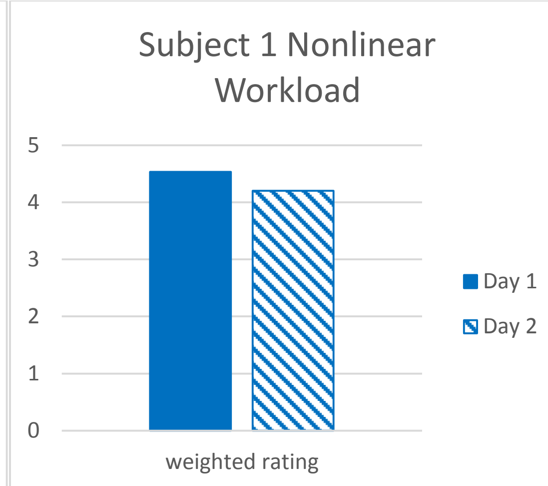

Subject 1 Digital Adjusted Ratings
Adjusted Rating
100
80
60
40
20
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

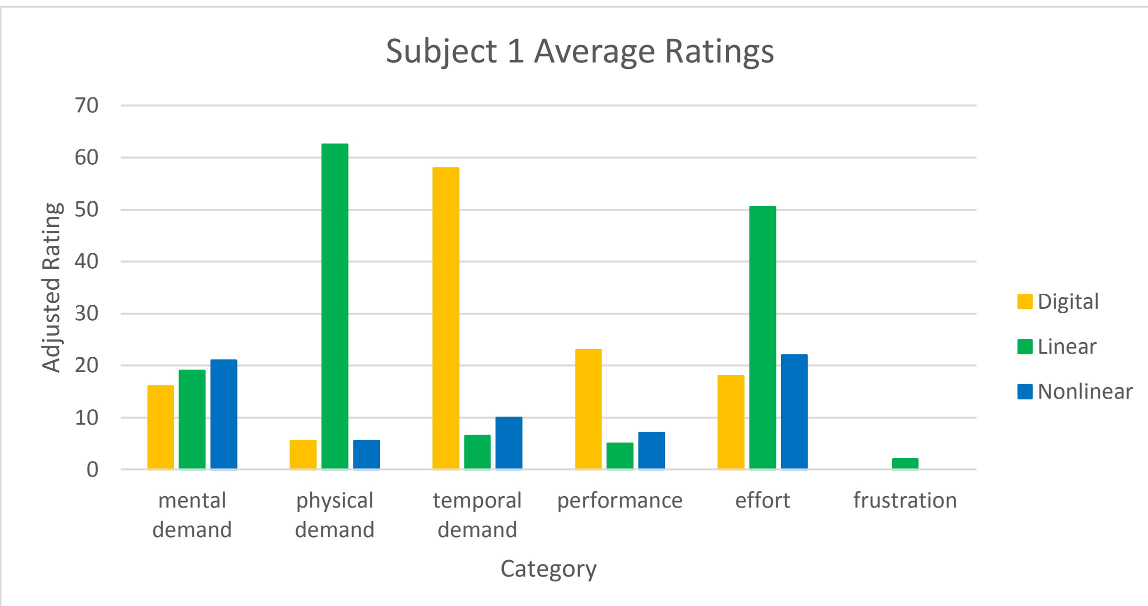

Subject 1 Digital Overall Workload
10
9
8
7
6
5
4
3
2
1
0
weighted rating
Day 1
Day 2

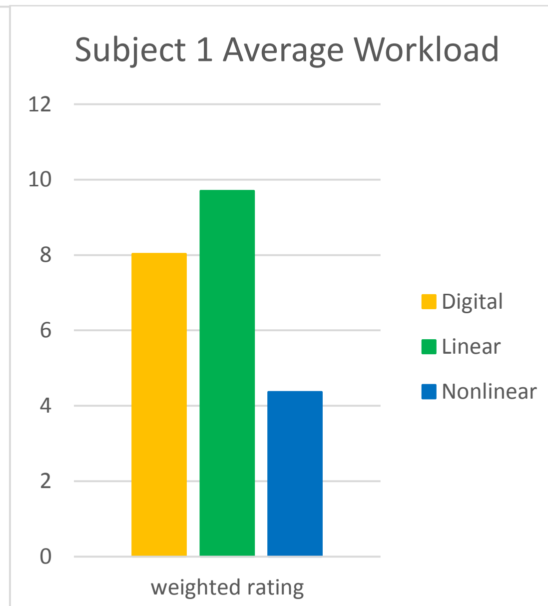

Subject 1 Linear Adjusted Ratings
Adjusted Rating
100
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 1 Linear Workload
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 1 Nonlinear Adjusted Ratings
Adjusted Rating
35
30
25
20
15
10
5
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 1 Nonlinear Workload
5
4
3
2
1
0
weighted rating
Day 1
Day 2


Subject 1 Average Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear


Subject 1 Average Workload
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

Subject 2

Day 1

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	1	1	1
physical demand	3	6	18
temporal demand	2	3	6
performance	5	4	20
effort	4	4	16
frustration	0	1	0
		sum	61
	weighted rating		4.066666667

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	0	4	0
physical demand	2	10	20
temporal demand	1	8	8
performance	5	16	80
effort	4	18	72
frustration	3	11	33
		sum	213
	weighted rating		14.2

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	1	1	1
physical demand	2	1	2
temporal demand	3	1	3
performance	5	3	15
effort	4	2	8
frustration	0	2	0
		sum	29
	weighted rating		1.933333333

Day 2

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	2	1	2
physical demand	3	1	3
temporal demand	1	1	1
performance	5	3	15
effort	4	1	4
frustration	0	1	0
		sum	25
	weighted rating		1.666666667

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	1	1	1
physical demand	3	2	6
temporal demand	2	2	4
performance	5	4	20
effort	4	4	16
frustration	0	1	0
		sum	47
	weighted rating		3.133333333

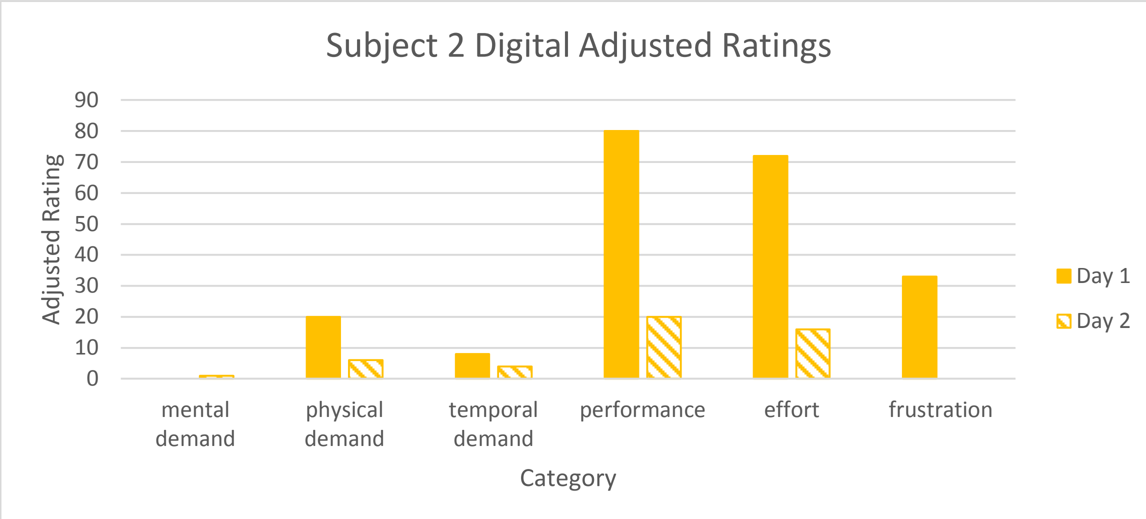
course linear			
scale title	weight	raw rating	adjusted rating
mental demand	3	1	3
physical demand	5	17	85
temporal demand	1	1	1
performance	3	2	6
effort	3	16	48
frustration	0	1	0
		sum	143
	weighted rating		9.533333333

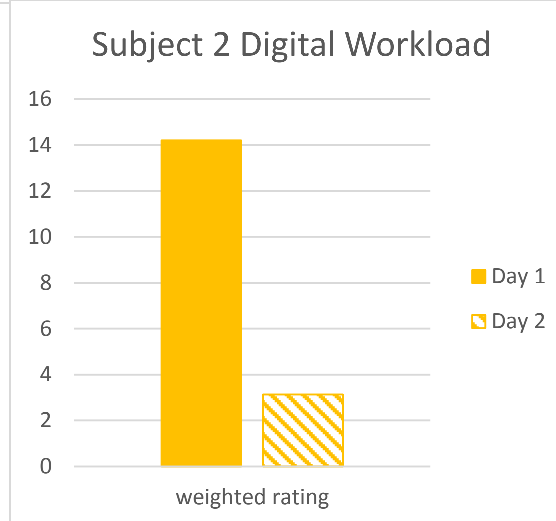
Averages

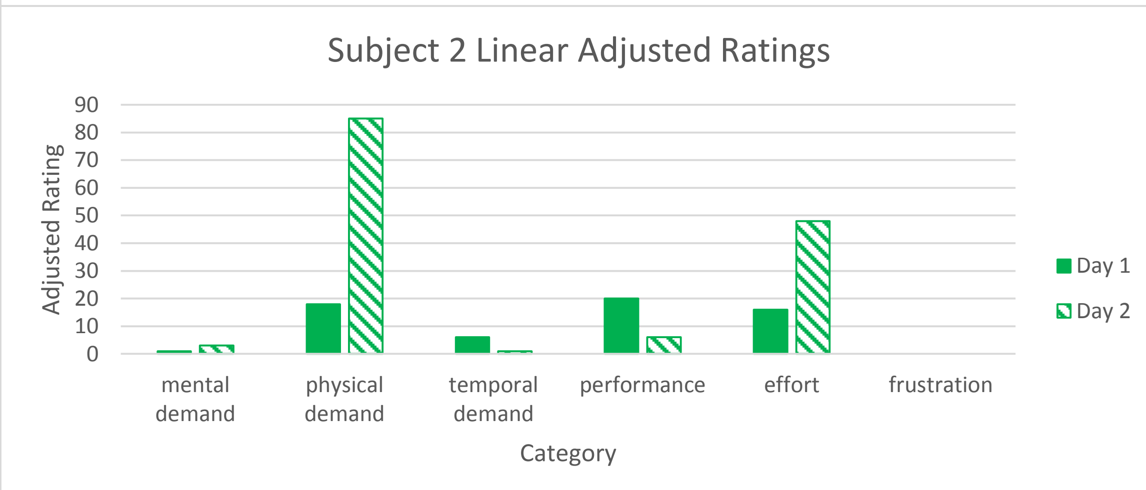
course digital	
scale title	adjusted rating
mental demand	0.5
physical demand	13
temporal demand	6
performance	50
effort	44
frustration	16.5
sum	130
weighted rating	8.666666667

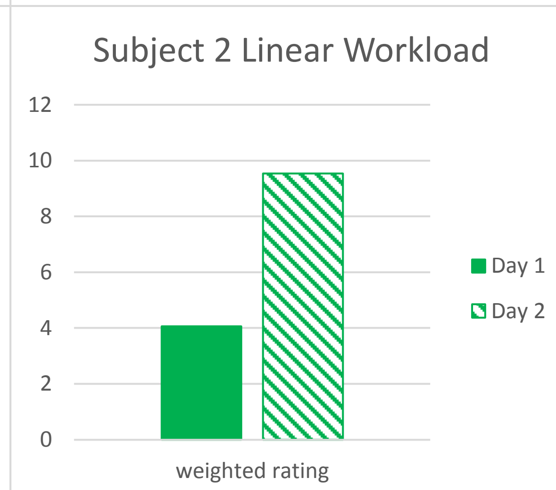
course linear	
scale title	adjusted rating
mental demand	2
physical demand	51.5
temporal demand	3.5
performance	13
effort	32
frustration	0
sum	102
weighted rating	6.8

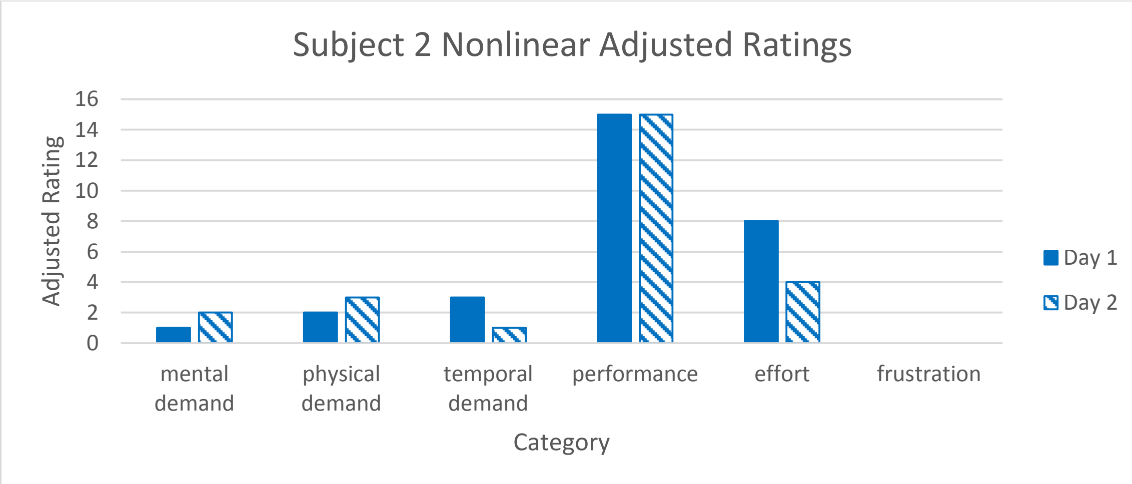
course nonlinear	
scale title	adjusted rating
mental demand	1.5
physical demand	2.5
temporal demand	2
performance	15
effort	6
frustration	0
sum	27
weighted rating	1.8

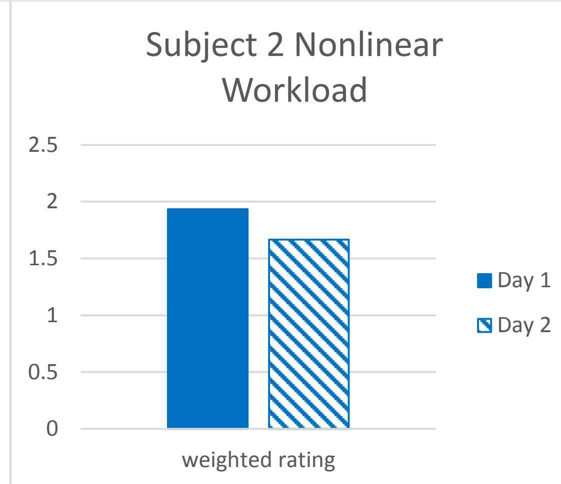

Subject 2 Digital Adjusted Ratings
Adjusted Rating
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

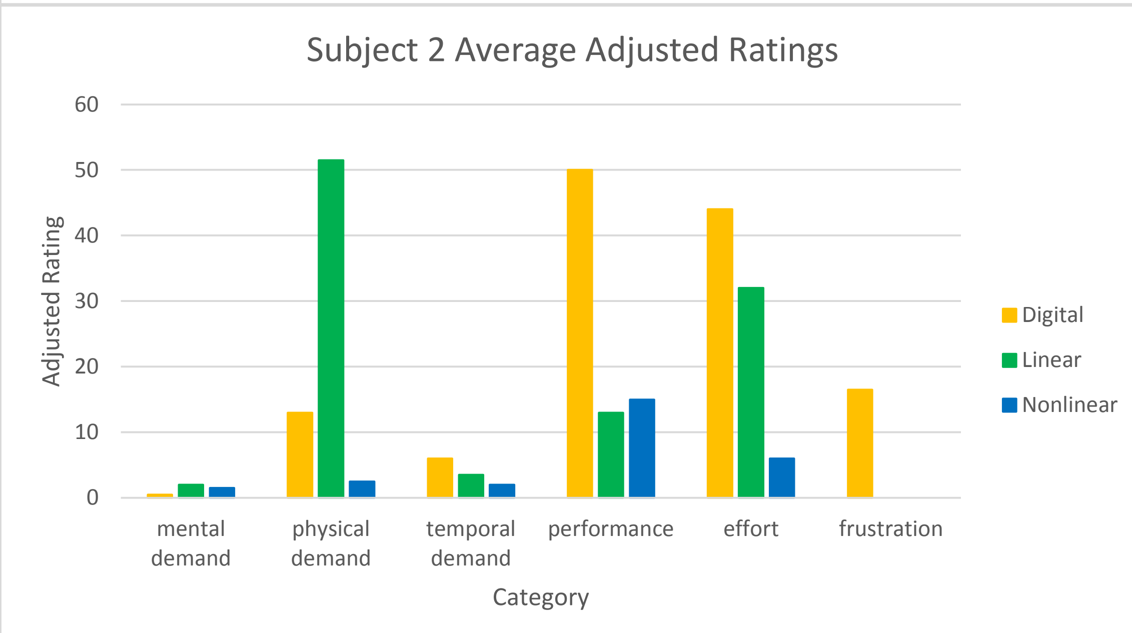

Subject 2 Digital Workload
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2

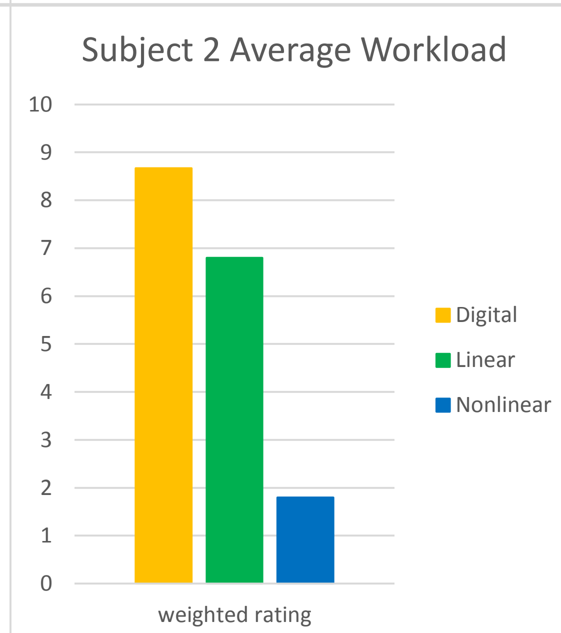

Subject 2 Linear Adjusted Ratings
Adjusted Rating
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 2 Linear Workload
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 2 Nonlinear Adjusted Ratings
Adjusted Rating
16
14
12
10
8
6
4
2
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 2 Nonlinear Workload
2.5
2
1.5
1
0.5
0
weighted rating
Day 1
Day 2


Subject 2 Average Adjusted Ratings
Adjusted Rating
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear


Subject 2 Average Workload
10
9
8
7
6
5
4
3
2
1
0
weighted rating
Digital
Linear
Nonlinear

Subject 3

Day 1

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	1	12	12
physical demand	5	15	75
temporal demand	0	11	0
performance	3	4	12
effort	4	15	60
frustration	2	3	6
		sum	165
		weighted rating	11

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	1	3	3
physical demand	5	16	80
temporal demand	2	2	4
performance	3	8	24
effort	4	7	28
frustration	0	2	0
		sum	139
		weighted rating	9.266666667

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	1	3	3
physical demand	5	13	65
temporal demand	2	2	4
performance	3	9	27
effort	4	12	48
frustration	0	1	0
		sum	147
		weighted rating	9.8

Day 2

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	0	3	0
physical demand	5	8	40
temporal demand	3	4	12
performance	3	8	24
effort	3	4	12
frustration	1	2	2
		sum	90
		weighted rating	6

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	2	6	12
physical demand	5	5	25
temporal demand	2	5	10
performance	1	5	5
effort	2	9	18
frustration	3	4	12
		sum	82
		weighted rating	5.466666667

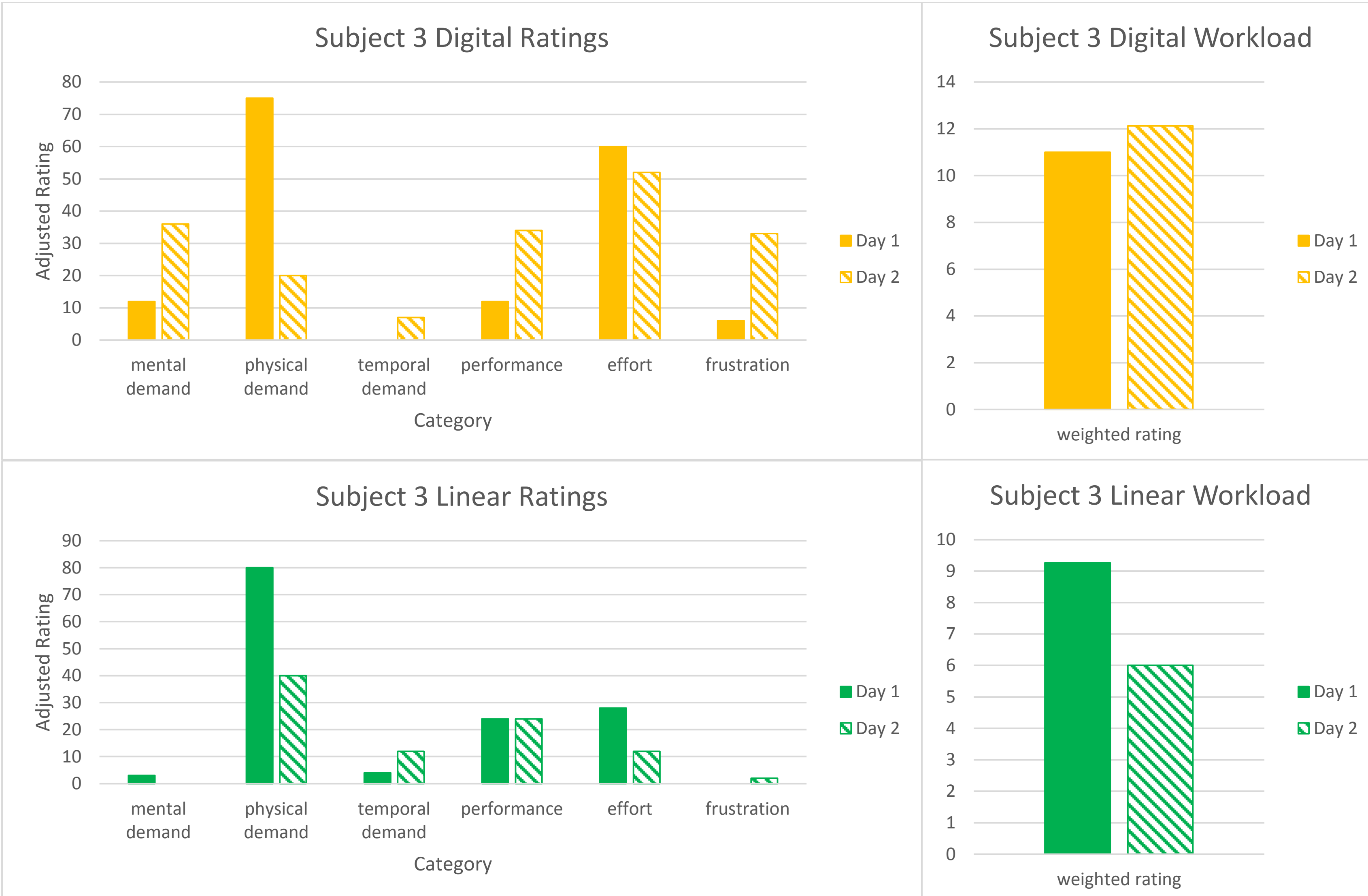
course digital			
scale title	weight	raw rating	adjusted rating
mental demand	3	12	36
physical demand	2	10	20
temporal demand	1	7	7
performance	2	17	34
effort	4	13	52
frustration	3	11	33
		sum	182
		weighted rating	12.13333333

Averages

course digital	
scale title	adjusted rating
mental demand	24
physical demand	47.5
temporal demand	3.5
performance	23
effort	56
frustration	19.5
sum	173.5
weighted rating	11.56666667

course linear	
scale title	adjusted rating
mental demand	1.5
physical demand	60
temporal demand	8
performance	24
effort	20
frustration	1
sum	114.5
weighted rating	7.633333333

course nonlinear	
scale title	adjusted rating
mental demand	7.5
physical demand	45
temporal demand	7
performance	16
effort	33
frustration	6
sum	114.5
weighted rating	7.633333333


Subject 3 Digital Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2
Subject 3 Digital Workload
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2
Subject 3 Linear Ratings
Adjusted Rating
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2
Subject 3 Linear Workload
10
9
8
7
6
5
4
3
2
1
0
weighted rating
Day 1
Day 2


Subject 3 Nonlinear Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2
Subject 3 Nonlinear Workload
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2
Subject 3 Average Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear
Subject 3 Average Workload
14
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

Subject 4

Day 1

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	5	18	90
physical demand	4	18	72
temporal demand	2	13	26
performance	1	10	10
effort	3	20	60
frustration	0	10	0
		sum	258
		weighted rating	17.2

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	4	5	20
physical demand	3	7	21
temporal demand	2	2	4
performance	2	3	6
effort	4	5	20
frustration	0	3	0
		sum	71
		weighted rating	4.733333333

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	5	6	30
physical demand	4	17	68
temporal demand	3	6	18
performance	1	9	9
effort	2	16	32
frustration	0	5	0
		sum	157
		weighted rating	10.46666667

Day 2

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	4	3	12
physical demand	4	8	32
temporal demand	1	1	1
performance	2	3	6
effort	4	2	8
frustration	0	1	0
		sum	59
		weighted rating	3.933333333

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	4	3	12
physical demand	3	3	9
temporal demand	2	1	2
performance	3	3	9
effort	3	3	9
frustration	0	2	0
		sum	41
		weighted rating	2.733333333

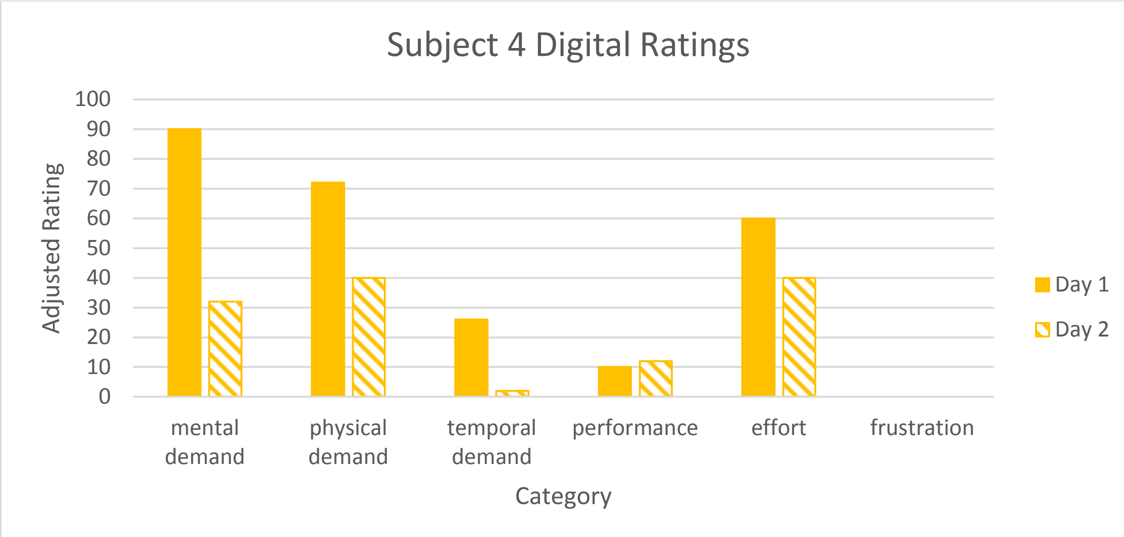
course digital			
scale title	weight	raw rating	adjusted rating
mental demand	4	8	32
physical demand	4	10	40
temporal demand	1	2	2
performance	2	6	12
effort	4	10	40
frustration	0	1	0
		sum	126
		weighted rating	8.4

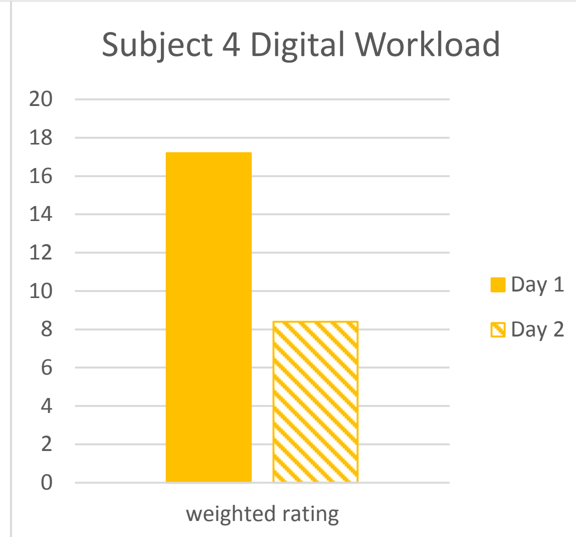
Averages

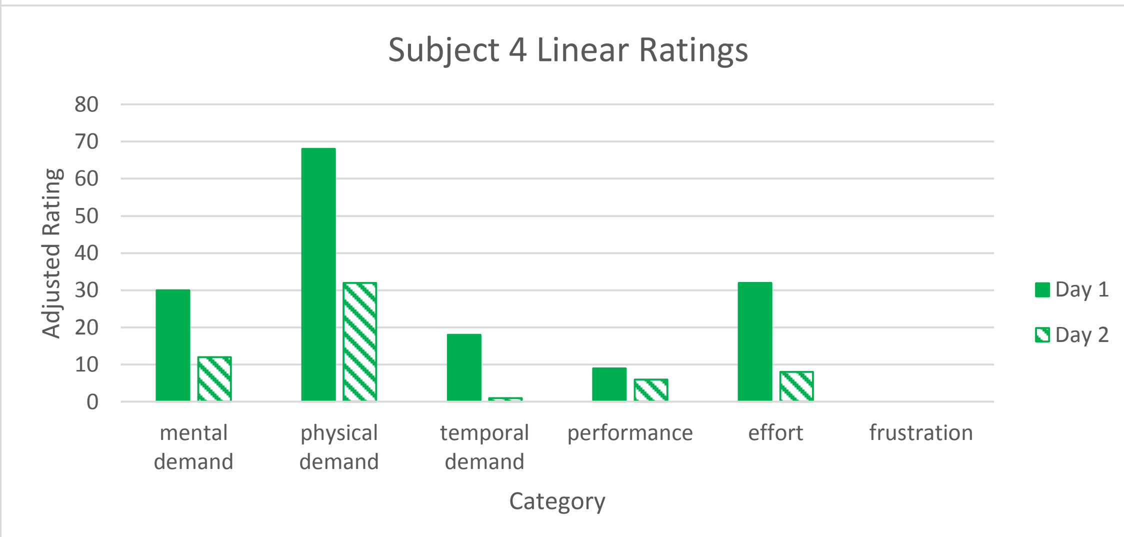
course digital	
scale title	adjusted rating
mental demand	61
physical demand	56
temporal demand	14
performance	11
effort	50
frustration	0
sum	192
weighted rating	12.8

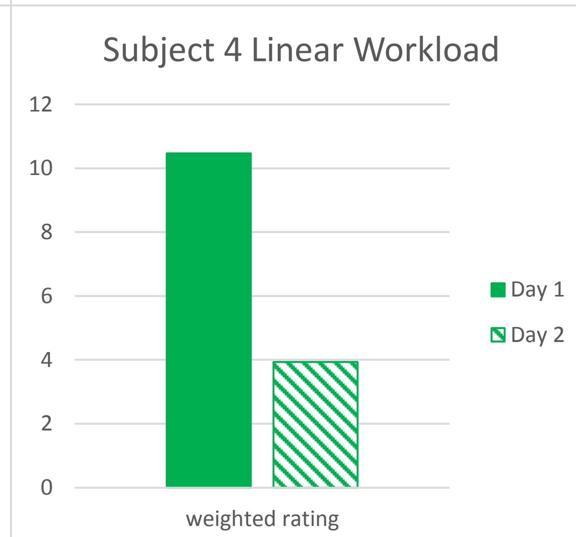
course linear	
scale title	adjusted rating
mental demand	21
physical demand	50
temporal demand	9.5
performance	7.5
effort	20
frustration	0
sum	108
weighted rating	7.2

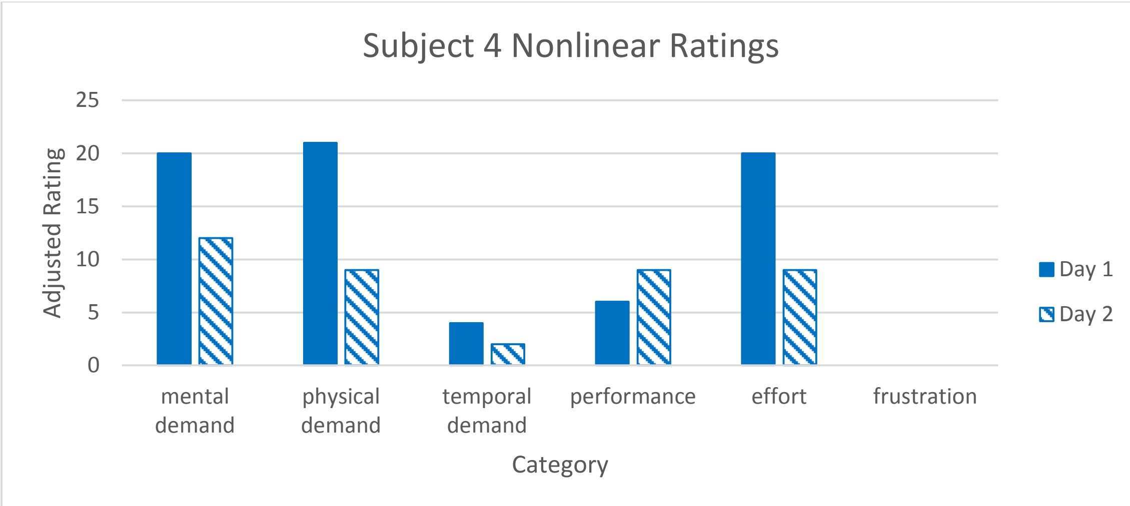
course nonlinear	
scale title	adjusted rating
mental demand	16
physical demand	15
temporal demand	3
performance	7.5
effort	14.5
frustration	0
sum	56
weighted rating	3.733333333

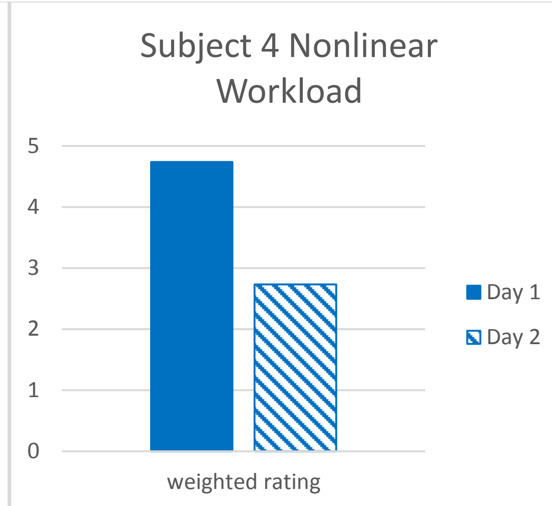

Subject 4 Digital Ratings
Adjusted Rating
100
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

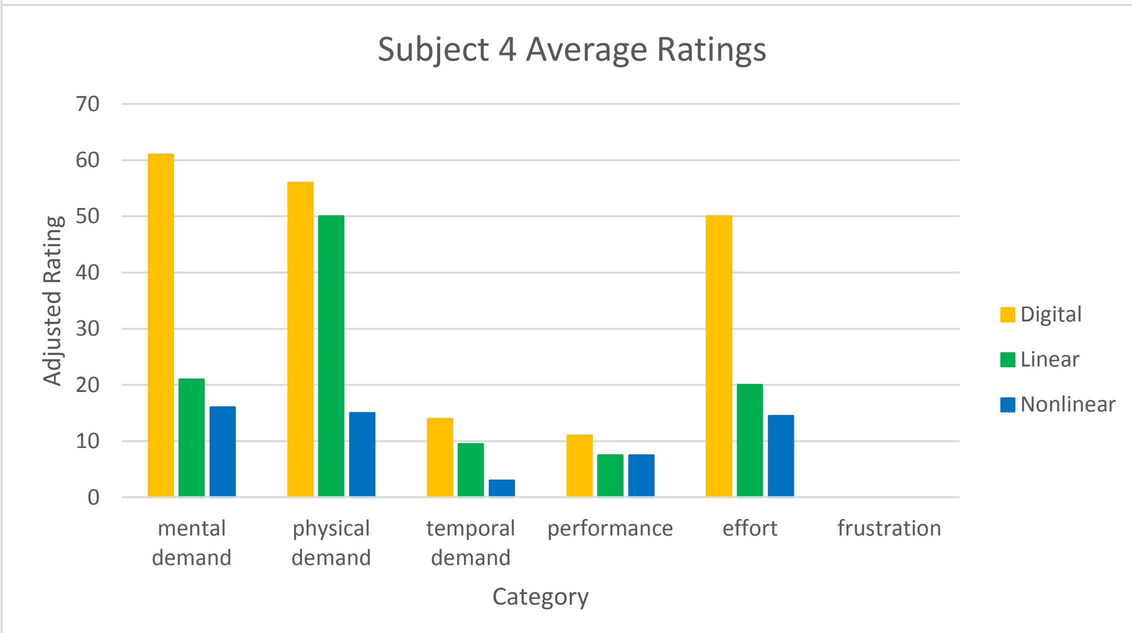

Subject 4 Digital Workload
20
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2

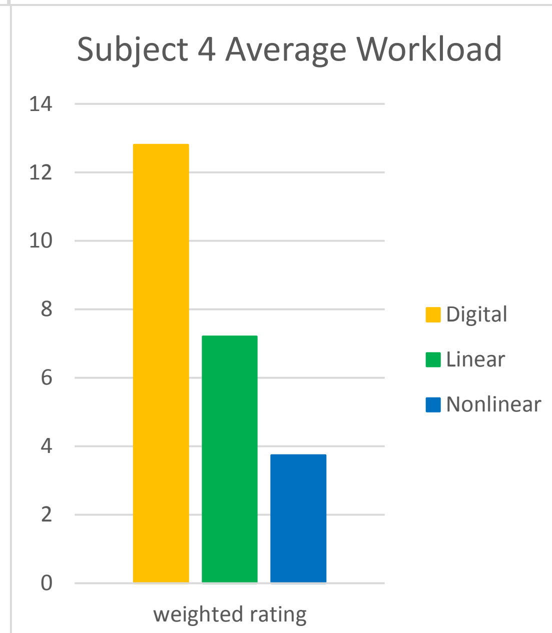

Subject 4 Linear Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 4 Linear Workload
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 4 Nonlinear Ratings
Adjusted Rating
25
20
15
10
5
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 4 Nonlinear Workload
5
4
3
2
1
0
weighted rating
Day 1
Day 2


Subject 4 Average Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear


Subject 4 Average Workload
14
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

Subject 5

Day 1

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	5	12	60
physical demand	2	7	14
temporal demand	1	5	5
performance	3	16	48
effort	4	10	40
frustration	0	5	0
		sum	167
		weighted rating	11.13333333

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	5	11	55
physical demand	2	8	16
temporal demand	0	5	0
performance	2	7	14
effort	3	12	36
frustration	3	11	33
		sum	154
		weighted rating	10.26666667

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	5	9	45
physical demand	2	5	10
temporal demand	1	4	4
performance	4	11	44
effort	3	11	33
frustration	0	5	0
		sum	136
		weighted rating	9.066666667

Day 2

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	5	9	45
physical demand	2	4	8
temporal demand	1	3	3
performance	3	8	24
effort	4	12	48
frustration	0	2	0
		sum	128
		weighted rating	8.533333333

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	5	13	65
physical demand	1	7	7
temporal demand	1	5	5
performance	1	6	6
effort	4	12	48
frustration	3	7	21
		sum	152
		weighted rating	10.13333333

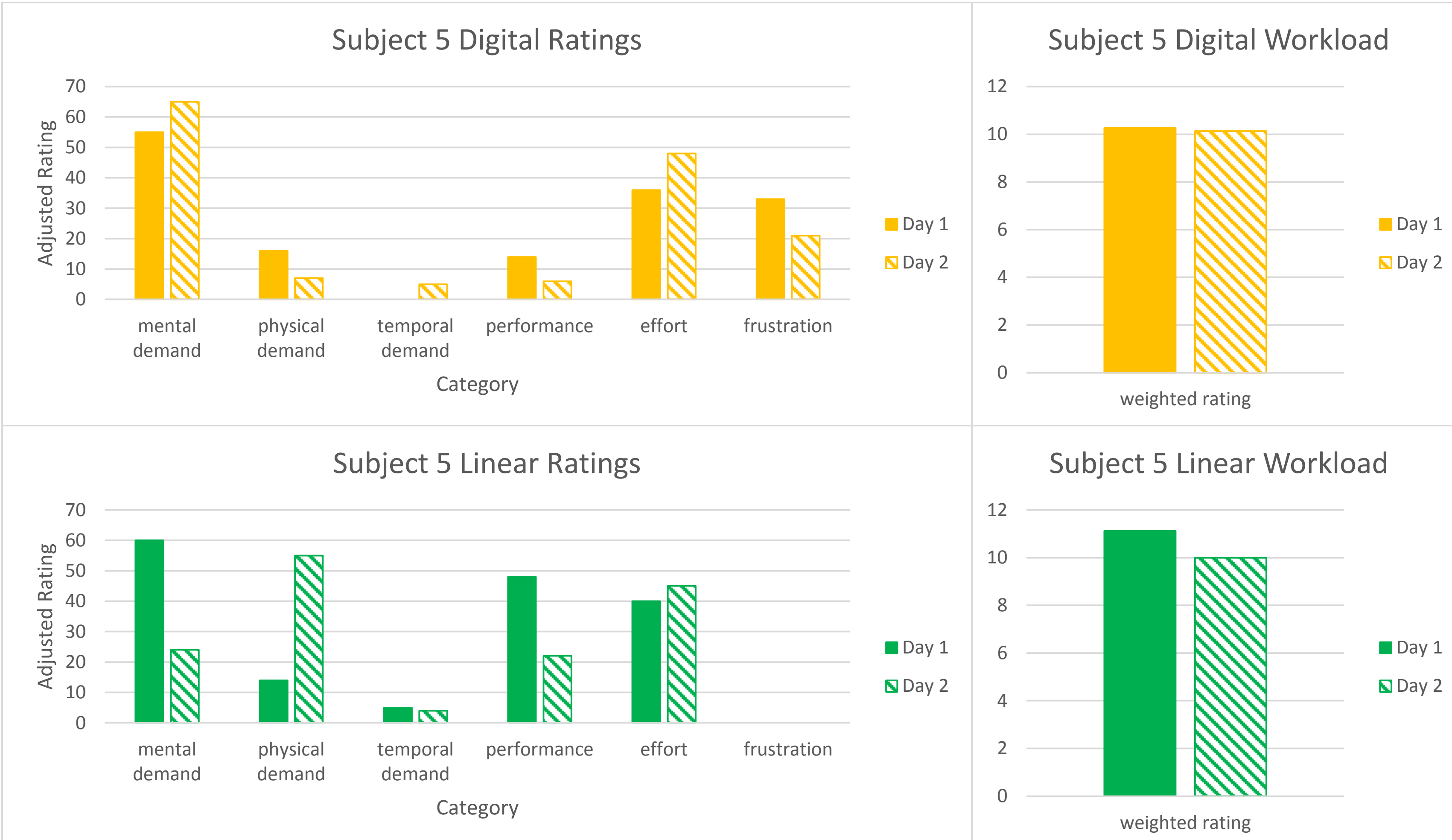
course linear			
scale title	weight	raw rating	adjusted rating
mental demand	4	6	24
physical demand	5	11	55
temporal demand	1	4	4
performance	2	11	22
effort	3	15	45
frustration	0	3	0
		sum	150
		weighted rating	10

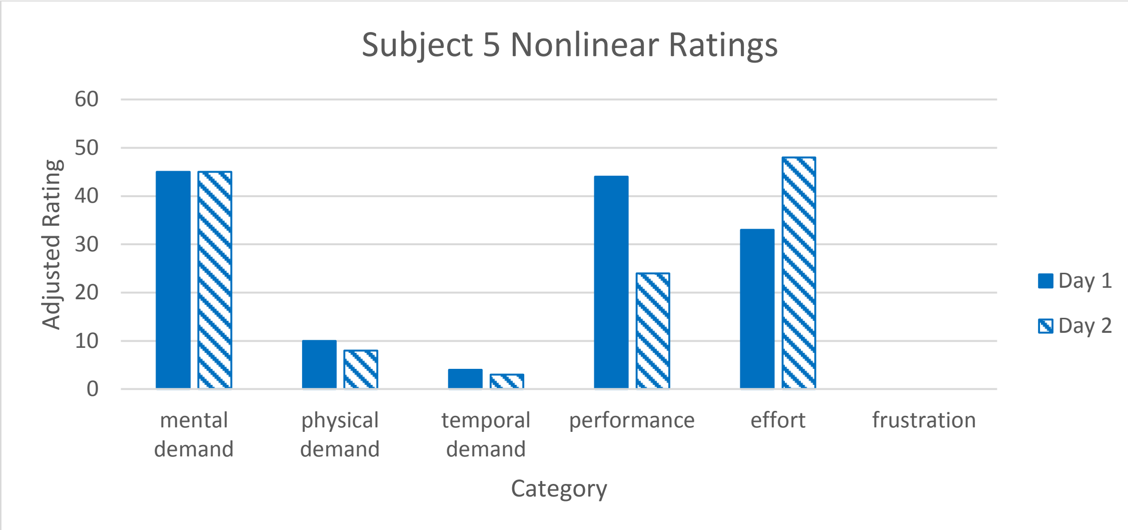
Averages

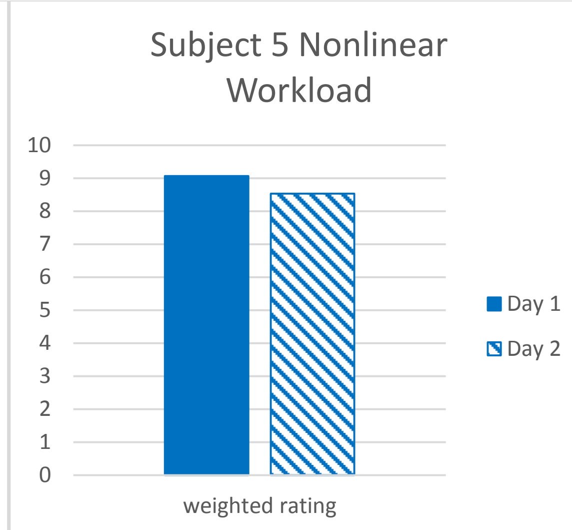
course digital	
scale title	adjusted rating
mental demand	60
physical demand	11.5
temporal demand	2.5
performance	10
effort	42
frustration	27
sum	153
weighted rating	10.2

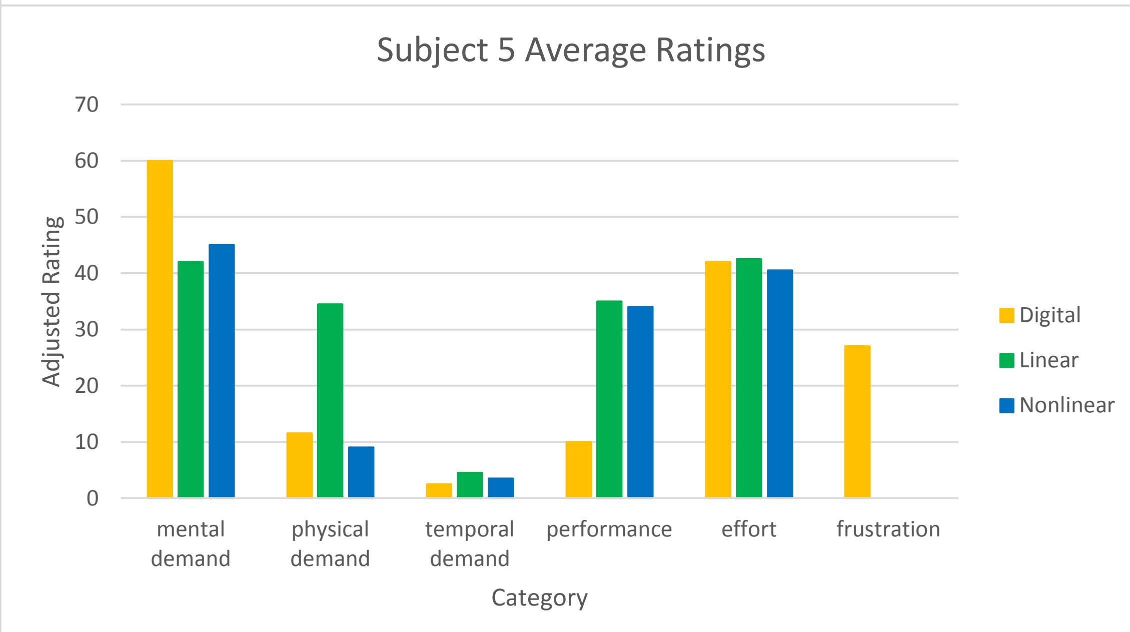
course linear	
scale title	adjusted rating
mental demand	42
physical demand	34.5
temporal demand	4.5
performance	35
effort	42.5
frustration	0
sum	158.5
weighted rating	10.56666667

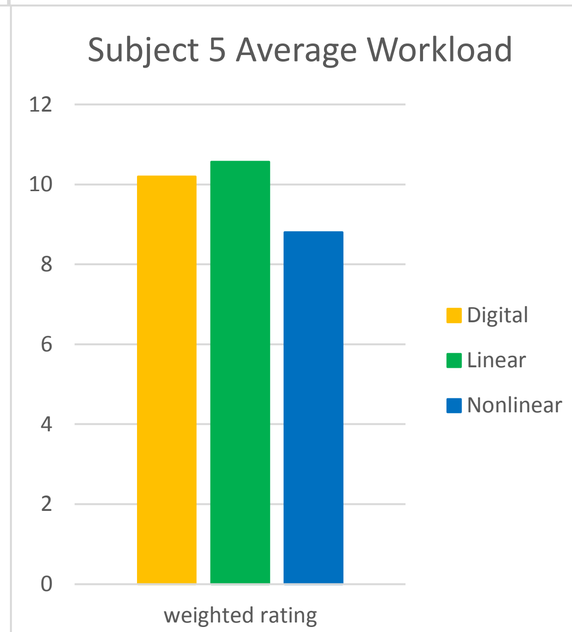
course nonlinear	
scale title	adjusted rating
mental demand	45
physical demand	9
temporal demand	3.5
performance	34
effort	40.5
frustration	0
sum	132
weighted rating	8.8


Subject 5 Digital Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2
Subject 5 Digital Workload
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2
Subject 5 Linear Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2
Subject 5 Linear Workload
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 5 Nonlinear Ratings
Adjusted Rating
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 5 Nonlinear Workload
10
9
8
7
6
5
4
3
2
1
0
weighted rating
Day 1
Day 2


Subject 5 Average Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear


Subject 5 Average Workload
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

Subject 6

Day 1

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	4	18	72
physical demand	1	10	10
temporal demand	1	13	13
performance	2	8	16
effort	4	20	80
frustration	3	15	45
		sum	236
		weighted rating	15.73333333

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	5	19	95
physical demand	0	15	0
temporal demand	2	16	32
performance	3	6	18
effort	2	18	36
frustration	3	20	60
		sum	241
		weighted rating	16.06666667

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	4	18	72
physical demand	3	12	36
temporal demand	1	17	17
performance	2	7	14
effort	2	13	26
frustration	3	10	30
		sum	195
		weighted rating	13

Day 2

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	2	14	28
physical demand	3	16	48
temporal demand	1	6	6
performance	3	1	3
effort	4	6	24
frustration	2	2	4
		sum	113
		weighted rating	7.533333333

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	4	14	56
physical demand	3	15	45
temporal demand	2	4	8
performance	3	1	3
effort	3	14	42
frustration	0	3	0
		sum	154
		weighted rating	10.26666667

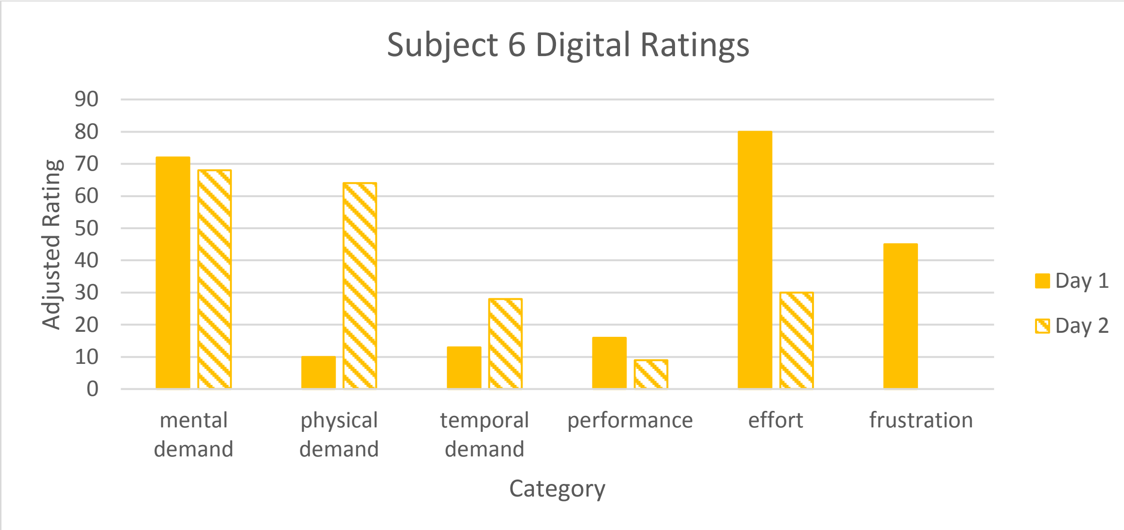
course digital			
scale title	weight	raw rating	adjusted rating
mental demand	4	17	68
physical demand	4	16	64
temporal demand	2	14	28
performance	3	3	9
effort	2	15	30
frustration	0	9	0
		sum	199
		weighted rating	13.26666667

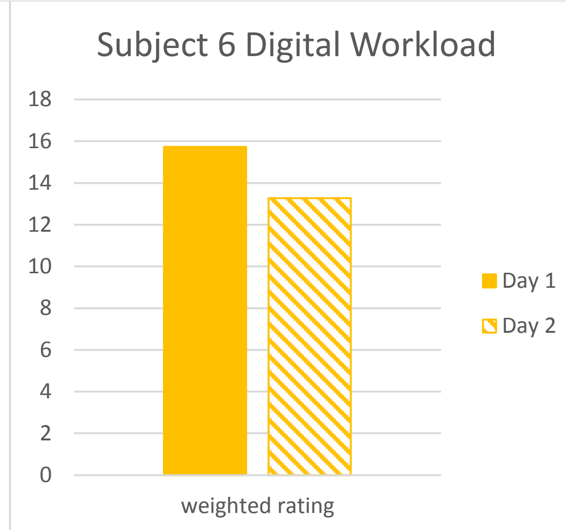
Averages

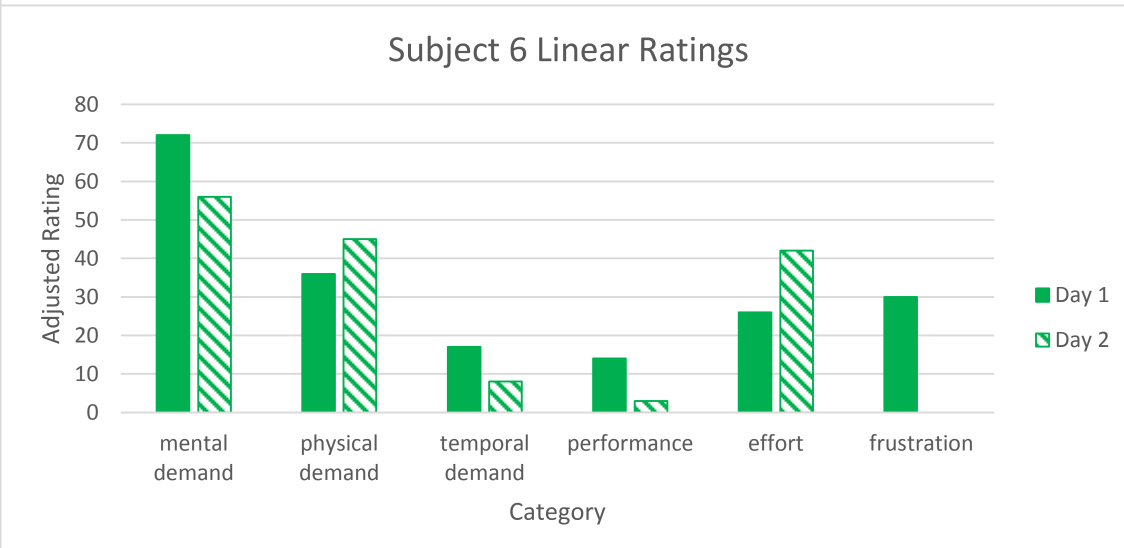
course digital	
scale title	adjusted rating
mental demand	70
physical demand	37
temporal demand	20.5
performance	12.5
effort	55
frustration	22.5
sum	217.5
weighted rating	14.5

course linear	
scale title	adjusted rating
mental demand	64
physical demand	40.5
temporal demand	12.5
performance	8.5
effort	34
frustration	15
sum	174.5
weighted rating	11.63333333

course nonlinear	
scale title	adjusted rating
mental demand	61.5
physical demand	24
temporal demand	19
performance	10.5
effort	30
frustration	32
sum	177
weighted rating	11.8


Subject 6 Digital Ratings
Adjusted Rating
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 6 Digital Workload
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 6 Linear Ratings
Adjusted Rating
80
70
60
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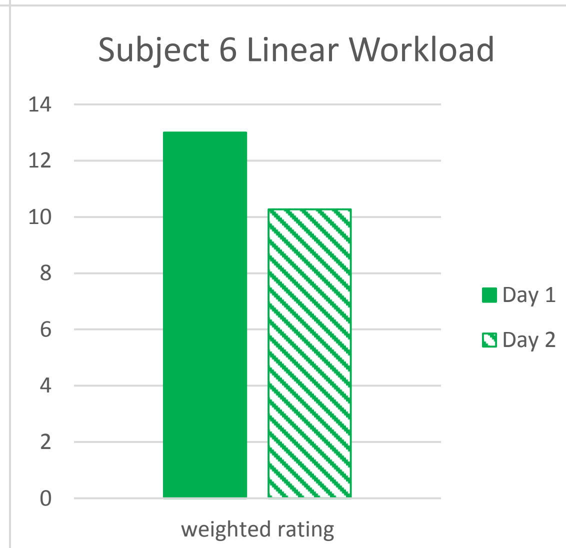
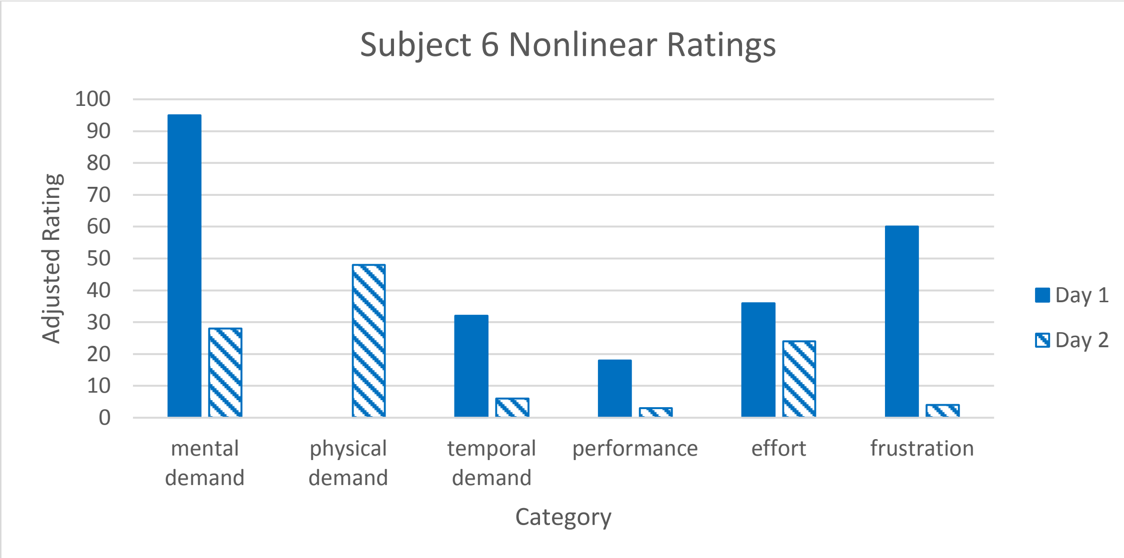
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 6 Linear Workload
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 6 Nonlinear Ratings
Adjusted Rating
100
90
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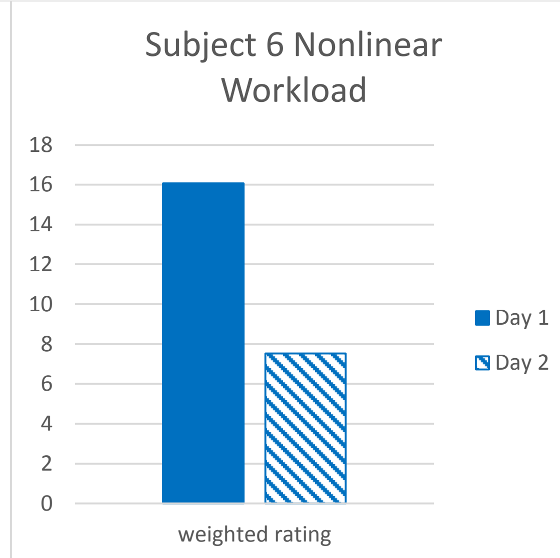
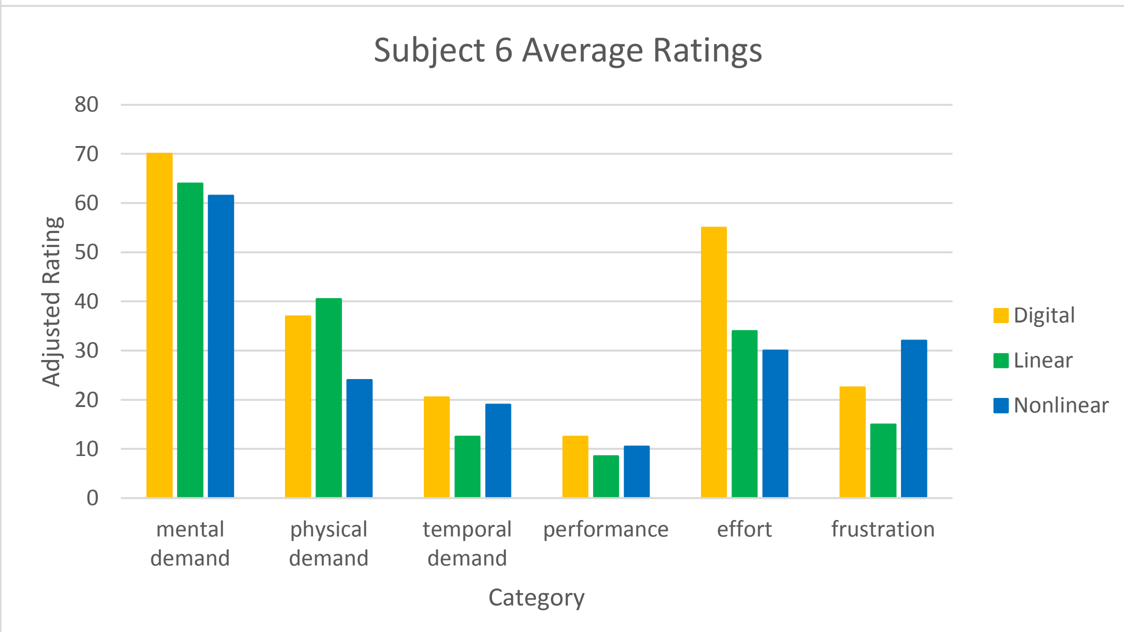
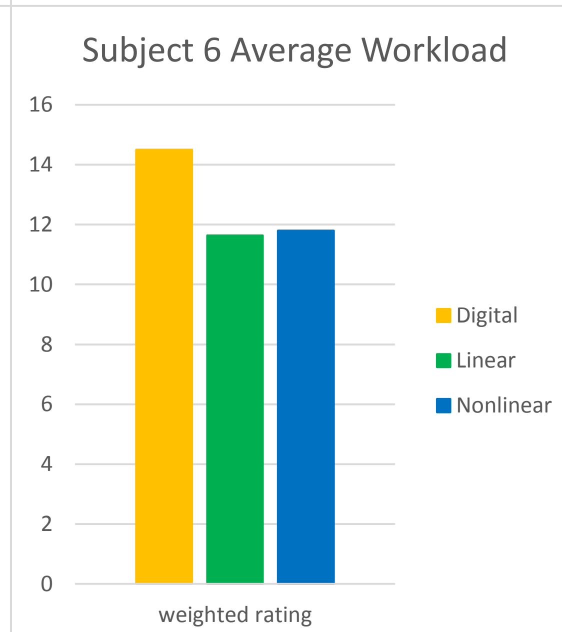
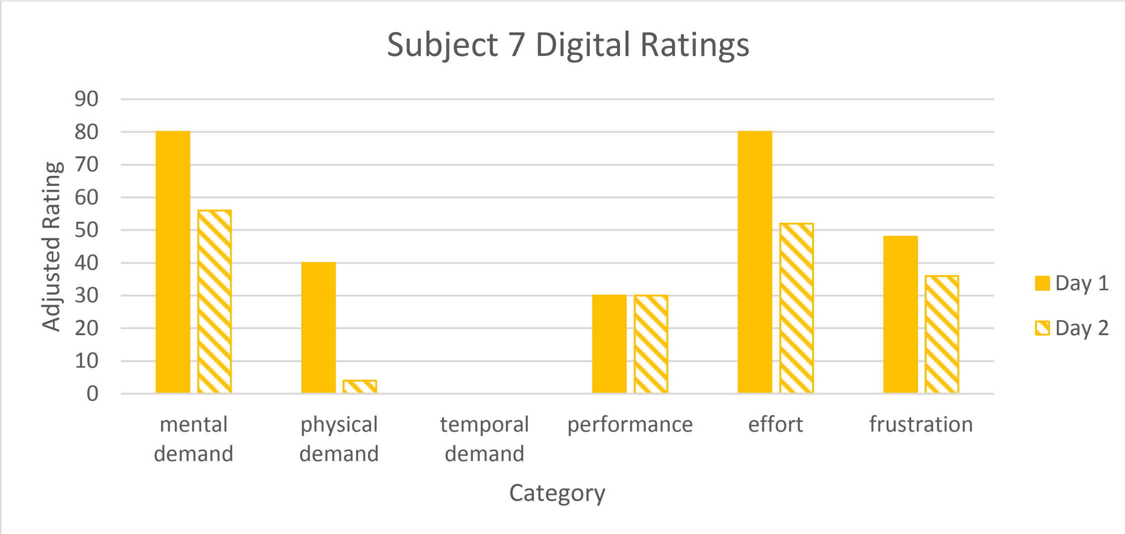
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

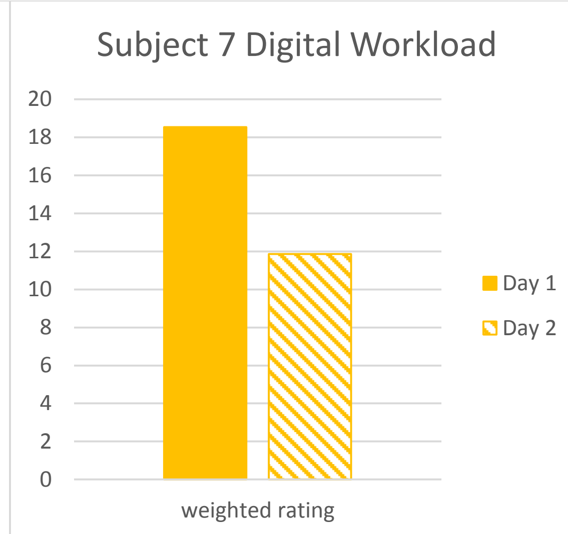

Subject 6 Nonlinear Workload
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2

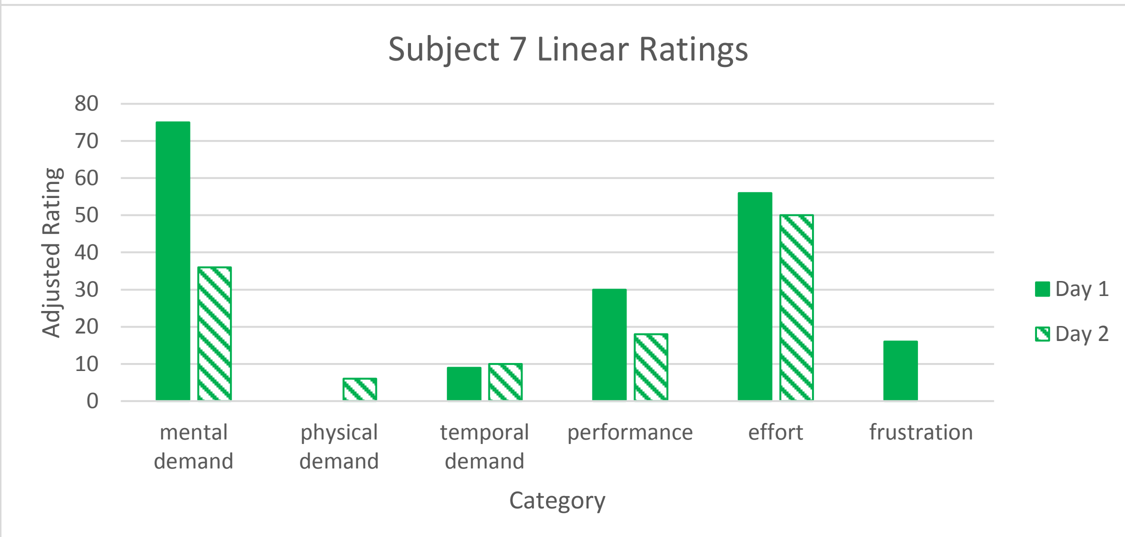

Subject 6 Average Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear

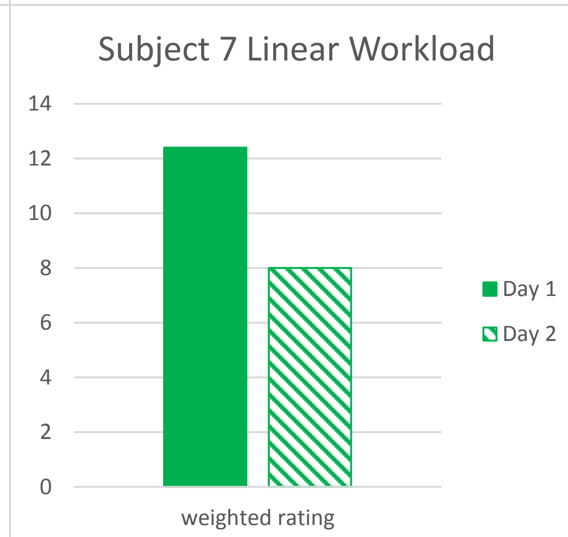

Subject 6 Average Workload
16
14
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

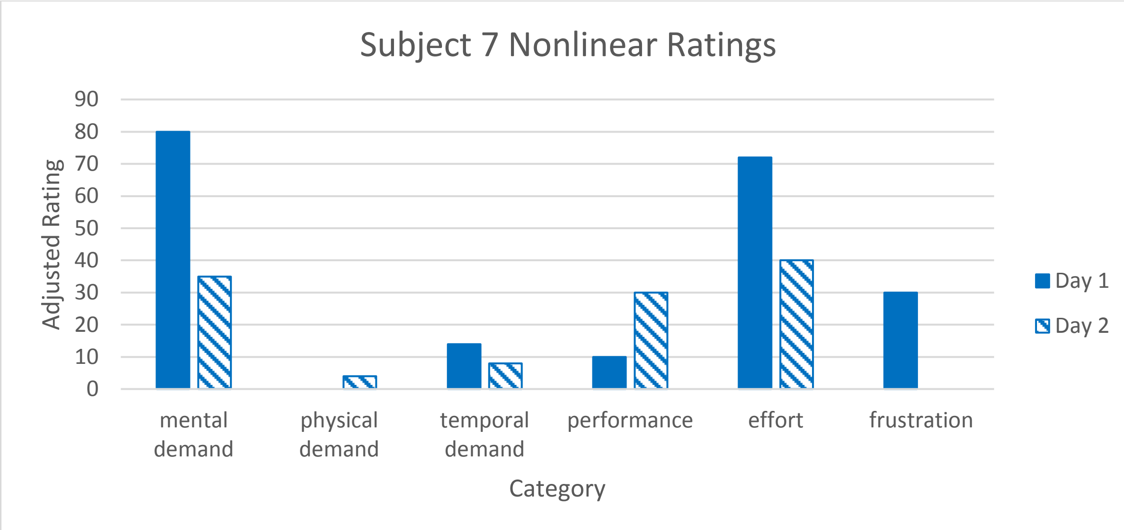
Subject 7											
Day 1					Day 2					Averages	
course nonlinear					course linear					course digital	
scale title	weight	raw rating	adjusted rating		scale title	weight	raw rating	adjusted rating		scale title	adjusted rating
mental demand	5	16	80		mental demand	4	9	36		mental demand	68
physical demand	0	6	0		physical demand	1	6	6		physical demand	22
temporal demand	2	7	14		temporal demand	2	5	10		temporal demand	0
performance	1	10	10		performance	3	6	18		performance	30
effort	4	18	72		effort	5	10	50		effort	66
frustration	3	10	30		frustration	0	3	0		frustration	42
		sum	206				sum	120		sum	228
		weighted rating	13.73333333				weighted rating	8		weighted rating	15.2
course linear					course nonlinear					course linear	
scale title	weight	raw rating	adjusted rating		scale title	weight	raw rating	adjusted rating		scale title	adjusted rating
mental demand	5	15	75		mental demand	5	7	35		mental demand	55.5
physical demand	0	8	0		physical demand	1	4	4		physical demand	3
temporal demand	1	9	9		temporal demand	2	4	8		temporal demand	9.5
performance	3	10	30		performance	3	10	30		performance	24
effort	4	14	56		effort	4	10	40		effort	53
frustration	2	8	16		frustration	0	4	0		frustration	8
		sum	186				sum	117		sum	153
		weighted rating	12.4				weighted rating	7.8		weighted rating	10.2
course digital					course digital					course nonlinear	
scale title	weight	raw rating	adjusted rating		scale title	weight	raw rating	adjusted rating		scale title	adjusted rating
mental demand	4	20	80		mental demand	4	14	56		mental demand	57.5
physical demand	2	20	40		physical demand	1	4	4		physical demand	2
temporal demand	0	10	0		temporal demand	0	5	0		temporal demand	11
performance	2	15	30		performance	2	15	30		performance	20
effort	4	20	80		effort	4	13	52		effort	56
frustration	3	16	48		frustration	4	9	36		frustration	15
		sum	278				sum	178		sum	161.5
		weighted rating	18.53333333				weighted rating	11.86666667		weighted rating	10.76666667

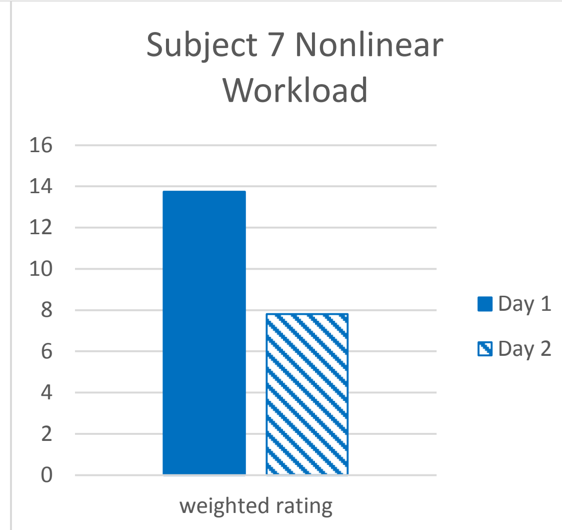

Subject 7 Digital Ratings
Adjusted Rating
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

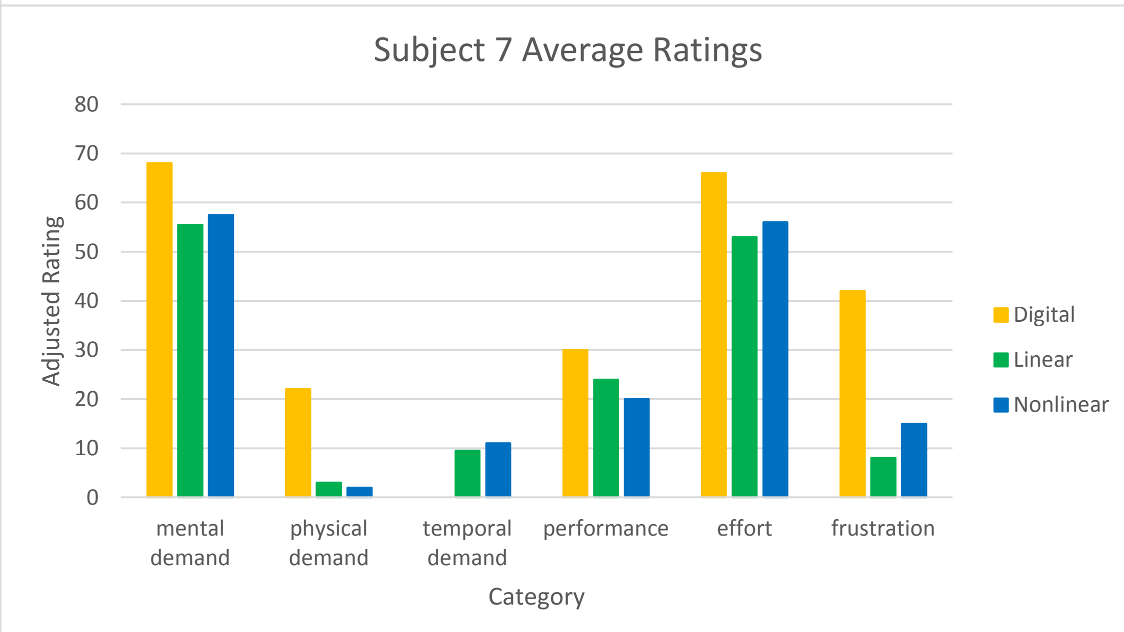

Subject 7 Digital Workload
20
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2

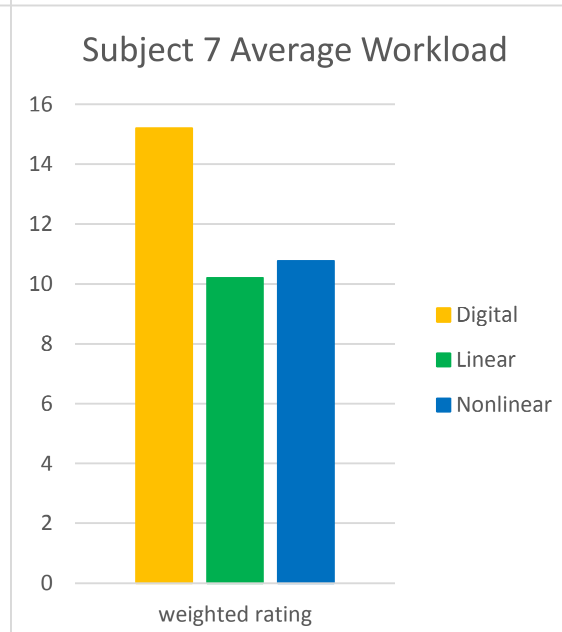

Subject 7 Linear Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 7 Linear Workload
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 7 Nonlinear Ratings
Adjusted Rating
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

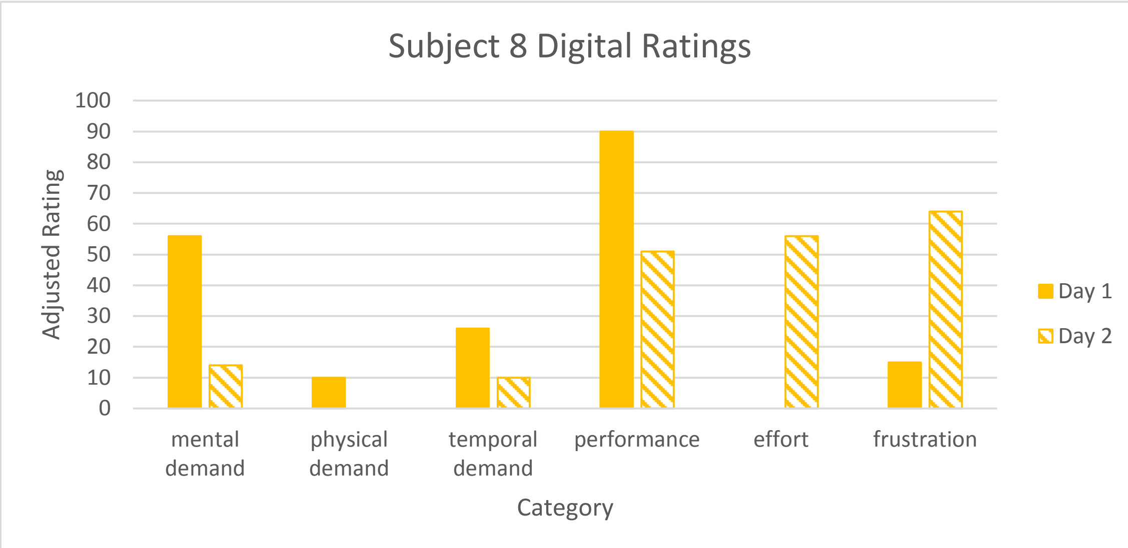

Subject 7 Nonlinear Workload
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2

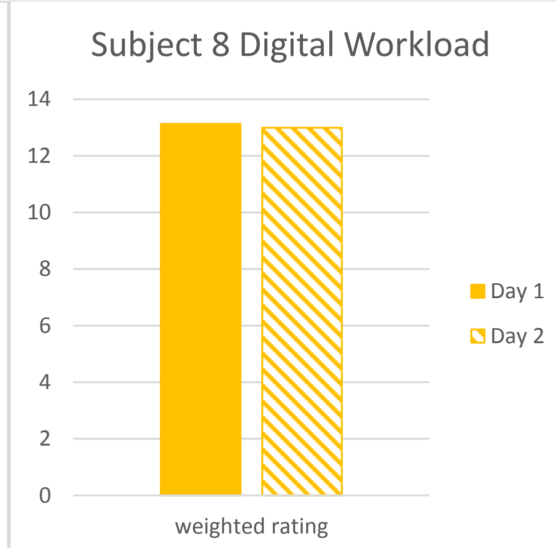

Subject 7 Average Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear

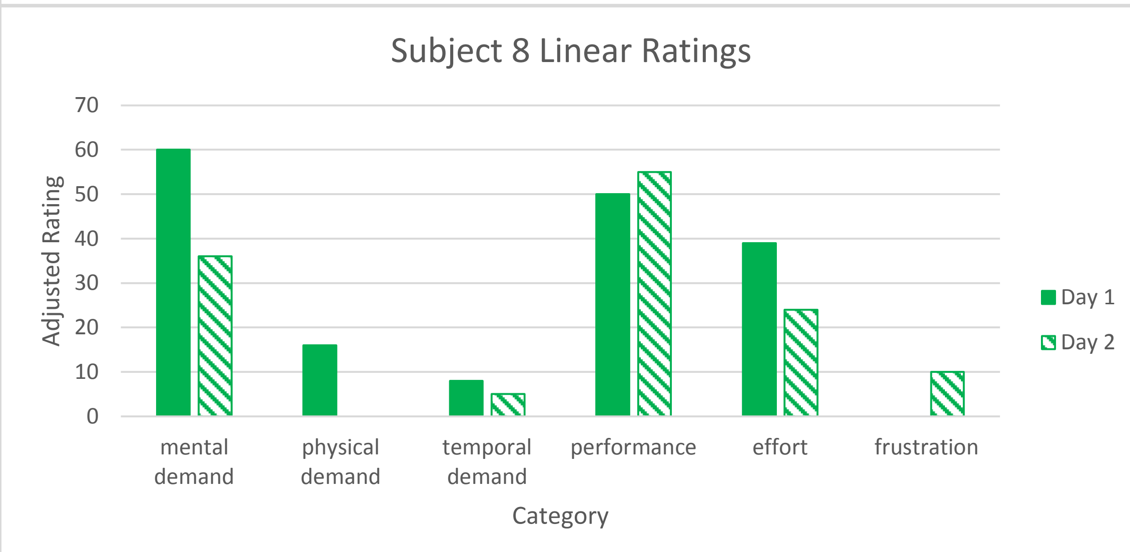

Subject 7 Average Workload
16
14
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

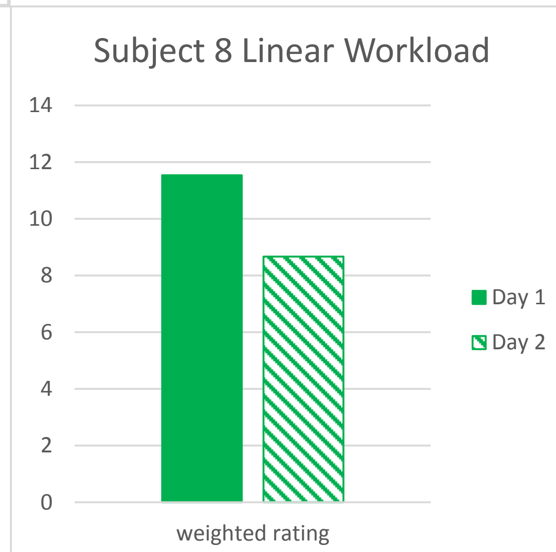
Subject 8

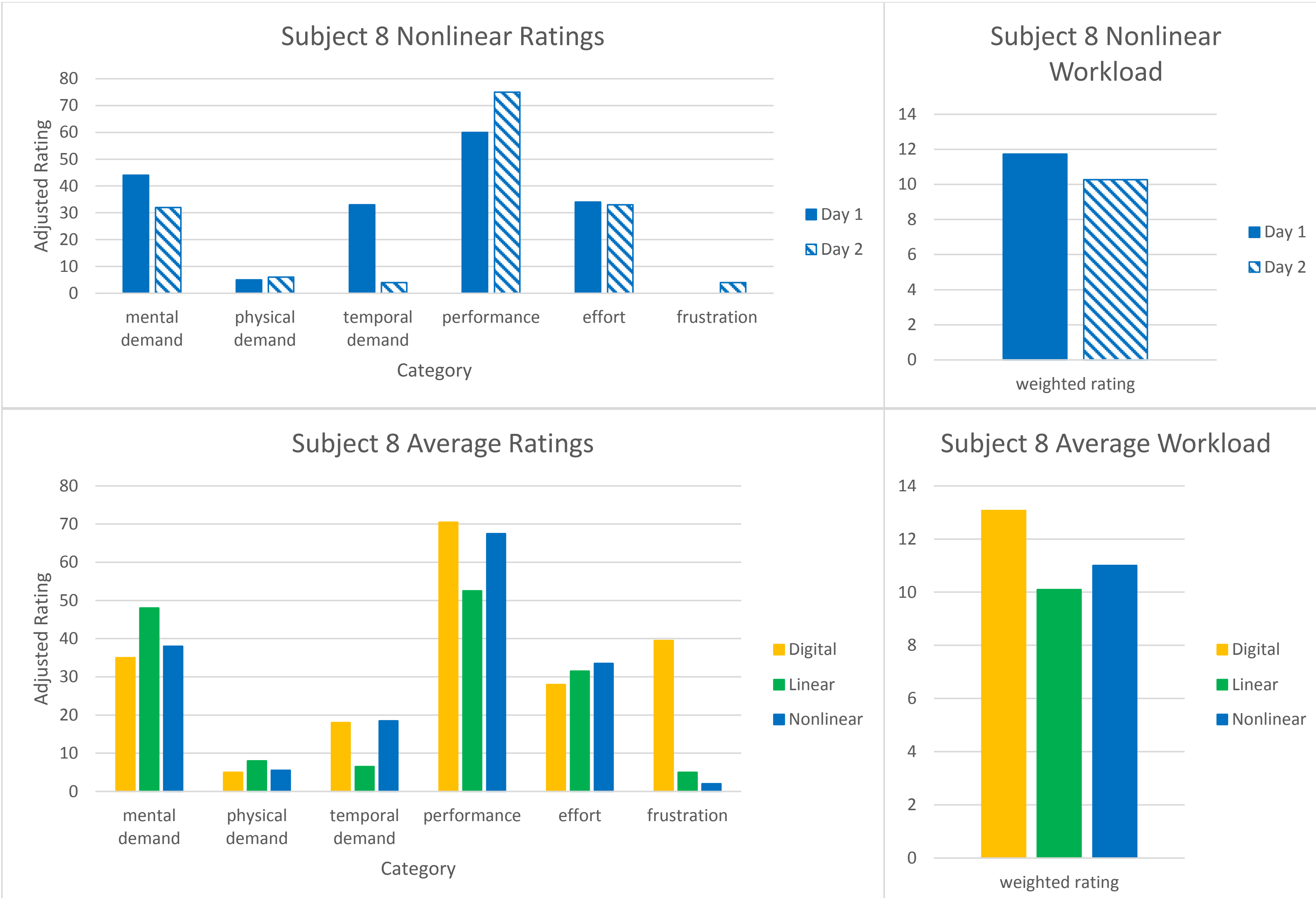
Day 1				Day 2				Averages	
course digital				course linear				course digital	
scale title	weight	raw rating	adjusted rating	scale title	weight	raw rating	adjusted rating	scale title	adjusted rating
mental demand	4	14	56	mental demand	4	9	36	mental demand	35
physical demand	1	10	10	physical demand	0	5	0	physical demand	5
temporal demand	2	13	26	temporal demand	1	5	5	temporal demand	18
performance	5	18	90	performance	5	11	55	performance	70.5
effort	0	17	0	effort	3	8	24	effort	28
frustration	3	5	15	frustration	2	5	10	frustration	39.5
		sum	197			sum	130	sum	196
		weighted rating	13.13333333			weighted rating	8.666666667	weighted rating	13.06666667
course nonlinear				course nonlinear				course linear	
scale title	weight	raw rating	adjusted rating	scale title	weight	raw rating	adjusted rating	scale title	adjusted rating
mental demand	4	11	44	mental demand	4	8	32	mental demand	48
physical demand	1	5	5	physical demand	1	6	6	physical demand	8
temporal demand	3	11	33	temporal demand	1	4	4	temporal demand	6.5
performance	5	12	60	performance	5	15	75	performance	52.5
effort	2	17	34	effort	3	11	33	effort	31.5
frustration	0	4	0	frustration	1	4	4	frustration	5
		sum	176			sum	154	sum	151.5
		weighted rating	11.73333333			weighted rating	10.26666667	weighted rating	10.1
course linear				course digital				course nonlinear	
scale title	weight	raw rating	adjusted rating	scale title	weight	raw rating	adjusted rating	scale title	adjusted rating
mental demand	4	15	60	mental demand	2	7	14	mental demand	38
physical demand	2	8	16	physical demand	0	5	0	physical demand	5.5
temporal demand	1	8	8	temporal demand	2	5	10	temporal demand	18.5
performance	5	10	50	performance	3	17	51	performance	67.5
effort	3	13	39	effort	4	14	56	effort	33.5
frustration	0	2	0	frustration	4	16	64	frustration	2
		sum	173			sum	195	sum	165
		weighted rating	11.53333333			weighted rating	13	weighted rating	11


Subject 8 Digital Ratings
Adjusted Rating
100
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 8 Digital Workload
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 8 Linear Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 8 Linear Workload
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2



Subject 8 Nonlinear Ratings
Adjusted Rating
Category
mental demand
physical demand
temporal demand
performance
effort
frustration
Day 1
Day 2
Subject 8 Nonlinear Workload
weighted rating
Subject 8 Average Ratings
Digital
Linear
Nonlinear
Subject 8 Average Workload

Subject 9

Day 1

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	4	16	64
physical demand	1	8	8
temporal demand	2	3	6
performance	5	6	30
effort	3	7	21
frustration	0	1	0
		sum	129
		weighted rating	8.6

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	1	8	8
physical demand	5	20	100
temporal demand	4	10	40
performance	3	10	30
effort	2	20	40
frustration	0	4	0
		sum	218
		weighted rating	14.53333333

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	1	3	3
physical demand	4	12	48
temporal demand	4	11	44
performance	4	2	8
effort	2	9	18
frustration	0	1	0
		sum	121
		weighted rating	8.066666667

Day 2

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	3	3	9
physical demand	1	9	9
temporal demand	4	9	36
performance	4	17	68
effort	2	10	20
frustration	1	7	7
		sum	149
		weighted rating	9.933333333

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	3	5	15
physical demand	4	10	40
temporal demand	3	4	12
performance	4	7	28
effort	1	8	8
frustration	0	2	0
		sum	103
		weighted rating	6.866666667

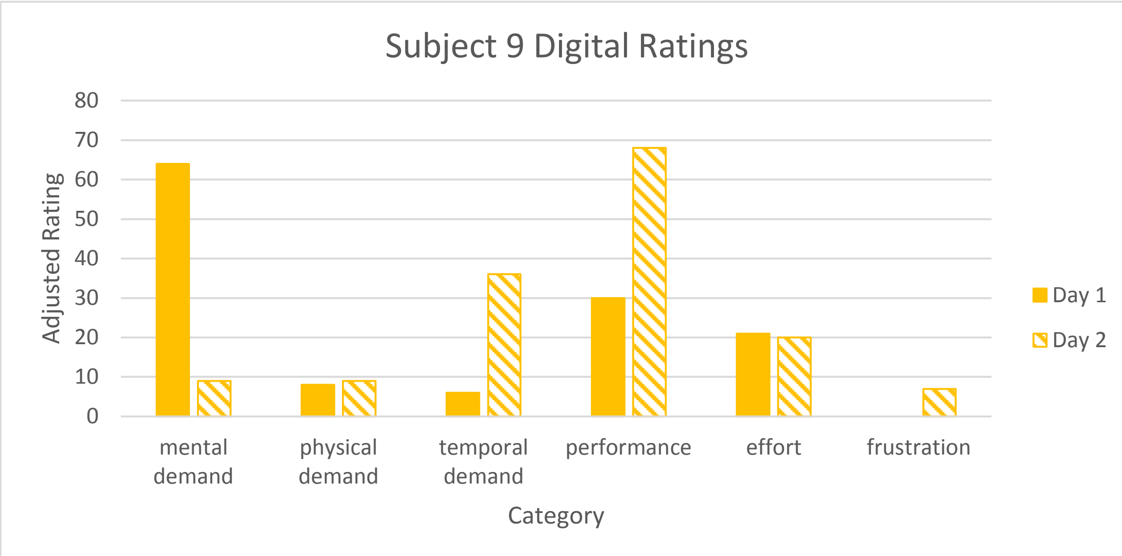
course linear			
scale title	weight	raw rating	adjusted rating
mental demand	3	5	15
physical demand	3	10	30
temporal demand	3	4	12
performance	4	3	12
effort	2	10	20
frustration	0	1	0
		sum	89
		weighted rating	5.933333333

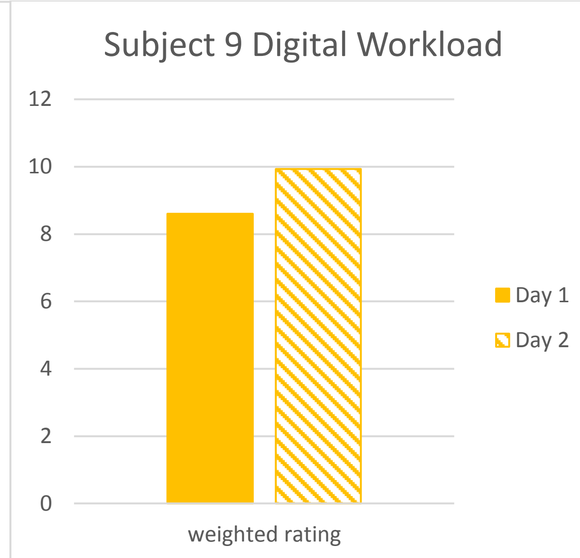
Averages

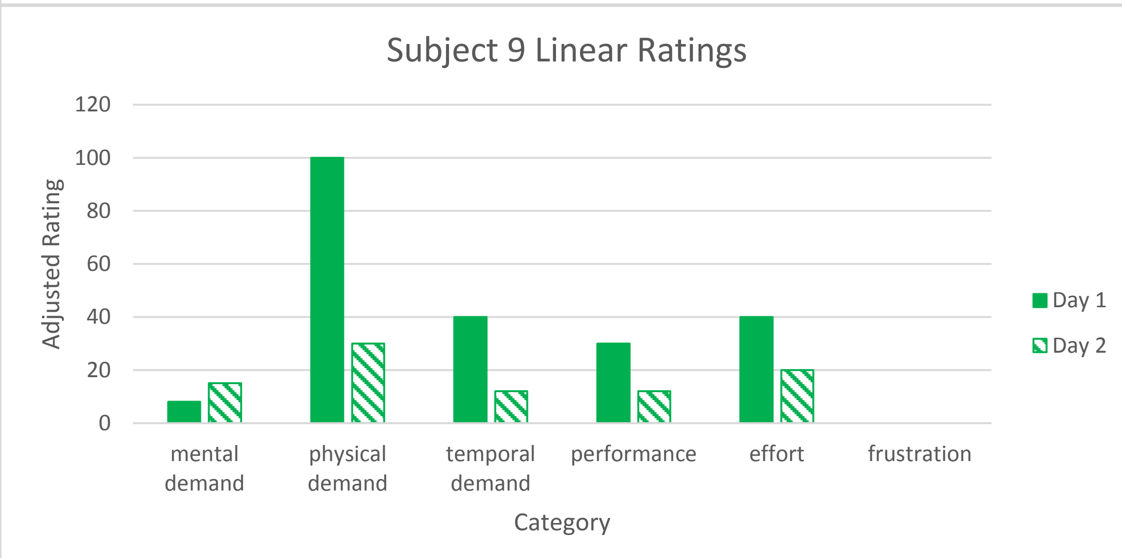
course digital	
scale title	adjusted rating
mental demand	36.5
physical demand	8.5
temporal demand	21
performance	49
effort	20.5
frustration	3.5
sum	139
weighted rating	9.266666667

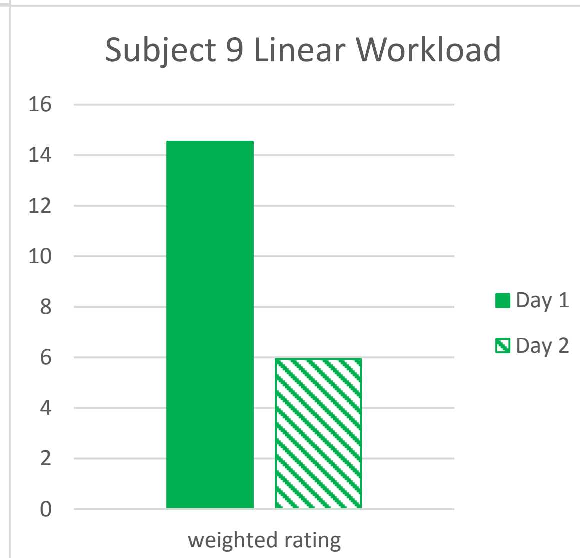
course linear	
scale title	adjusted rating
mental demand	11.5
physical demand	65
temporal demand	26
performance	21
effort	30
frustration	0
sum	153.5
weighted rating	10.23333333

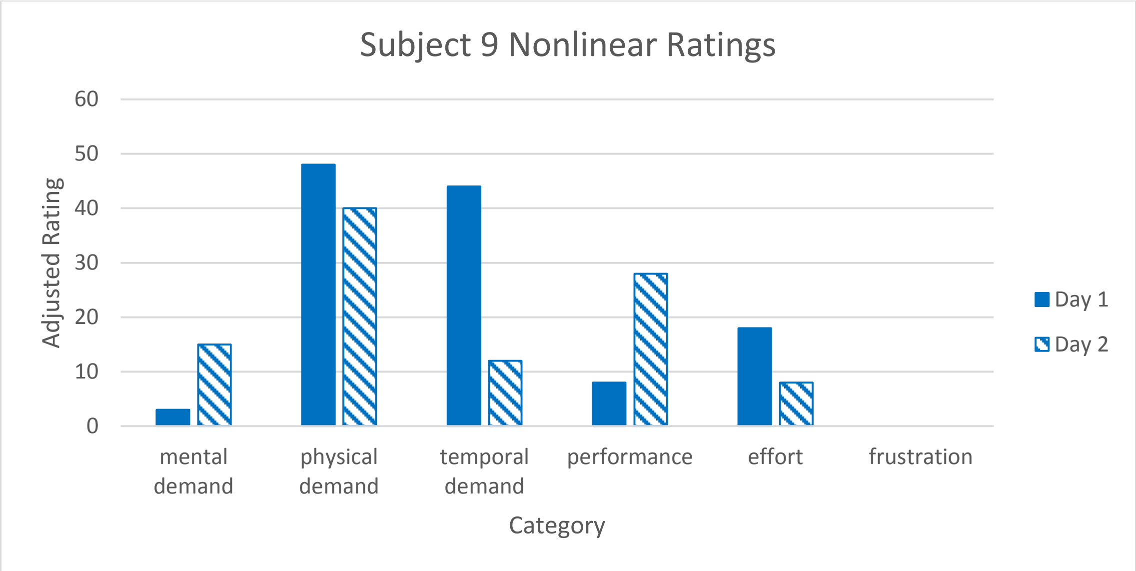
course nonlinear	
scale title	adjusted rating
mental demand	9
physical demand	44
temporal demand	28
performance	18
effort	13
frustration	0
sum	112
weighted rating	7.466666667


Subject 9 Digital Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

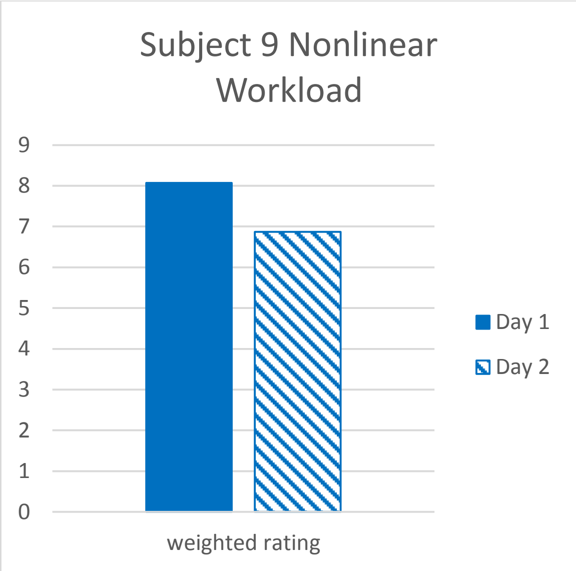

Subject 9 Digital Workload
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 9 Linear Ratings
Adjusted Rating
120
100
80
60
40
20
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

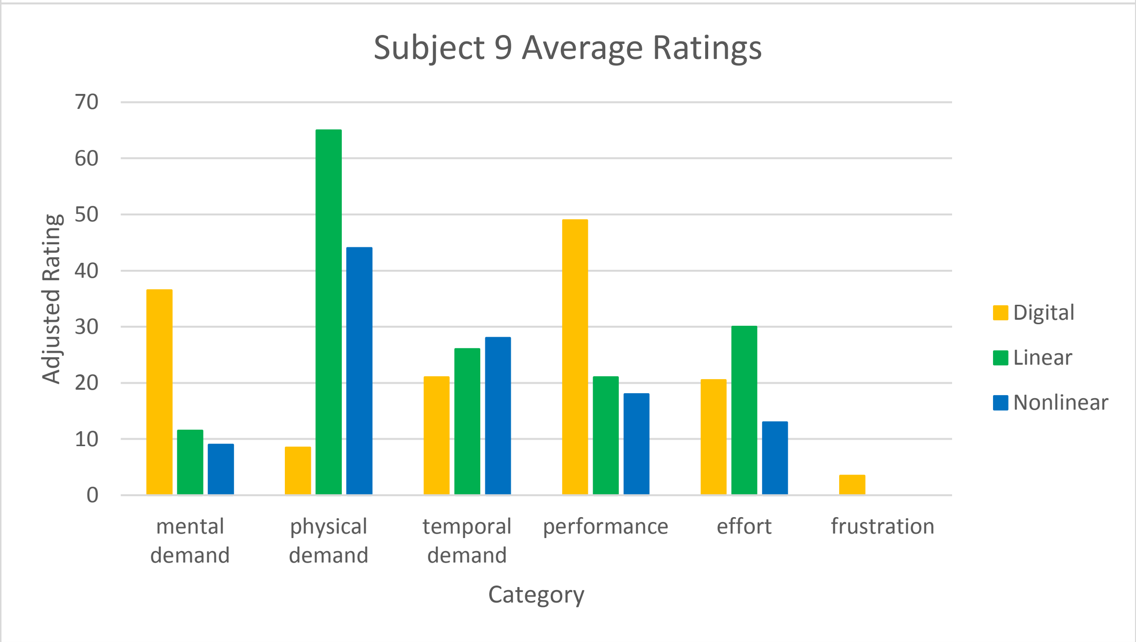

Subject 9 Linear Workload
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2



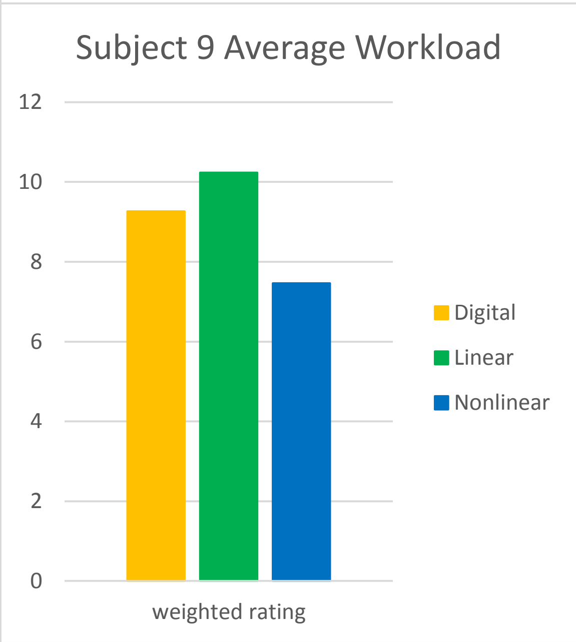
Subject 9 Nonlinear Ratings
Adjusted Rating
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2



Subject 9 Nonlinear Workload
9
8
7
6
5
4
3
2
1
0
weighted rating
Day 1
Day 2

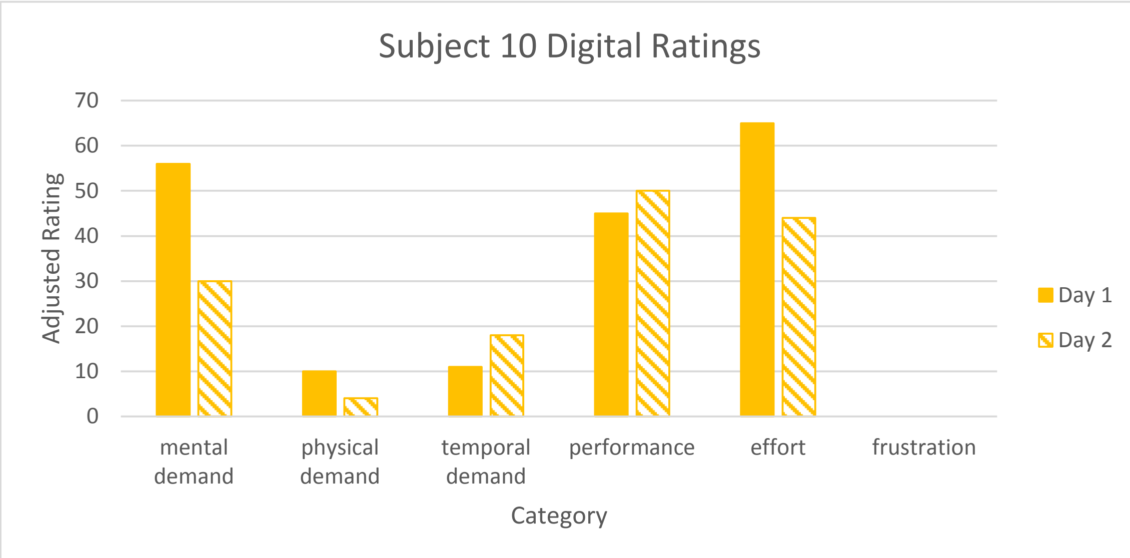


Subject 9 Average Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear

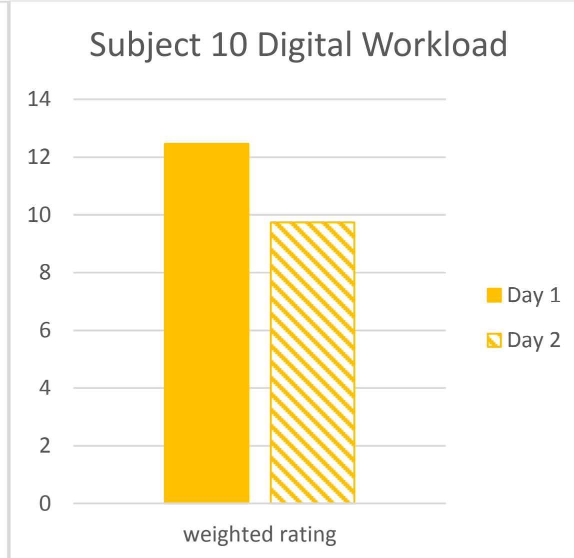


Subject 9 Average Workload
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

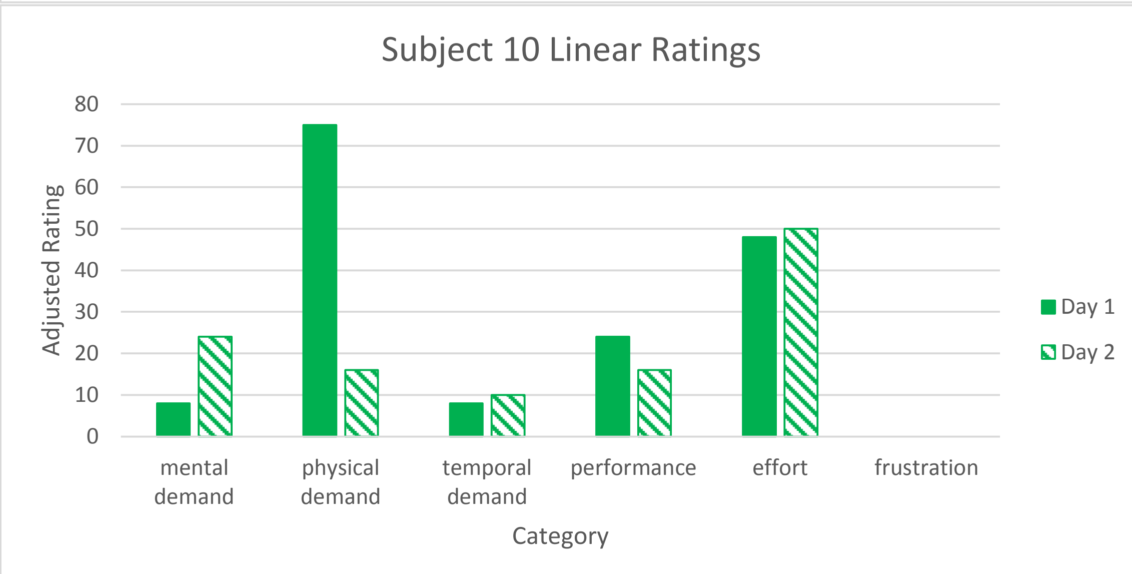
Subject 10									
Day 1				Day 2				Averages	
course nonlinear				course linear				course digital	
scale title	weight	raw rating	adjusted rating	scale title	weight	raw rating	adjusted rating	scale title	adjusted rating
mental demand	5	10	50	mental demand	3	8	24	mental demand	43
physical demand	0	4	0	physical demand	2	8	16	physical demand	7
temporal demand	2	8	16	temporal demand	1	10	10	temporal demand	14.5
performance	3	8	24	performance	4	4	16	performance	47.5
effort	4	12	48	effort	5	10	50	effort	54.5
frustration	1	3	3	frustration	0	2	0	frustration	0
		sum	141			sum	116	sum	166.5
		weighted rating	9.4			weighted rating	7.733333333	weighted rating	11.1
course linear				course digital				course linear	
scale title	weight	raw rating	adjusted rating	scale title	weight	raw rating	adjusted rating	scale title	adjusted rating
mental demand	2	4	8	mental demand	3	10	30	mental demand	16
physical demand	5	15	75	physical demand	1	4	4	physical demand	45.5
temporal demand	1	8	8	temporal demand	2	9	18	temporal demand	9
performance	3	8	24	performance	5	10	50	performance	20
effort	4	12	48	effort	4	11	44	effort	49
frustration	0	4	0	frustration	0	5	0	frustration	0
		sum	163			sum	146	sum	139.5
		weighted rating	10.86666667			weighted rating	9.733333333	weighted rating	9.3
course digital				course nonlinear				course nonlinear	
scale title	weight	raw rating	adjusted rating	scale title	weight	raw rating	adjusted rating	scale title	adjusted rating
mental demand	4	14	56	mental demand	3	4	12	mental demand	31
physical demand	2	5	10	physical demand	2	4	8	physical demand	4
temporal demand	1	11	11	temporal demand	1	10	10	temporal demand	13
performance	3	15	45	performance	4	5	20	performance	22
effort	5	13	65	effort	5	5	25	effort	36.5
frustration	0	8	0	frustration	0	2	0	frustration	1.5
		sum	187			sum	75	sum	108
		weighted rating	12.46666667			weighted rating	5	weighted rating	7.2



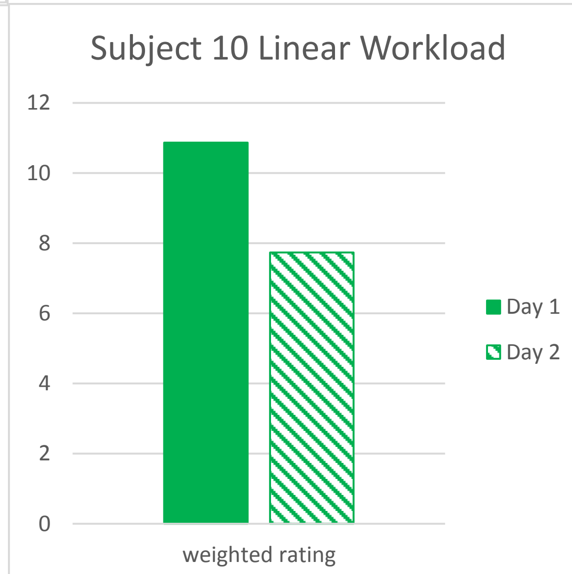
Subject 10 Digital Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2



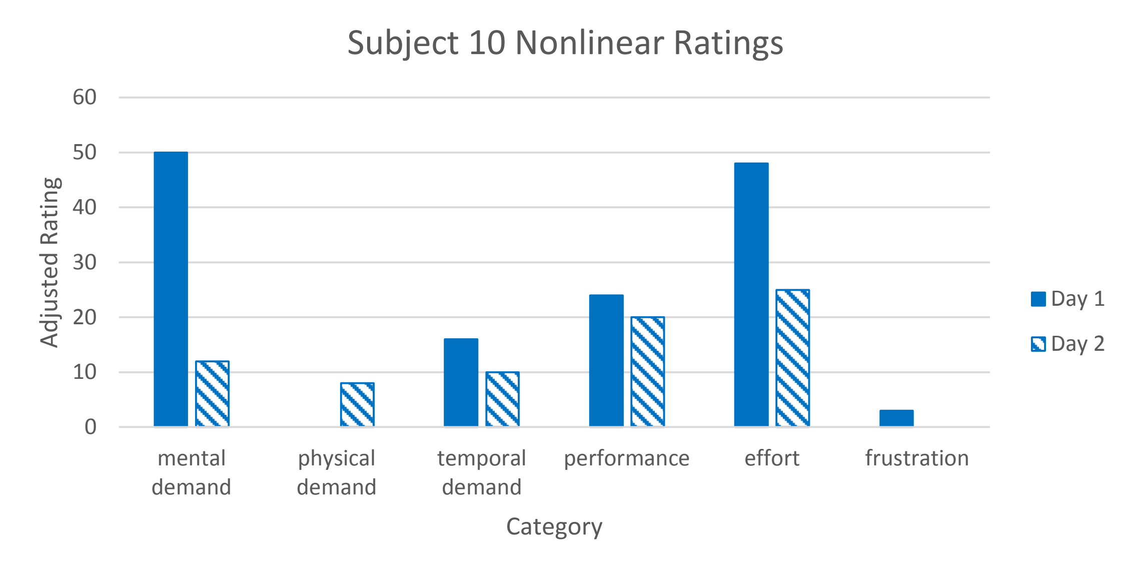
Subject 10 Digital Workload
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2



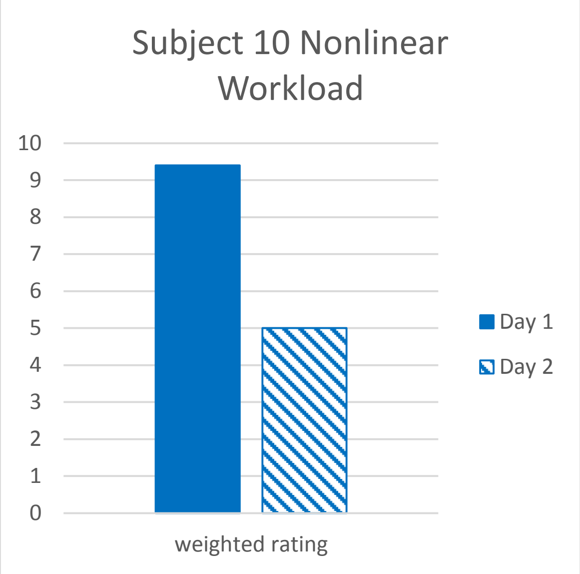
Subject 10 Linear Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2



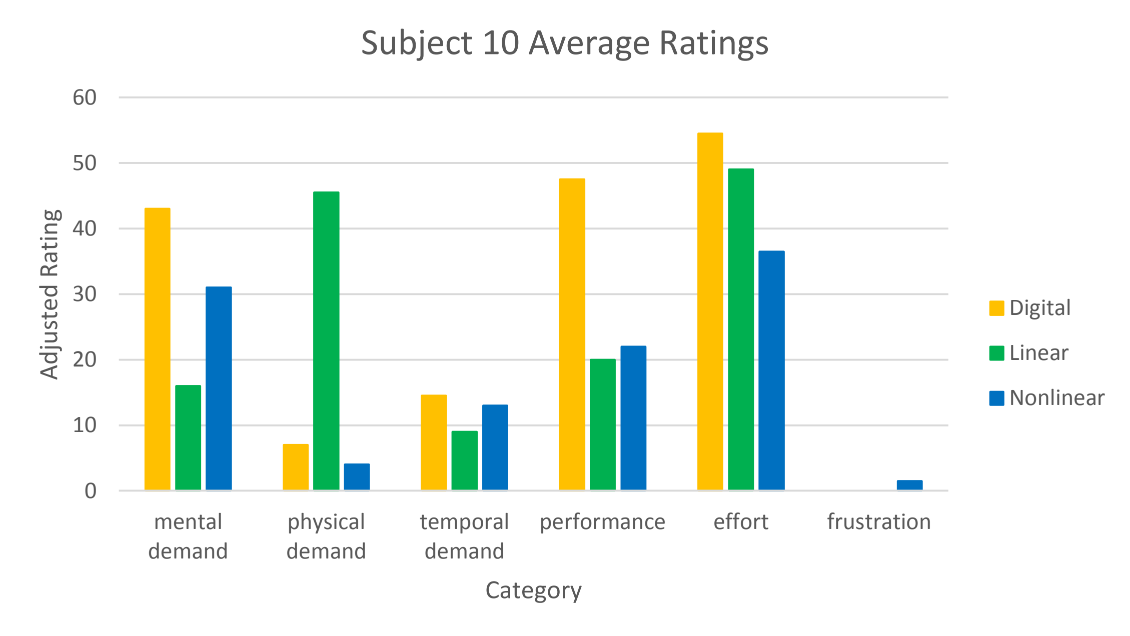
Subject 10 Linear Workload
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2



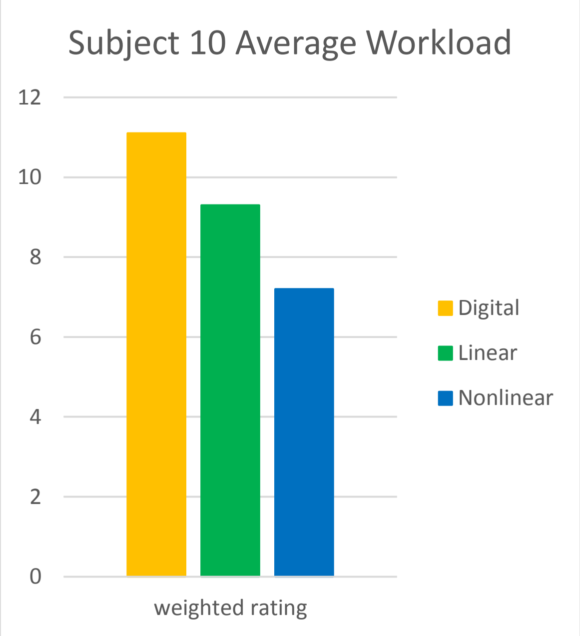
Subject 10 Nonlinear Ratings
Adjusted Rating
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2



Subject 10 Nonlinear Workload
10
9
8
7
6
5
4
3
2
1
0
weighted rating
Day 1
Day 2



Subject 10 Average Ratings
Adjusted Rating
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear



Subject 10 Average Workload
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

Subject 11

Day 1

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	4	17	68
physical demand	4	17	68
temporal demand	3	17	51
performance	1	10	10
effort	3	15	45
frustration	0	6	0
		sum	242
		weighted rating	16.13333333

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	2	16	32
physical demand	1	12	12
temporal demand	4	14	56
performance	0	13	0
effort	4	15	60
frustration	4	9	36
		sum	196
		weighted rating	13.06666667

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	3	9	27
physical demand	3	12	36
temporal demand	3	12	36
performance	1	10	10
effort	5	11	55
frustration	0	5	0
		sum	164
		weighted rating	10.93333333

Day 2

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	2	11	22
physical demand	2	10	20
temporal demand	5	12	60
performance	2	12	24
effort	4	13	52
frustration	0	3	0
		sum	178
		weighted rating	11.86666667

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	1	7	7
physical demand	2	7	14
temporal demand	5	10	50
performance	3	9	27
effort	4	10	40
frustration	0	2	0
		sum	138
		weighted rating	9.2

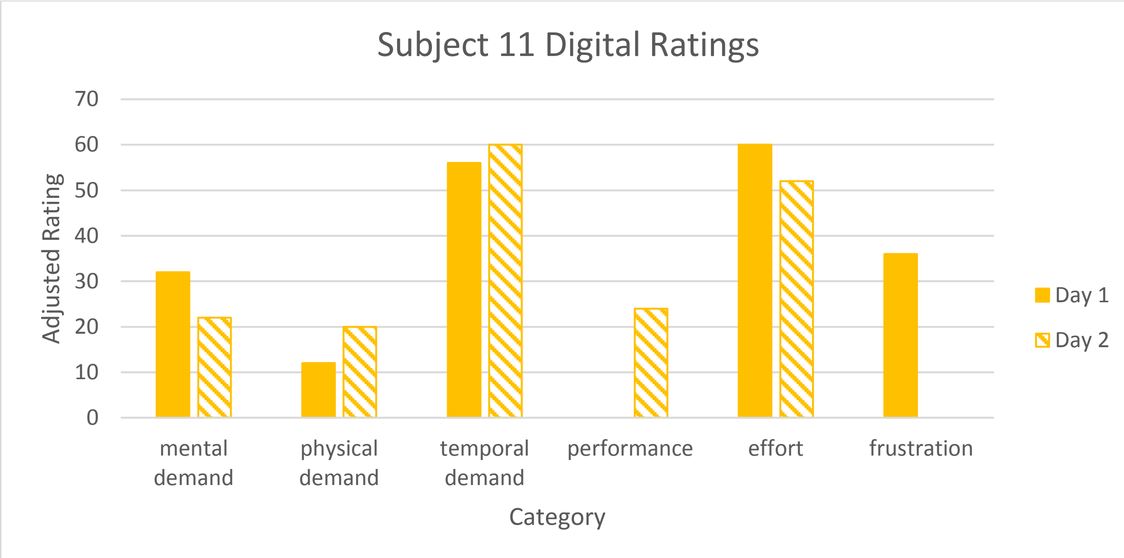
course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	2	5	10
physical demand	2	7	14
temporal demand	5	10	50
performance	2	7	14
effort	4	11	44
frustration	0	2	0
		sum	132
		weighted rating	8.8

Averages

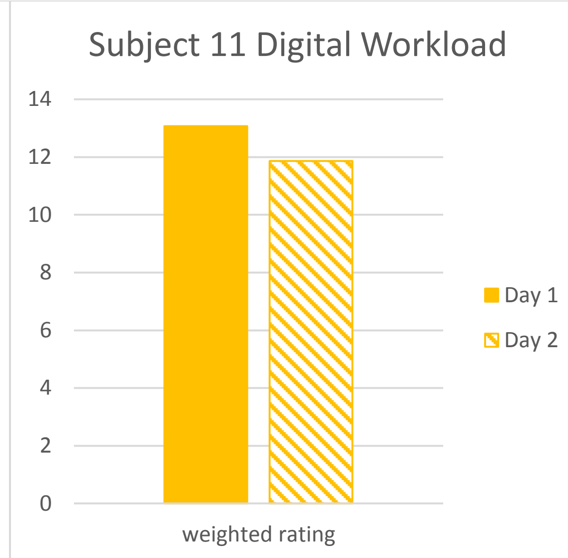
course digital	
scale title	adjusted rating
mental demand	27
physical demand	16
temporal demand	58
performance	12
effort	56
frustration	18
sum	187
weighted rating	12.46666667

course linear	
scale title	adjusted rating
mental demand	17
physical demand	25
temporal demand	43
performance	18.5
effort	47.5
frustration	0
sum	151
weighted rating	10.06666667

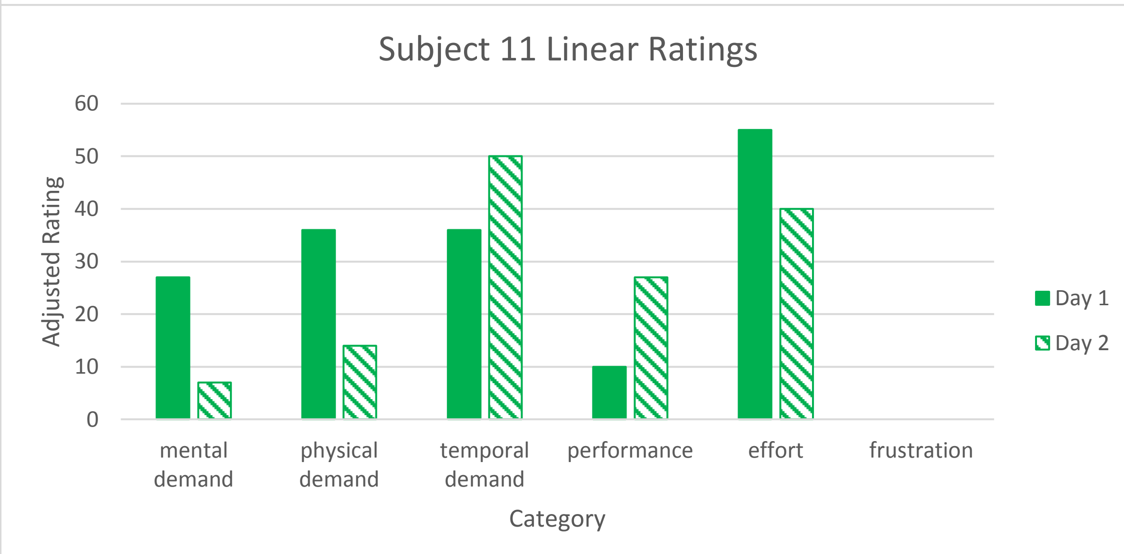
course nonlinear	
scale title	adjusted rating
mental demand	39
physical demand	41
temporal demand	50.5
performance	12
effort	44.5
frustration	0
sum	187
weighted rating	12.46666667



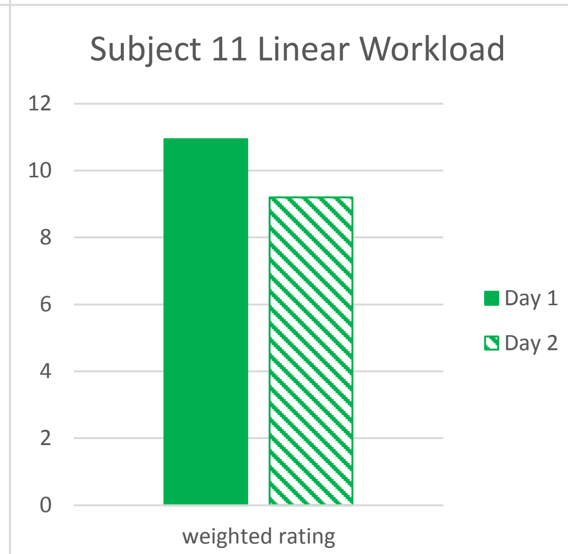
Subject 11 Digital Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2



Subject 11 Digital Workload
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2



Subject 11 Linear Ratings
Adjusted Rating
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2



Subject 11 Linear Workload
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 11 Nonlinear Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2
Subject 11 Nonlinear Workload
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2
Subject 11 Average Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear
Subject 11 Average Workload
14
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

Subject 12

Day 1

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	4	20	80
physical demand	4	20	80
temporal demand	0	7	0
performance	1	10	10
effort	3	20	60
frustration	3	15	45
		sum	275
		weighted rating	18.33333333

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	4	20	80
physical demand	4	20	80
temporal demand	0	5	0
performance	1	11	11
effort	4	20	80
frustration	2	9	18
		sum	269
		weighted rating	17.93333333

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	3	20	60
physical demand	4	20	80
temporal demand	1	13	13
performance	2	11	22
effort	5	20	100
frustration	0	14	0
		sum	275
		weighted rating	18.33333333

Day 2

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	3	16	48
physical demand	4	20	80
temporal demand	1	3	3
performance	2	13	26
effort	5	20	100
frustration	0	4	0
		sum	257
		weighted rating	17.13333333

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	3	14	42
physical demand	4	20	80
temporal demand	1	3	3
performance	2	4	8
effort	5	20	100
frustration	0	11	0
		sum	233
		weighted rating	15.53333333

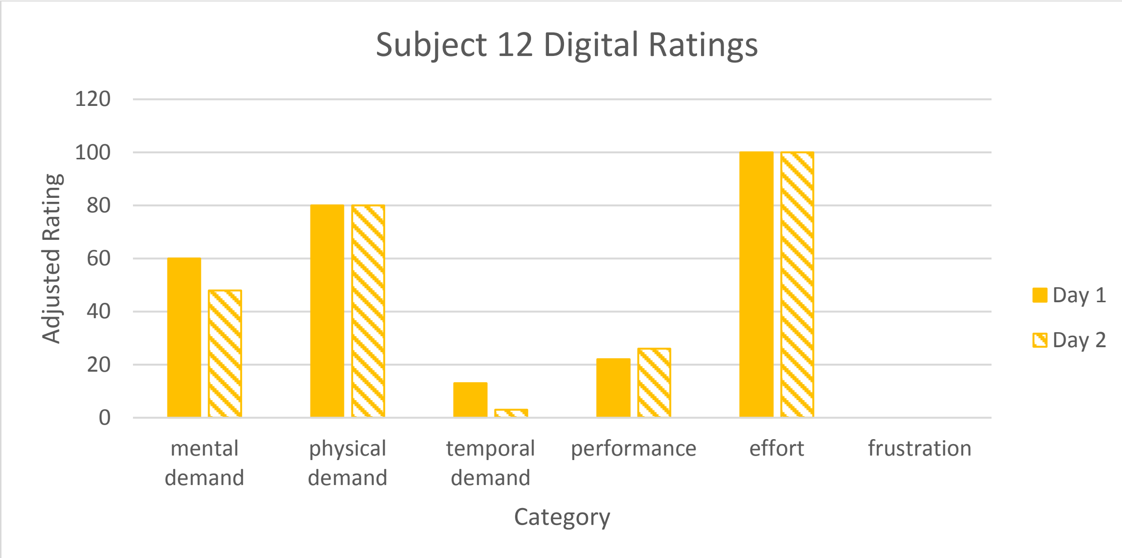
course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	3	10	30
physical demand	4	18	72
temporal demand	0	2	0
performance	2	8	16
effort	5	19	95
frustration	1	2	2
		sum	215
		weighted rating	14.33333333

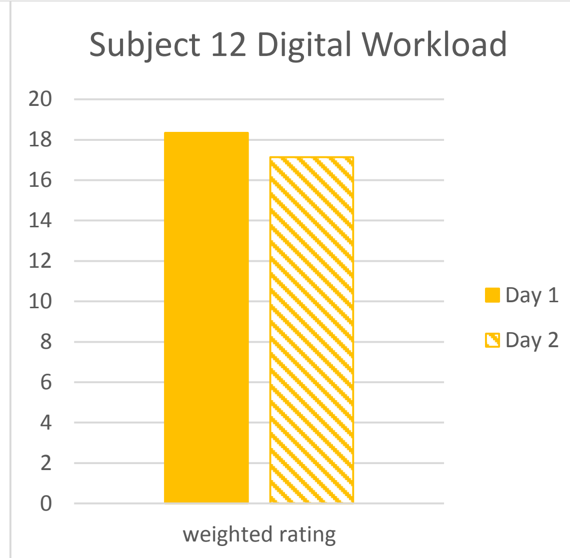
Averages

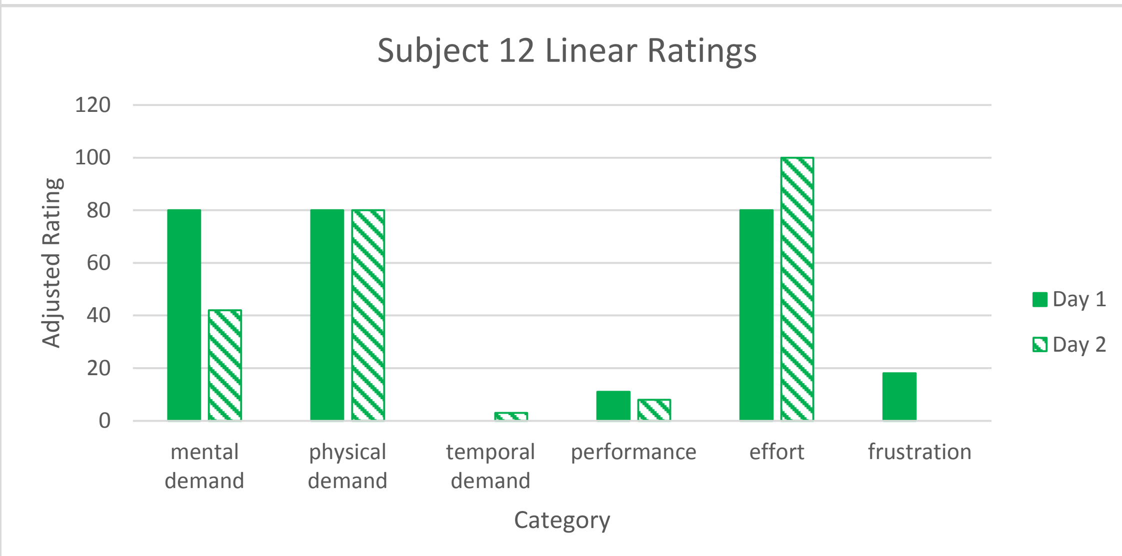
course digital	
scale title	adjusted rating
mental demand	54
physical demand	80
temporal demand	8
performance	24
effort	100
frustration	0
sum	266
weighted rating	17.73333333

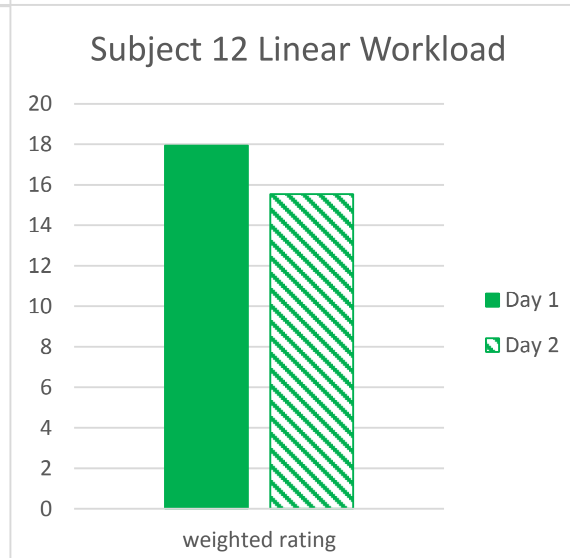
course linear	
scale title	adjusted rating
mental demand	61
physical demand	80
temporal demand	1.5
performance	9.5
effort	90
frustration	9
sum	251
weighted rating	16.73333333

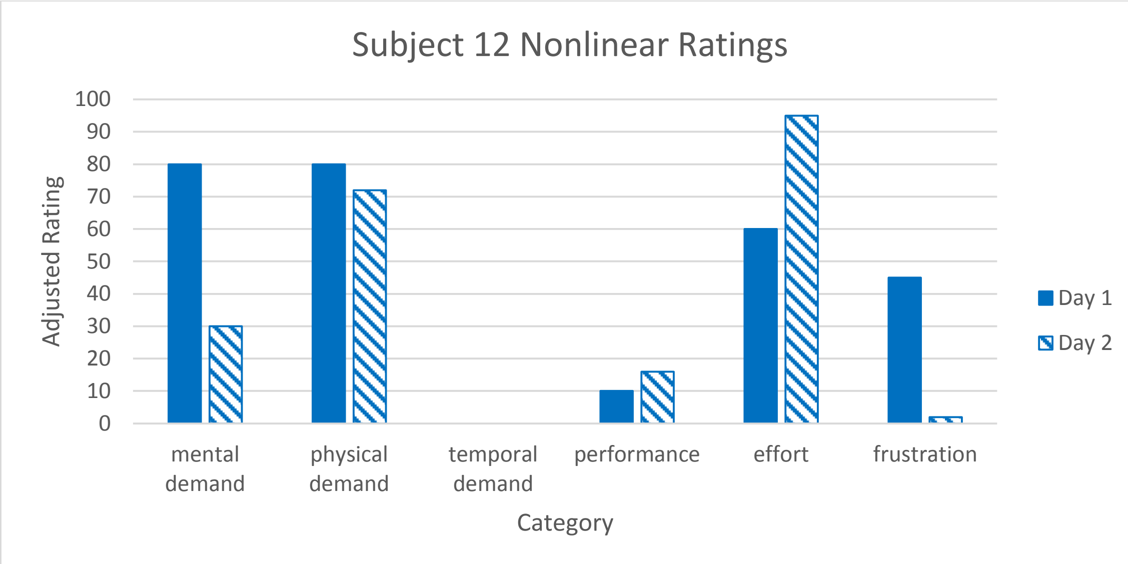
course nonlinear	
scale title	adjusted rating
mental demand	55
physical demand	76
temporal demand	0
performance	13
effort	77.5
frustration	23.5
sum	245
weighted rating	16.33333333

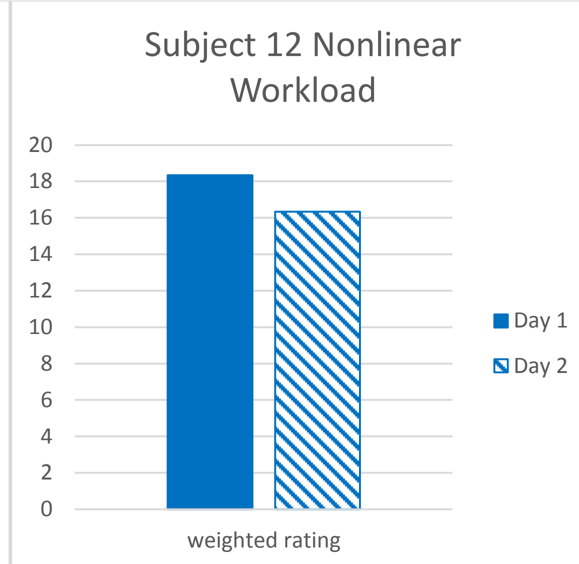

Subject 12 Digital Ratings
Adjusted Rating
120
100
80
60
40
20
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

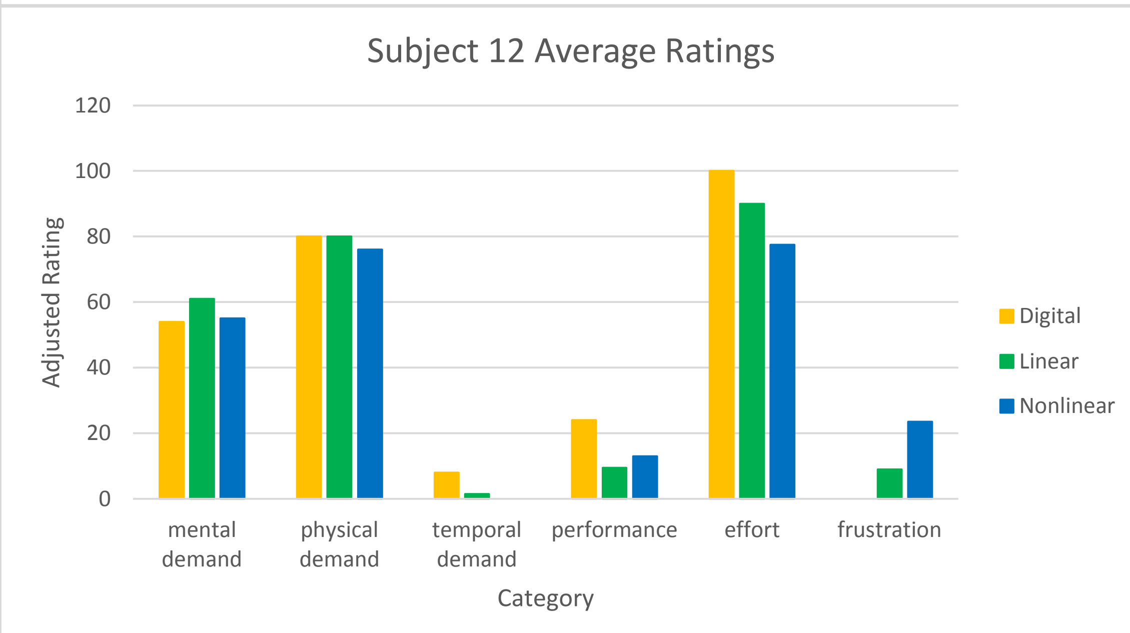

Subject 12 Digital Workload
20
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2

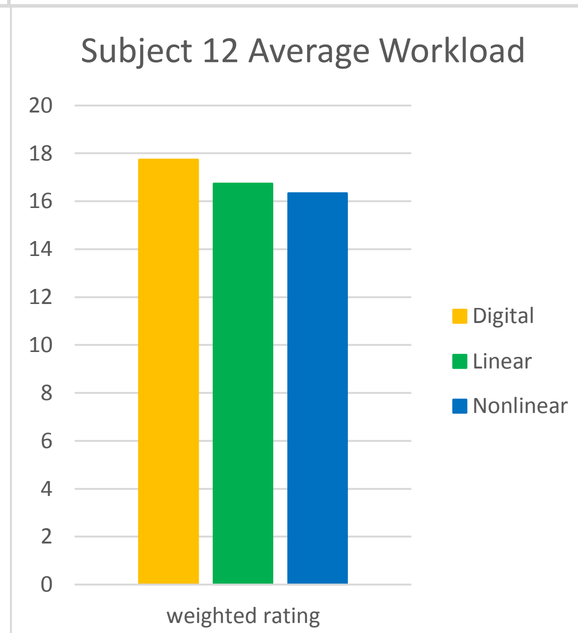

Subject 12 Linear Ratings
Adjusted Rating
120
100
80
60
40
20
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 12 Linear Workload
20
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 12 Nonlinear Ratings
Adjusted Rating
100
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 12 Nonlinear Workload
20
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 12 Average Ratings
Adjusted Rating
120
100
80
60
40
20
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear


Subject 12 Average Workload
20
18
16
14
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

Subject 13

Day 1

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	3	15	45
physical demand	1	9	9
temporal demand	0	15	0
performance	4	7	28
effort	5	14	70
frustration	2	15	30
		sum	182
		weighted rating	12.13333333

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	5	14	70
physical demand	0	8	0
temporal demand	1	11	11
performance	3	7	21
effort	4	16	64
frustration	2	13	26
		sum	192
		weighted rating	12.8

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	4	18	72
physical demand	1	11	11
temporal demand	0	15	0
performance	3	11	33
effort	4	18	72
frustration	3	17	51
		sum	239
		weighted rating	15.93333333

Day 2

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	4	7	28
physical demand	3	4	12
temporal demand	0	8	0
performance	2	6	12
effort	5	7	35
frustration	1	5	5
		sum	92
		weighted rating	6.133333333

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	4	6	24
physical demand	3	6	18
temporal demand	0	4	0
performance	2	7	14
effort	5	10	50
frustration	1	6	6
		sum	112
		weighted rating	7.466666667

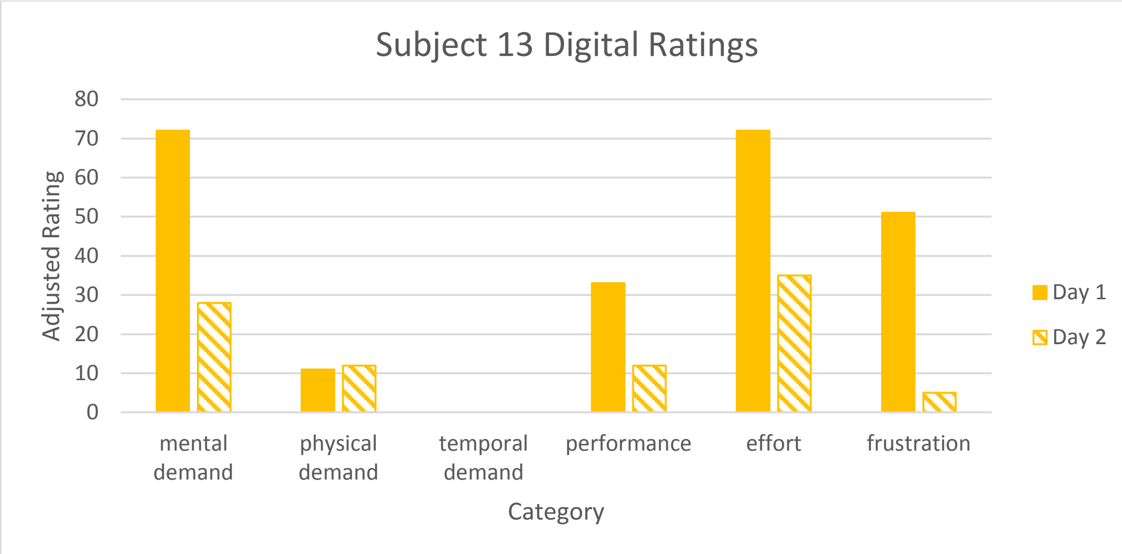
course linear			
scale title	weight	raw rating	adjusted rating
mental demand	4	6	24
physical demand	3	6	18
temporal demand	0	2	0
performance	2	9	18
effort	5	10	50
frustration	1	5	5
		sum	115
		weighted rating	7.666666667

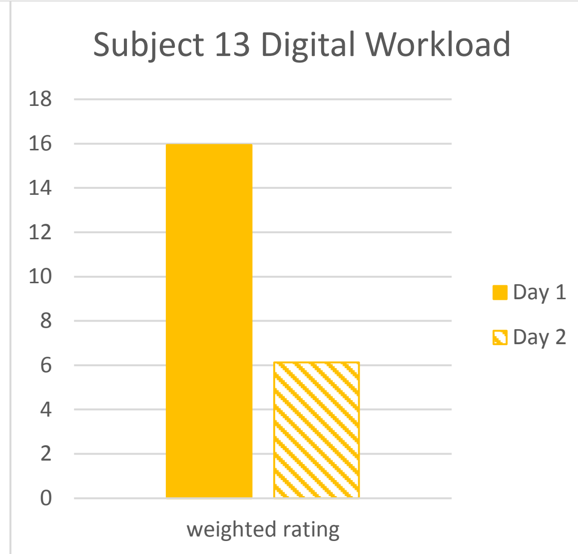
Averages

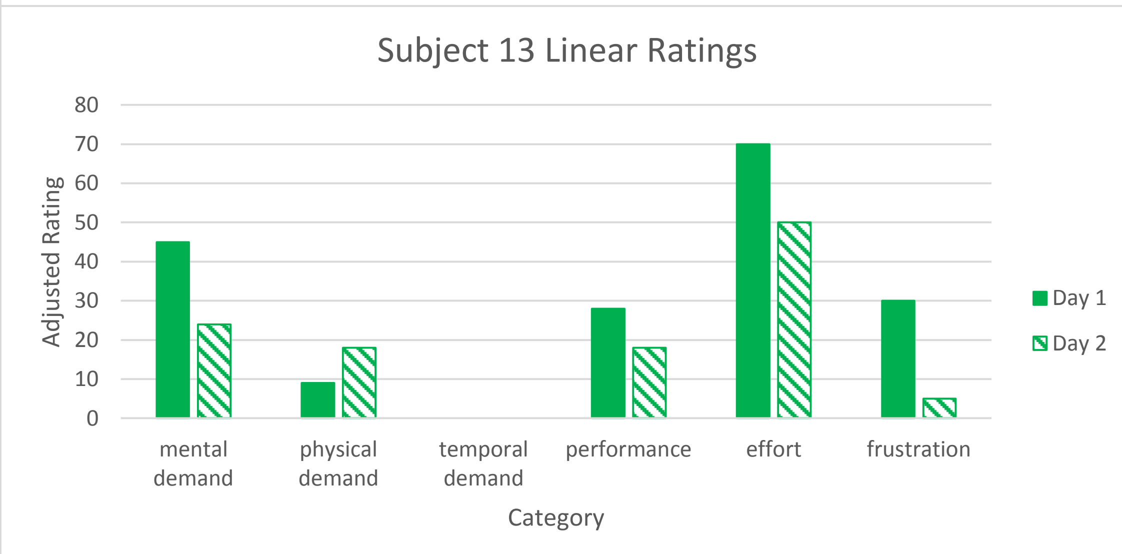
course digital	
scale title	adjusted rating
mental demand	50
physical demand	11.5
temporal demand	0
performance	22.5
effort	53.5
frustration	28
sum	165.5
weighted rating	11.03333333

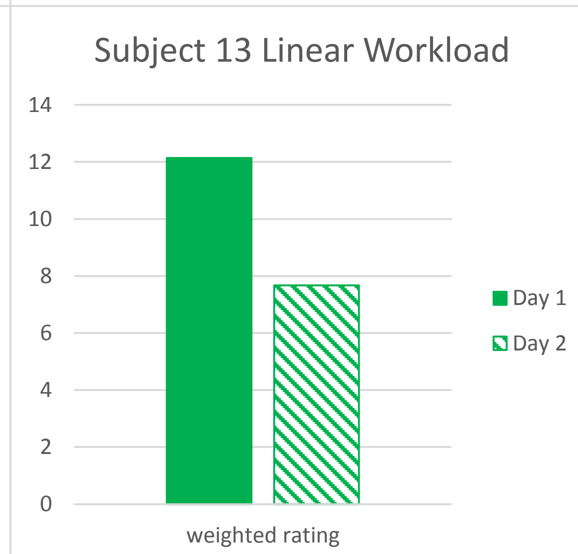
course linear	
scale title	adjusted rating
mental demand	34.5
physical demand	13.5
temporal demand	0
performance	23
effort	60
frustration	17.5
sum	148.5
weighted rating	9.9

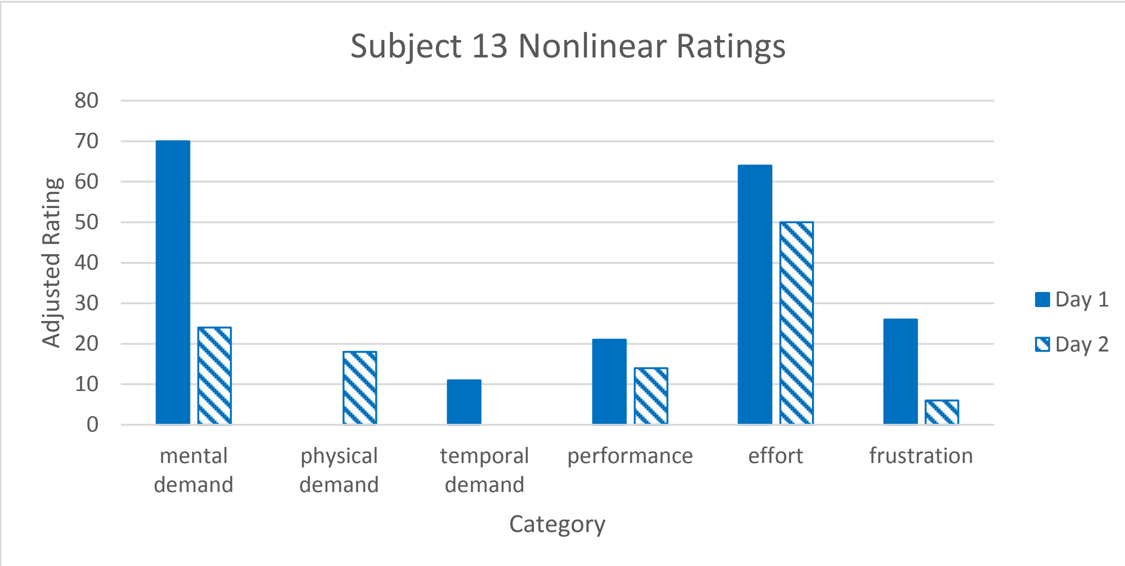
course nonlinear	
scale title	adjusted rating
mental demand	47
physical demand	9
temporal demand	5.5
performance	17.5
effort	57
frustration	16
sum	152
weighted rating	10.13333333

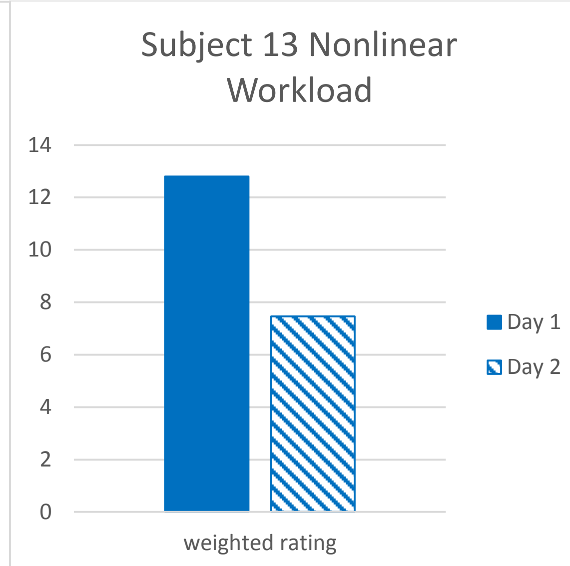

Subject 13 Digital Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

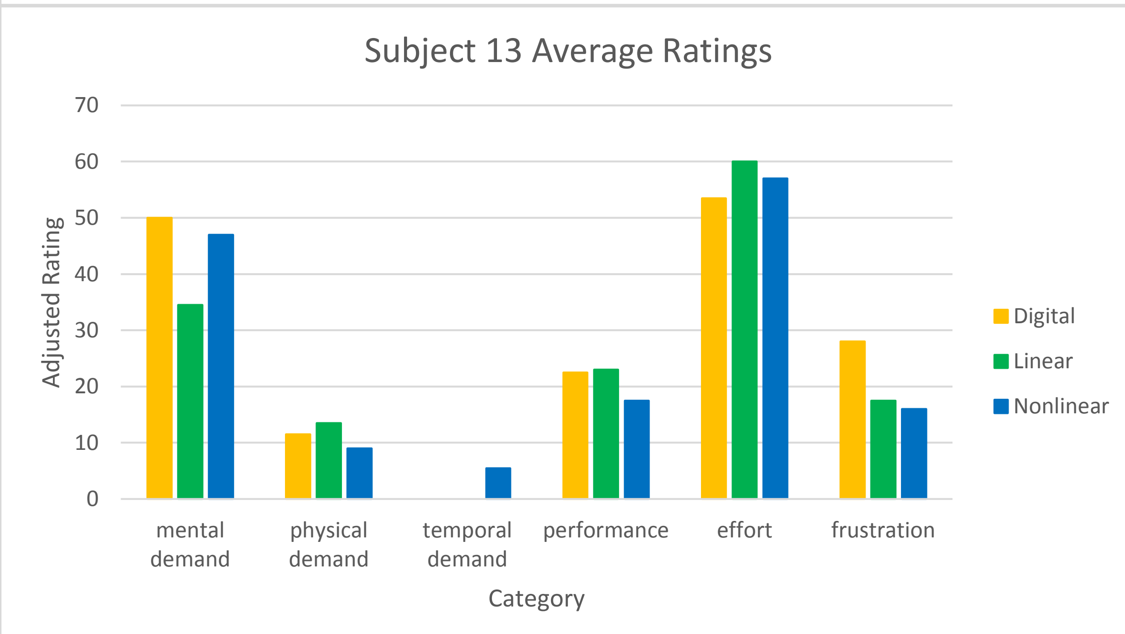

Subject 13 Digital Workload
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2

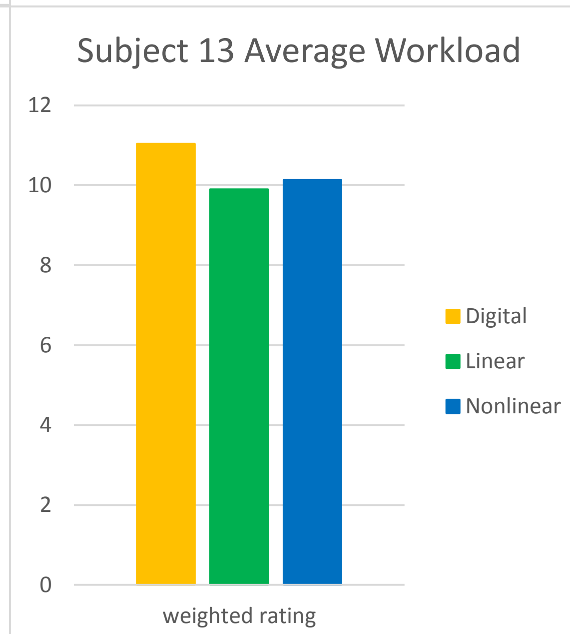

Subject 13 Linear Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 13 Linear Workload
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 13 Nonlinear Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 13 Nonlinear Workload
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 13 Average Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear


Subject 13 Average Workload
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

Subject 14

Day 1

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	2	18	36
physical demand	0	13	0
temporal demand	3	18	54
performance	4	15	60
effort	1	16	16
frustration	5	20	100
		sum	266
		weighted rating	17.73333333

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	2	18	36
physical demand	0	17	0
temporal demand	3	11	33
performance	4	16	64
effort	1	14	14
frustration	5	17	85
		sum	232
		weighted rating	15.46666667

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	2	11	22
physical demand	4	18	72
temporal demand	1	5	5
performance	5	5	25
effort	3	6	18
frustration	0	5	0
		sum	142
		weighted rating	9.466666667

Day 2

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	5	13	65
physical demand	1	10	10
temporal demand	4	11	44
performance	1	10	10
effort	3	10	30
frustration	1	5	5
		sum	164
		weighted rating	10.93333333

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	3	13	39
physical demand	4	15	60
temporal demand	2	7	14
performance	0	14	0
effort	1	12	12
frustration	5	18	90
		sum	215
		weighted rating	14.33333333

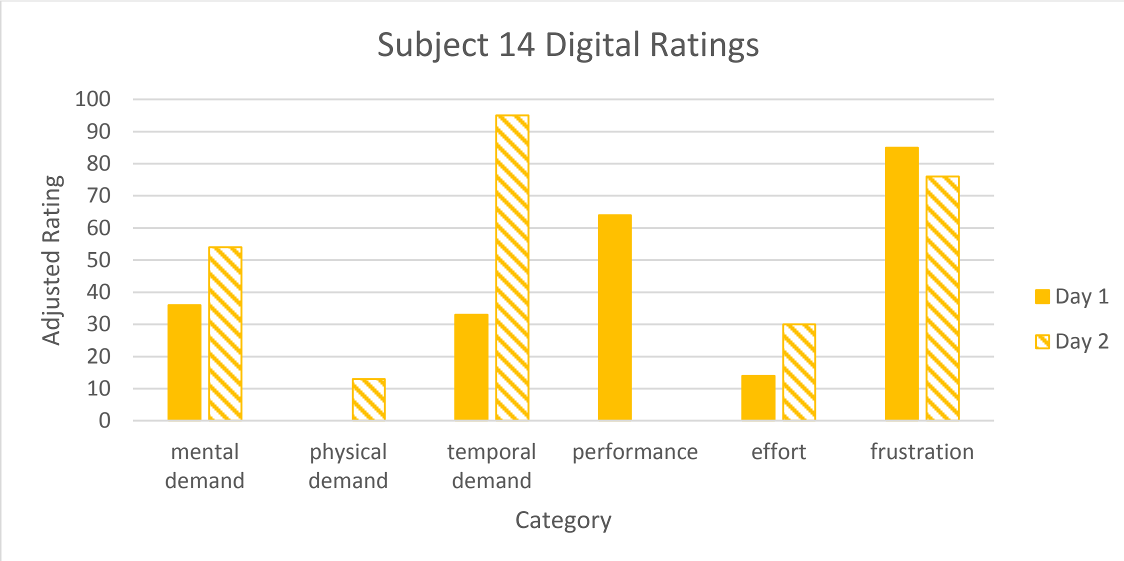
course digital			
scale title	weight	raw rating	adjusted rating
mental demand	3	18	54
physical demand	1	13	13
temporal demand	5	19	95
performance	0	15	0
effort	2	15	30
frustration	4	19	76
		sum	268
		weighted rating	17.86666667

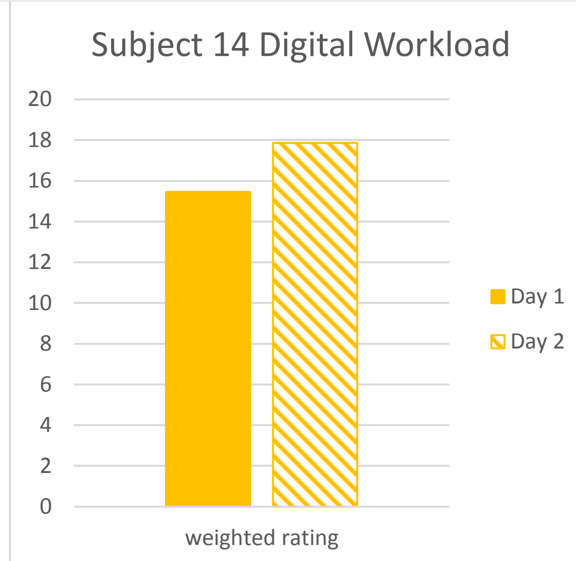
Averages

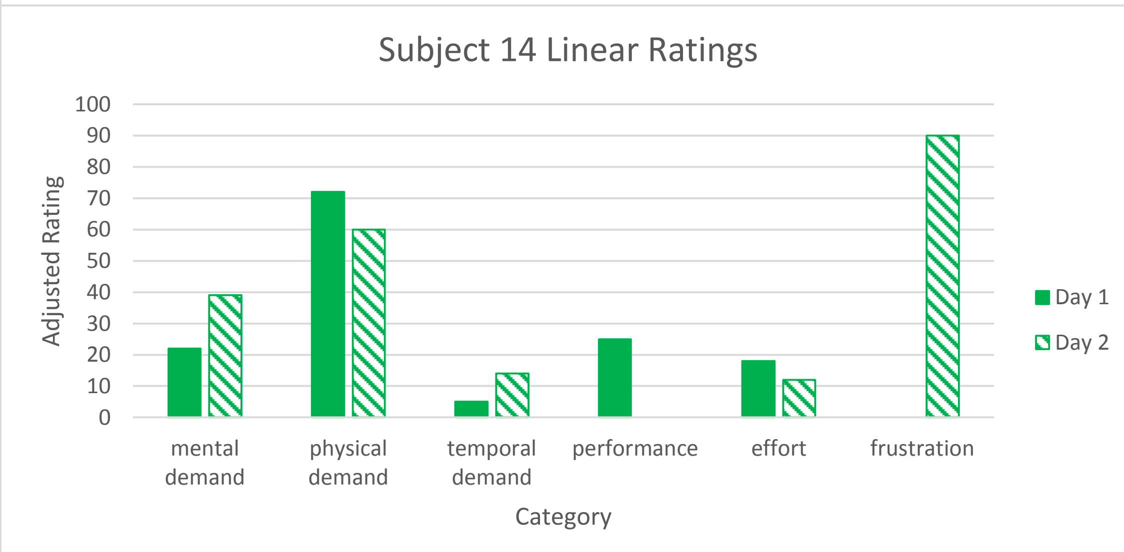
course digital	
scale title	adjusted rating
mental demand	45
physical demand	6.5
temporal demand	64
performance	32
effort	22
frustration	80.5
sum	250
weighted rating	16.66666667

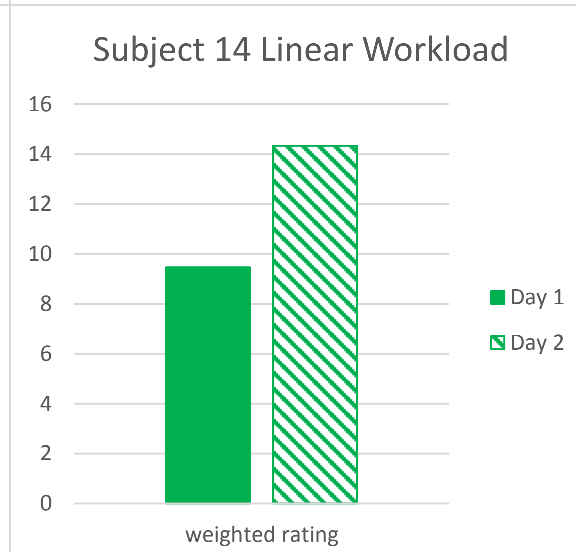
course linear	
scale title	adjusted rating
mental demand	30.5
physical demand	66
temporal demand	9.5
performance	12.5
effort	15
frustration	45
sum	178.5
weighted rating	11.9

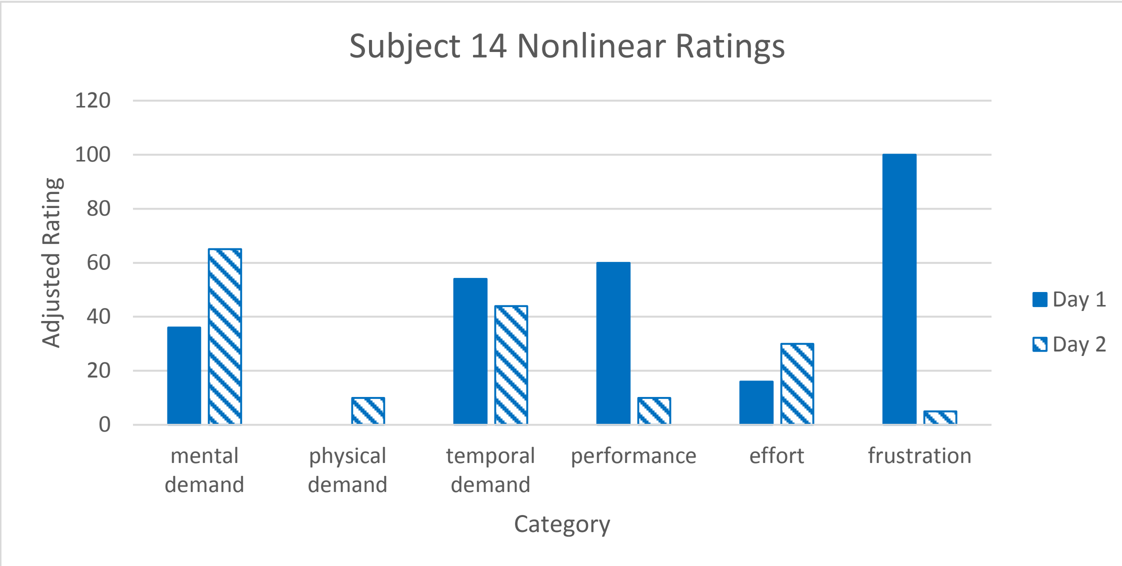
course nonlinear	
scale title	adjusted rating
mental demand	50.5
physical demand	5
temporal demand	49
performance	35
effort	23
frustration	52.5
sum	215
weighted rating	14.33333333

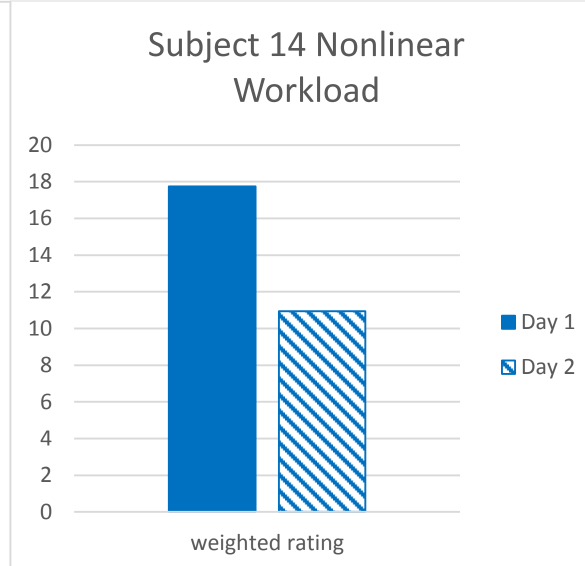

Subject 14 Digital Ratings
Adjusted Rating
100
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

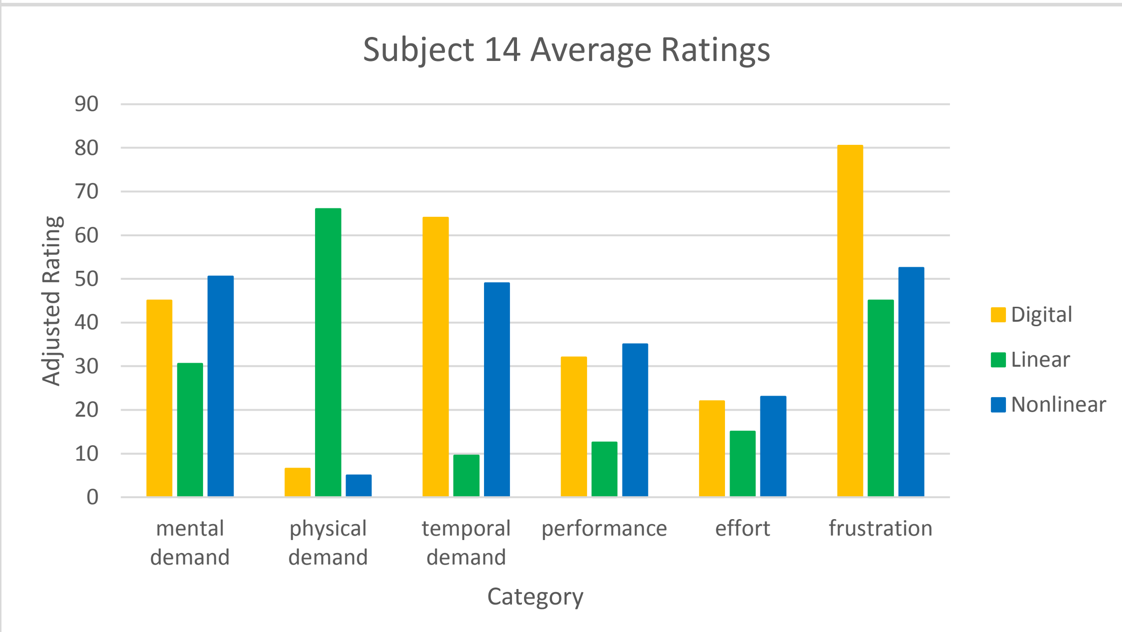

Subject 14 Digital Workload
20
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2

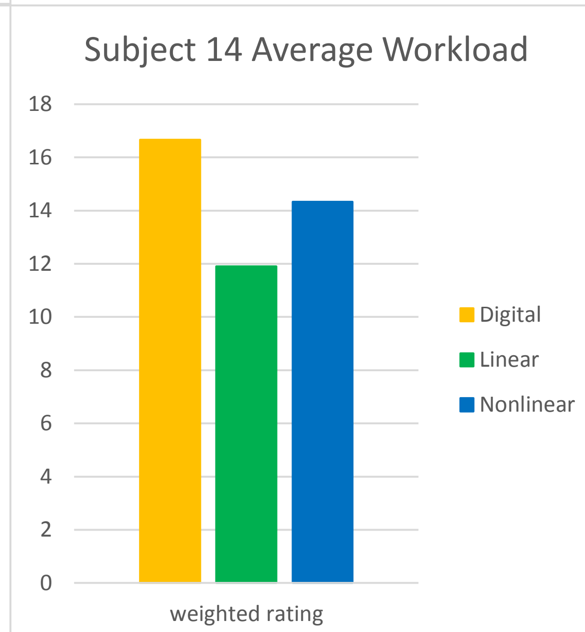

Subject 14 Linear Ratings
Adjusted Rating
100
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 14 Linear Workload
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 14 Nonlinear Ratings
Adjusted Rating
120
100
80
60
40
20
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 14 Nonlinear Workload
20
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 14 Average Ratings
Adjusted Rating
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear


Subject 14 Average Workload
18
16
14
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

Subject 15

Day 1

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	3	10	30
physical demand	1	10	10
temporal demand	0	9	0
performance	4	13	52
effort	2	11	22
frustration	5	14	70
		sum	184
		weighted rating	12.26666667

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	4	10	40
physical demand	0	10	0
temporal demand	1	10	10
performance	5	12	60
effort	2	12	24
frustration	3	12	36
		sum	170
		weighted rating	11.33333333

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	4	9	36
physical demand	1	8	8
temporal demand	0	7	0
performance	4	11	44
effort	2	11	22
frustration	4	12	48
		sum	158
		weighted rating	10.53333333

Day 2

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	4	10	40
physical demand	2	7	14
temporal demand	1	6	6
performance	2	11	22
effort	3	11	33
frustration	3	10	30
		sum	145
		weighted rating	9.666666667

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	5	9	45
physical demand	2	6	12
temporal demand	0	3	0
performance	2	11	22
effort	4	11	44
frustration	2	9	18
		sum	141
		weighted rating	9.4

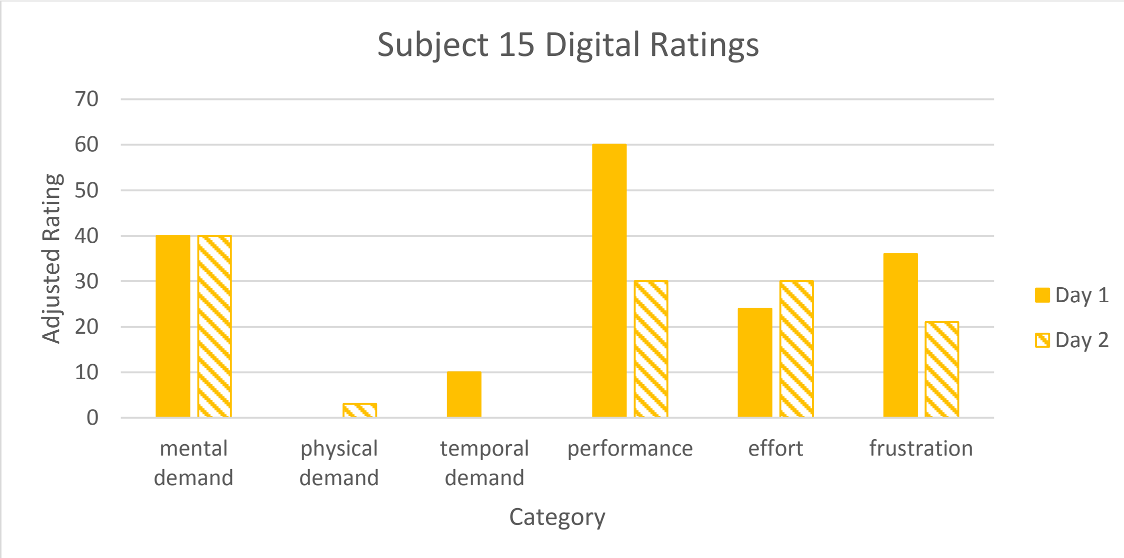
course digital			
scale title	weight	raw rating	adjusted rating
mental demand	5	8	40
physical demand	1	3	3
temporal demand	0	3	0
performance	3	10	30
effort	3	10	30
frustration	3	7	21
		sum	124
		weighted rating	8.266666667

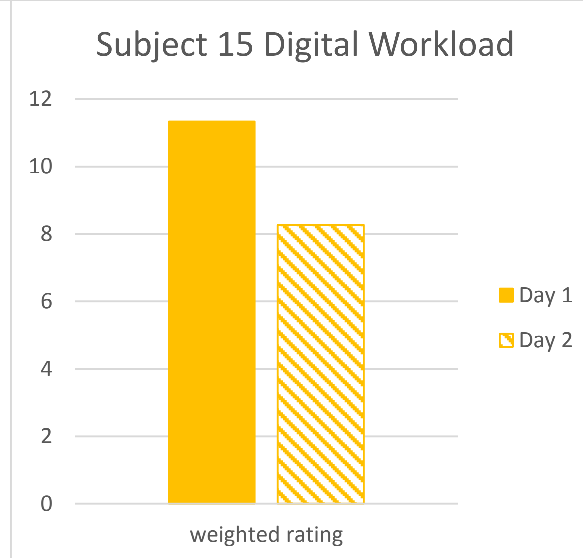
Averages

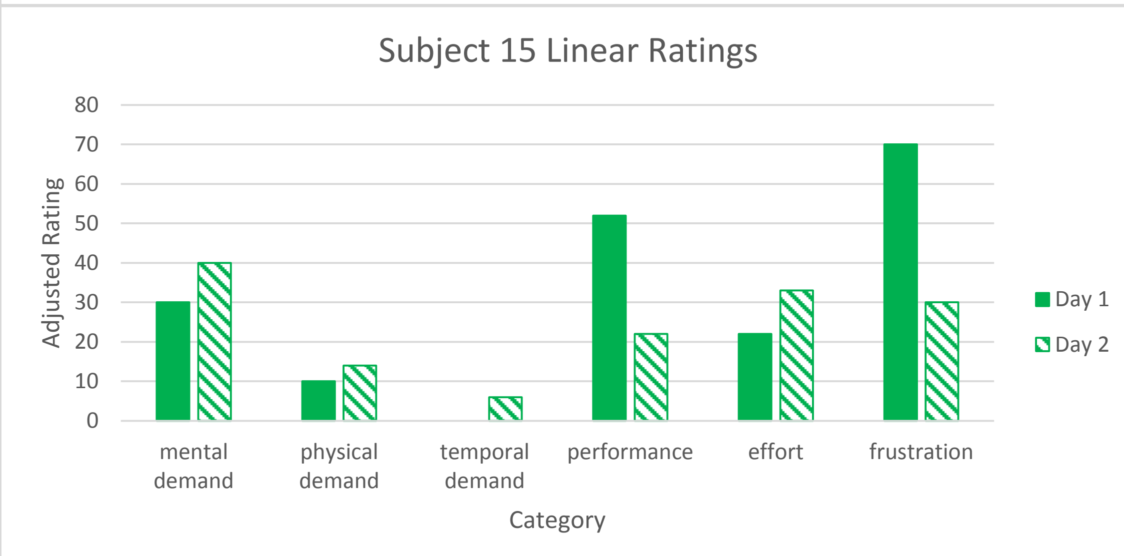
course digital	
scale title	adjusted rating
mental demand	40
physical demand	1.5
temporal demand	5
performance	45
effort	27
frustration	28.5
sum	147
weighted rating	9.8

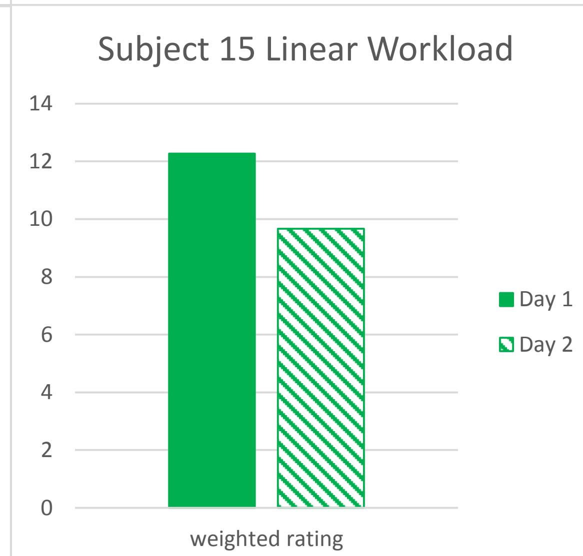
course linear	
scale title	adjusted rating
mental demand	35
physical demand	12
temporal demand	3
performance	37
effort	27.5
frustration	50
sum	164.5
weighted rating	10.96666667

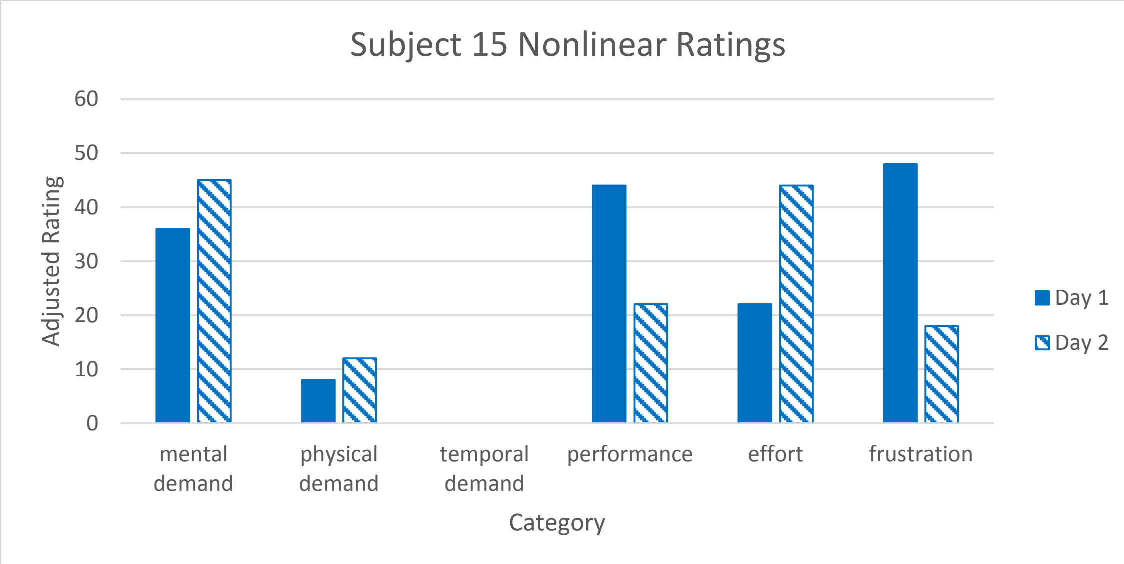
course nonlinear	
scale title	adjusted rating
mental demand	40.5
physical demand	10
temporal demand	0
performance	33
effort	33
frustration	33
sum	149.5
weighted rating	9.966666667

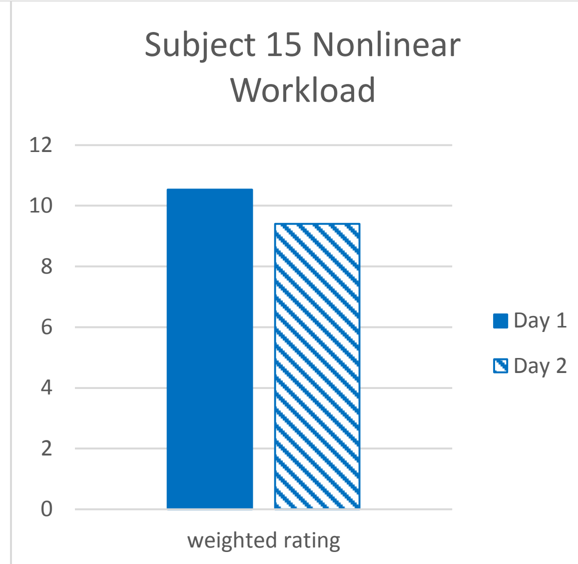

Subject 15 Digital Ratings
Adjusted Rating
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

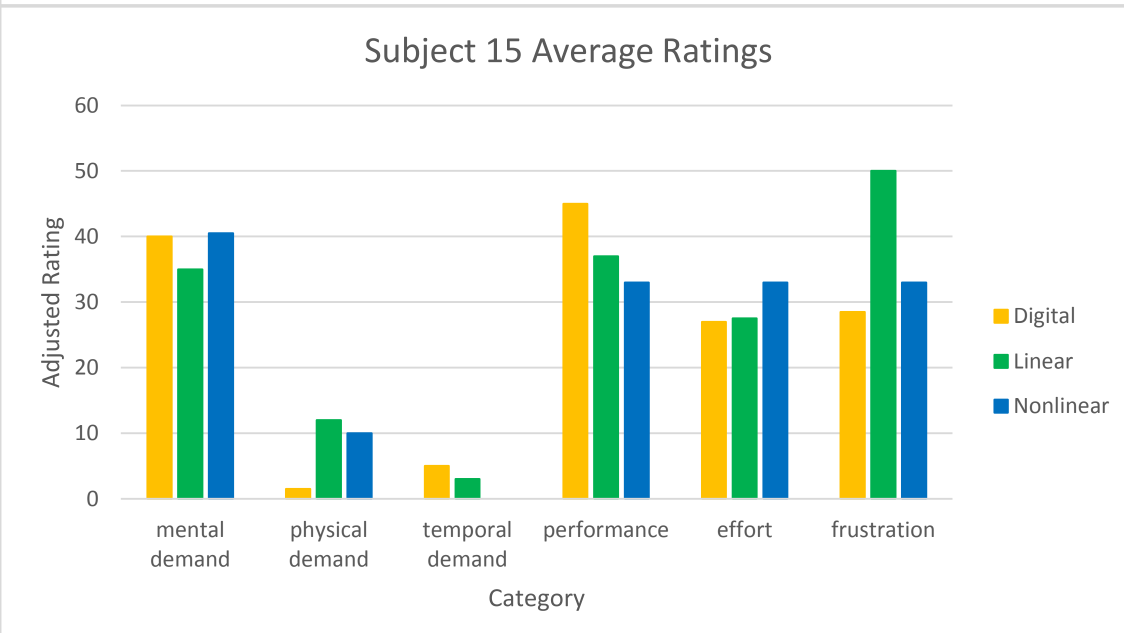

Subject 15 Digital Workload
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2

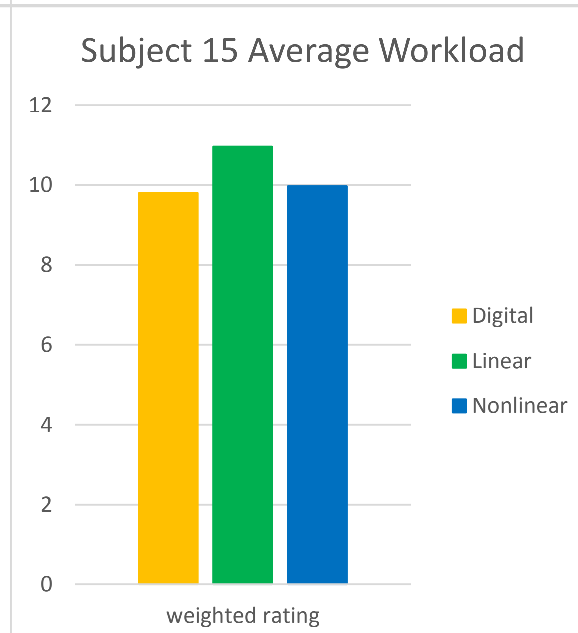

Subject 15 Linear Ratings
Adjusted Rating
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 15 Linear Workload
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 15 Nonlinear Ratings
Adjusted Rating
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2


Subject 15 Nonlinear Workload
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2


Subject 15 Average Ratings
Adjusted Rating
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear


Subject 15 Average Workload
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

Subject 16

Day 1

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	4	18	72
physical demand	0	12	0
temporal demand	3	16	48
performance	1	11	11
effort	2	20	40
frustration	5	18	90
		sum	261
		weighted rating	17.4

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	1	18	18
physical demand	5	18	90
temporal demand	0	15	0
performance	2	5	10
effort	3	19	57
frustration	4	18	72
		sum	247
		weighted rating	16.46666667

course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	3	19	57
physical demand	5	20	100
temporal demand	0	19	0
performance	3	15	45
effort	1	20	20
frustration	3	20	60
		sum	282
		weighted rating	18.8

Day 2

course linear			
scale title	weight	raw rating	adjusted rating
mental demand	3	10	30
physical demand	5	18	90
temporal demand	0	11	0
performance	2	3	6
effort	4	20	80
frustration	1	16	16
		sum	222
		weighted rating	14.8

course digital			
scale title	weight	raw rating	adjusted rating
mental demand	1	15	15
physical demand	3	20	60
temporal demand	0	15	0
performance	4	20	80
effort	3	20	60
frustration	4	20	80
		sum	295
		weighted rating	19.66666667

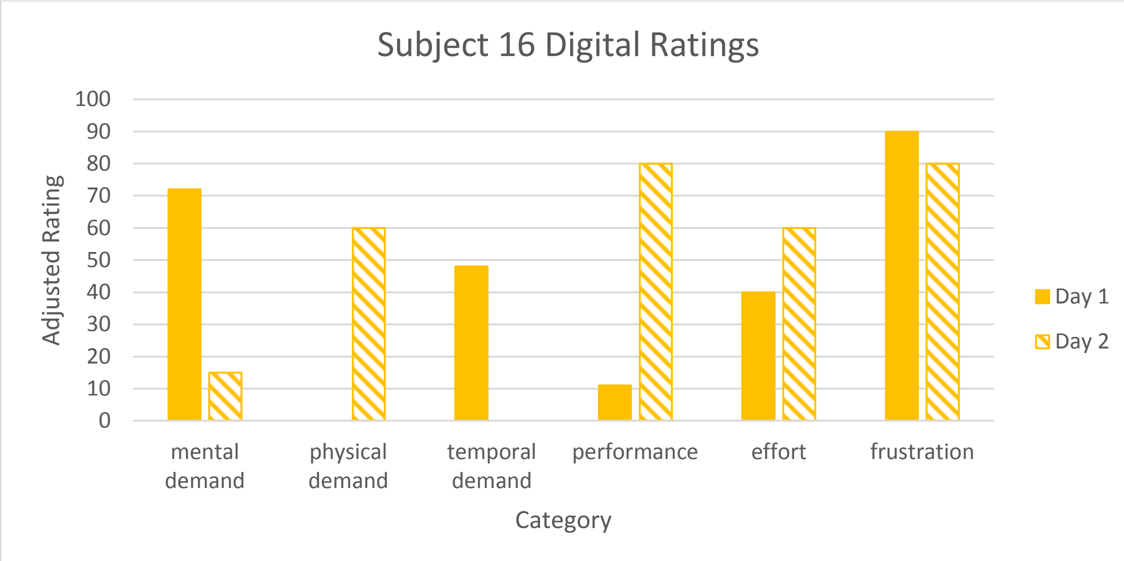
course nonlinear			
scale title	weight	raw rating	adjusted rating
mental demand	1	18	18
physical demand	2	20	40
temporal demand	0	16	0
performance	5	11	55
effort	3	18	54
frustration	4	18	72
		sum	239
		weighted rating	15.93333333

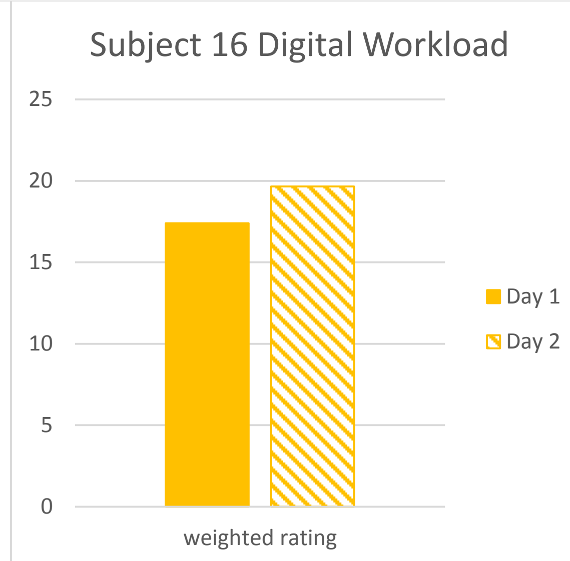
Averages

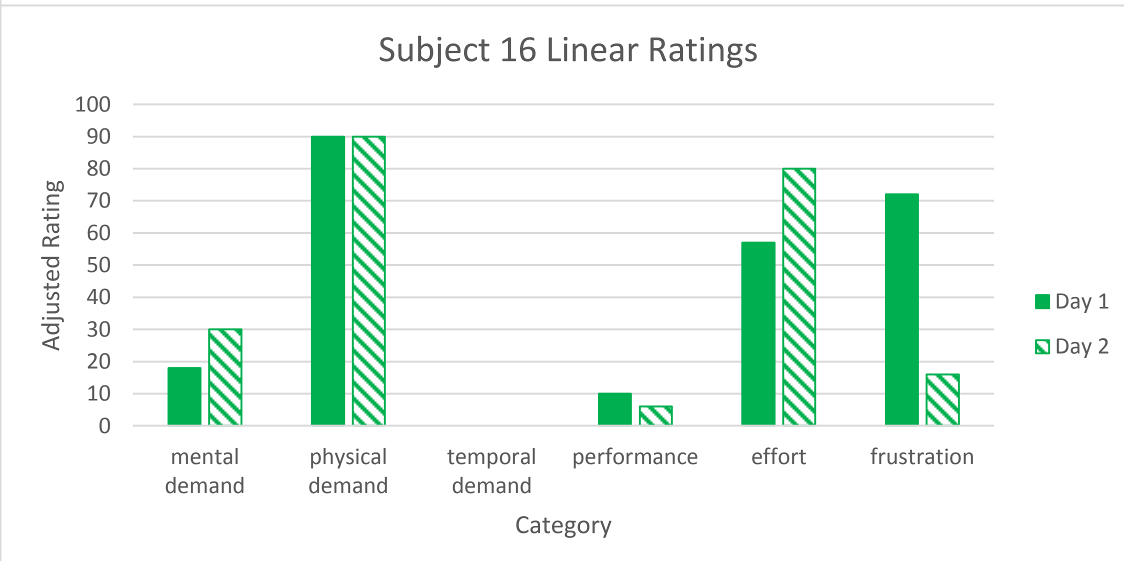
course digital	
scale title	adjusted rating
mental demand	43.5
physical demand	30
temporal demand	24
performance	45.5
effort	50
frustration	85
sum	278
weighted rating	18.53333333

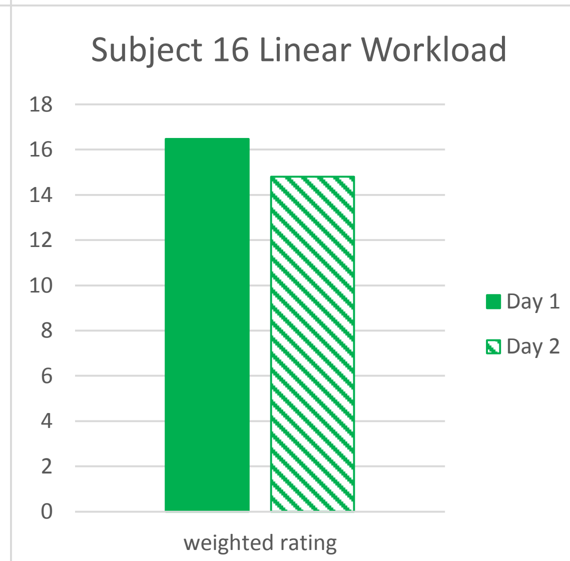
course linear	
scale title	adjusted rating
mental demand	24
physical demand	90
temporal demand	0
performance	8
effort	68.5
frustration	44
sum	234.5
weighted rating	15.63333333

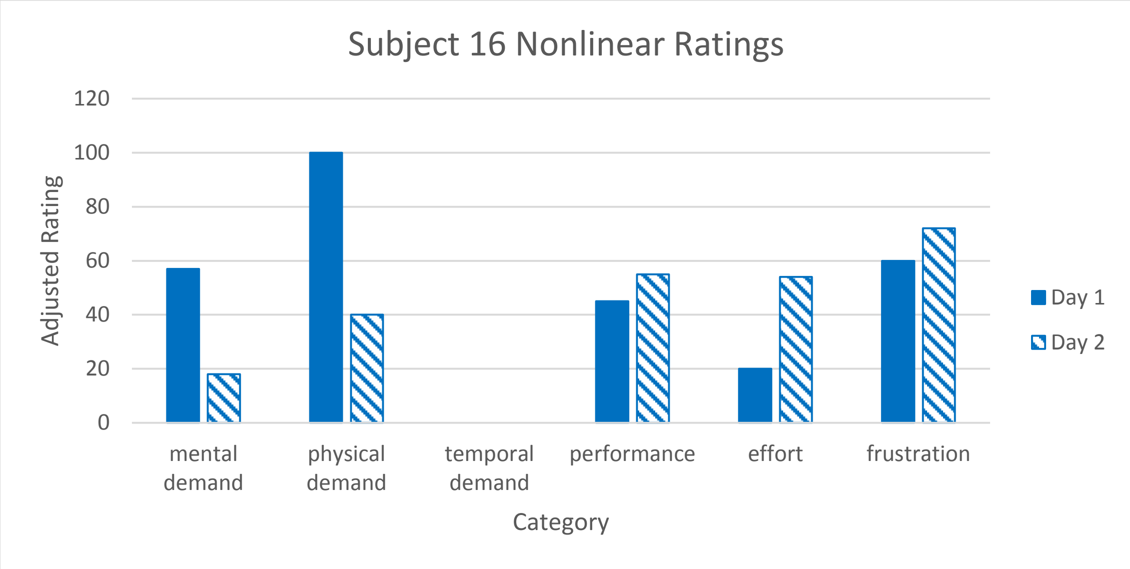
course nonlinear	
scale title	adjusted rating
mental demand	37.5
physical demand	70
temporal demand	0
performance	50
effort	37
frustration	66
sum	260.5
weighted rating	17.36666667


Subject 16 Digital Ratings
Adjusted Rating
100
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

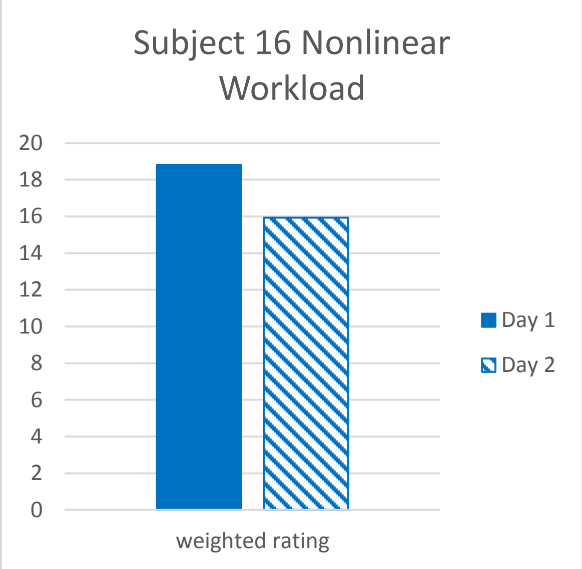

Subject 16 Digital Workload
25
20
15
10
5
0
weighted rating
Day 1
Day 2


Subject 16 Linear Ratings
Adjusted Rating
100
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2

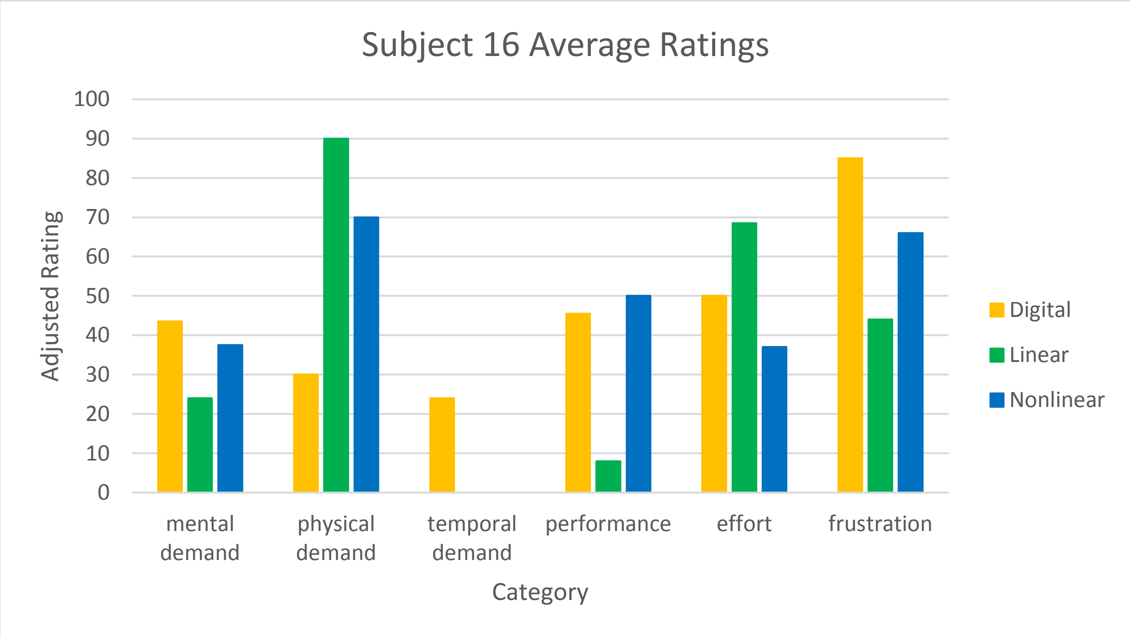

Subject 16 Linear Workload
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2



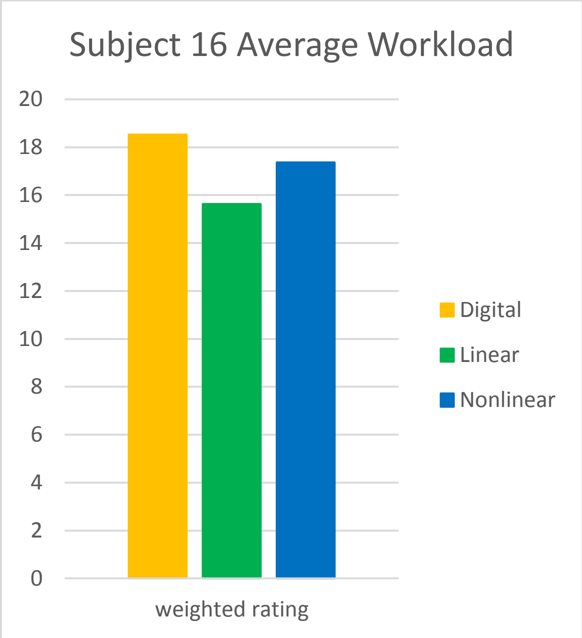
Subject 16 Nonlinear Ratings
Adjusted Rating
120
100
80
60
40
20
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Day 1
Day 2



Subject 16 Nonlinear Workload
20
18
16
14
12
10
8
6
4
2
0
weighted rating
Day 1
Day 2



Subject 16 Average Ratings
Adjusted Rating
100
90
80
70
60
50
40
30
20
10
0
mental demand
physical demand
temporal demand
performance
effort
frustration
Category
Digital
Linear
Nonlinear



Subject 16 Average Workload
20
18
16
14
12
10
8
6
4
2
0
weighted rating
Digital
Linear
Nonlinear

Appendix C: Generalized Estimating Equations Analysis

Time

Tests of Model Effects

Source	Type III		
	Wald Chi-Square	df	Sig.
(Intercept)	2287.693	1	0.000
day	37.637	1	.000
condition	3.855	2	.146
day * condition	36.574	2	.000

Dependent Variable: time
Model: (Intercept), day, condition, day * condition

Parameter Estimates

Parameter	B	Std. Error	Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	3.217	.0956	3.029	3.404	1131.340	1	0.000
[day=1]	1.272	.0956	1.084	1.459	176.799	1	0.000
[day=2]	0[a]						
[condition=1]	.612	.1193	.378	.846	26.319	1	.000
[condition=2]	.701	.2093	.291	1.111	11.211	1	.001
[condition=3]	0[a]						
[day=1] * [condition=1]	-.771	.2286	-1.219	-.322	11.357	1	.001
[day=1] * [condition=2]	-1.197	.2271	-1.642	-.752	27.781	1	.000
[day=1] * [condition=3]	0[a]						
[day=2] * [condition=1]	0[a]						
[day=2] * [condition=2]	0[a]						
[day=2] * [condition=3]	0[a]						
(Scale)	1						

Dependent Variable: time
Model: (Intercept), day, condition, day * condition

a. Set to zero because this parameter is redundant.

Estimated Marginal Means 1: day

Estimates

day	Mean	Std. Error	95% Wald Confidence Interval Lower	Upper
1	71.55	5.834	60.98	83.95
2	38.65	4.254	31.15	47.95

Pairwise Comparisons

(I) day		Mean Difference (I-J)	Std. Error	df	Sig.	95% Wald Confidence Interval for Difference Lower	Upper
1	2	32.90[a]	5.302	1	.000	22.51	43.30
2	1	-32.90[a]	5.302	1	.000	-43.30	-22.51

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable time

a. The mean difference is significant at the .05 level.

Overall Test Results

Chi-Squar	df	Sig.
38.506	1	.000

The Wald chi-square tests the effect of day. This test is based on the linearly

Estimated Marginal Means 2: condition

Estimates

condition	Mean	Std. Error	Interval	
			Lower	Upper
1	59.11	8.165	45.09	77.49
2	52.20	7.543	39.33	69.29
3	47.12	2.254	42.91	51.75

Pairwise Comparisons

(I) condition		Mean Difference (I-J)	Std. Error	df	Sig.	95% Wald Confidence Interval for Difference	
						Lower	Upper
1	2	6.91	10.053	1	.492	-12.80	26.61
	3	11.98	7.571	1	.113	-2.85	26.82
2	1	-6.91	10.053	1	.492	-26.61	12.80
	3	5.08	6.678	1	.447	-8.01	18.17
3	1	-11.98	7.571	1	.113	-26.82	2.85
	2	-5.08	6.678	1	.447	-18.17	8.01

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable time

Overall Test Results

Wald Chi-Square	df	Sig.
3.063	2	.216

The Wald chi-square tests the effect of condition. This test is based on the linearly

Estimated Marginal Means 3: day* condition

Estimates

day		Mean	Std. Error	Interval Lower	Interval Upper
1	1	75.94	15.983	50.27	114.72
	2	54.19	6.457	42.91	68.45
	3	89.00	0.000	89.00	89.00
2	1	46.01	6.415	35.00	60.47
	2	50.28	10.758	33.06	76.48
	3	24.95	2.386	20.69	30.10

Pairwise Comparisons

(I) day*condition		Mean Difference (I-J)	Std. Error	df	Sig.	Interval for Difference	
						Lower	Upper
[day=1]*[condition=1]	[day=1]*[condition=2]	21.75	17.076	1	.203	-11.72	55.22
	[day=1]*[condition=3]	-13.06	15.983	1	.414	-44.38	18.27
	[day=2]*[condition=1]	29.94	15.895	1	.060	-1.22	61.09
	[day=2]*[condition=2]	25.66	18.918	1	.175	-11.42	62.74
	[day=2]*[condition=3]	50.99[a]	15.784	1	.001	20.05	81.93
[day=1]*[condition=2]	[day=1]*[condition=1]	-21.75	17.076	1	.203	-55.22	11.72
	[day=1]*[condition=3]	-34.81[a]	6.457	1	.000	-47.46	-22.15
	[day=2]*[condition=1]	8.19	6.718	1	.223	-4.98	21.35
	[day=2]*[condition=2]	3.91	9.658	1	.685	-15.02	22.84
	[day=2]*[condition=3]	29.24[a]	4.924	1	.000	19.59	38.89
[day=1]*[condition=3]	[day=1]*[condition=1]	13.06	15.983	1	.414	-18.27	44.38
	[day=1]*[condition=2]	34.81[a]	6.457	1	.000	22.15	47.46
	[day=2]*[condition=1]	42.99[a]	6.415	1	.000	30.42	55.57
	[day=2]*[condition=2]	38.72[a]	10.758	1	.000	17.63	59.81
	[day=2]*[condition=3]	64.05[a]	2.386	1	0.000	59.37	68.73

[day=2]*[condition=1]	[day=1]*[condition=1]	-29.94	15.895	1	.060	-61.09	1.22
	[day=1]*[condition=2]	-8.19	6.718	1	.223	-21.35	4.98
	[day=1]*[condition=3]	-42.99[a]	6.415	1	.000	-55.57	-30.42
	[day=2]*[condition=2]	-4.27	11.647	1	.714	-27.10	18.55
	[day=2]*[condition=3]	21.06[a]	5.510	1	.000	10.26	31.85
[day=2]*[condition=2]	[day=1]*[condition=1]	-25.66	18.918	1	.175	-62.74	11.42
	[day=1]*[condition=2]	-3.91	9.658	1	.685	-22.84	15.02
	[day=1]*[condition=3]	-38.72[a]	10.758	1	.000	-59.81	-17.63
	[day=2]*[condition=1]	4.27	11.647	1	.714	-18.55	27.10
	[day=2]*[condition=3]	25.33[a]	10.367	1	.015	5.01	45.65
[day=2]*[condition=3]	[day=1]*[condition=1]	-50.99[a]	15.784	1	.001	-81.93	-20.05
	[day=1]*[condition=2]	-29.24[a]	4.924	1	.000	-38.89	-19.59
	[day=1]*[condition=3]	-64.05[a]	2.386	1	0.000	-68.73	-59.37
	[day=2]*[condition=1]	-21.06[a]	5.510	1	.000	-31.85	-10.26
	[day=2]*[condition=2]	-25.33[a]	10.367	1	.015	-45.65	-5.01

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable time

a. The mean difference is significant at the .05 level.

Overall Test Results

Wald Chi-Square	df	Sig.
1335.355	5	0.000

The Wald chi-square tests the effect of day*condition. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Error

Tests of Model Effects

Source	Type III Wald Chi-Square	Type III df	Type III Sig.
(Intercept)	575.291	1	0.000
day	51.751	1	.000
condition	50.267	2	.000
day * condition	.485	2	.785

Dependent Variable: total errors
Model: (Intercept), day, condition, day *

Parameter Estimates

Parameter	B	Std. Error	Confidence Interval		Hypothesis Test		
			Lower	Upper	Wald Chi-Square	df	Sig.
(Intercept)	1.591	.1280	1.340	1.841	154.517	1	0.000
[day=1]	.441	.1575	.132	.750	7.848	1	.005
[day=2]	0[a]						
[condition=1]	.703	.1257	.457	.950	31.291	1	.000
[condition=2]	-.203	.1660	-.528	.122	1.495	1	.221
[condition=3]	0[a]						
[day=1] * [condition=1]	.120	.1724	-.218	.458	.485	1	.486
[day=1] * [condition=2]	.172	.3278	-.470	.814	.275	1	.600
[day=1] * [condition=3]	0[a]						
[day=2] * [condition=1]	0[a]						
[day=2] * [condition=2]	0[a]						
[day=2] * [condition=3]	0[a]						
(Scale)	1						

Dependent Variable: total errors
Model: (Intercept), day, condition, day * condition

a. Set to zero because this parameter is redundant.

Estimated Marginal Means 1: day

Estimates

day	Mean	Std. Error	Interval Lower	Interval Upper
1	9.93	.896	8.32	11.85
2	5.80	.548	4.82	6.98

Pairwise Comparisons

(I) day		Mean Difference (I-J)	Std. Error	df	Sig.	95% Wald Confidence Interval for Difference Lower	95% Wald Confidence Interval for Difference Upper
1	2	4.13[a]	.665	1	.000	2.83	5.44
2	1	-4.13[a]	.665	1	.000	-5.44	-2.83

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable total errors

a. The mean difference is significant at the .05 level.

Overall Test Results

Wald Chi-Square	df	Sig.
38.681	1	.000

The Wald chi-square tests the effect of day. This test is based on the linearly independent pairwise

Estimated Marginal Means 2: condition

Estimates

condition	Mean	Std. Error	Interval Lower	Interval Upper
1	13.12	.863	11.54	14.93
2	5.44	.609	4.37	6.78
3	6.12	.826	4.69	7.97

Pairwise Comparisons

(I) condition		Mean Difference (I-J)	Std. Error	df	Sig.	95% Wald Confidence Interval for Difference Lower	95% Wald Confidence Interval for Difference Upper
1	2	7.68[a]	1.007	1	.000	5.71	9.65
	3	7.01[a]	1.040	1	.000	4.97	9.04
2	1	-7.68[a]	1.007	1	.000	-9.65	-5.71
	3	-.68	.524	1	.197	-1.70	.35
3	1	-7.01[a]	1.040	1	.000	-9.04	-4.97
	2	.68	.524	1	.197	-.35	1.70

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable total errors

a. The mean difference is significant at the .05 level.

Overall Test Results

Wald Chi-Square	df	Sig.
58.278	2	.000

The Wald chi-square tests the effect of condition. This test is based on the linearly independent

Estimated Marginal Means 3: day* condition

Estimates

day		Mean	Std. Error	Interval Lower	Interval Upper
1	1	17.37	1.343	14.93	20.22
	2	7.39	1.063	5.58	9.80
	3	7.63	1.374	5.36	10.86
2	1	9.91	.952	8.21	11.97
	2	4.00	.637	2.93	5.47
	3	4.91	.628	3.82	6.30

Pairwise Comparisons							
						95% Wald Confidence Interval for Difference	
(I) day*condition		Mean Difference (I-J)	Std. Error	df	Sig.	Lower	Upper
[day=1]*[condition=1]	[day=1]*[condition=2]	9.98[a]	1.754	1	.000	6.54	13.42
	[day=1]*[condition=3]	9.75[a]	1.818	1	.000	6.18	13.31
	[day=2]*[condition=1]	7.46[a]	1.533	1	.000	4.46	10.47
	[day=2]*[condition=2]	13.37[a]	1.359	1	0.000	10.71	16.03
	[day=2]*[condition=3]	12.47[a]	1.419	1	0.000	9.69	15.25
[day=1]*[condition=2]	[day=1]*[condition=1]	-9.98[a]	1.754	1	.000	-13.42	-6.54
	[day=1]*[condition=3]	-.23	1.526	1	.879	-3.22	2.76
	[day=2]*[condition=1]	-2.52	1.526	1	.099	-5.51	.47
	[day=2]*[condition=2]	3.39[a]	1.189	1	.004	1.06	5.72
	[day=2]*[condition=3]	2.49[a]	.809	1	.002	.90	4.07
[day=1]*[condition=3]	[day=1]*[condition=1]	-9.75[a]	1.818	1	.000	-13.31	-6.18
	[day=1]*[condition=2]	.23	1.526	1	.879	-2.76	3.22
	[day=2]*[condition=1]	-2.29	1.618	1	.158	-5.46	.88
	[day=2]*[condition=2]	3.62[a]	.987	1	.000	1.69	5.56
	[day=2]*[condition=3]	2.72[a]	1.176	1	.021	.42	5.02
[day=2]*[condition=1]	[day=1]*[condition=1]	-7.46[a]	1.533	1	.000	-10.47	-4.46
	[day=1]*[condition=2]	2.52	1.526	1	.099	-.47	5.51
	[day=1]*[condition=3]	2.29	1.618	1	.158	-.88	5.46
	[day=2]*[condition=2]	5.91[a]	1.044	1	.000	3.86	7.95
	[day=2]*[condition=3]	5.01[a]	.908	1	.000	3.23	6.79

[day=2]*[condition=2]	[day=1]*[condition=1]	-13.37[a]	1.359	1	0.000	-16.03	-10.71
	[day=1]*[condition=2]	-3.39[a]	1.189	1	.004	-5.72	-1.06
	[day=1]*[condition=3]	-3.62[a]	.987	1	.000	-5.56	-1.69
	[day=2]*[condition=1]	-5.91[a]	1.044	1	.000	-7.95	-3.86
	[day=2]*[condition=3]	-.90	.723	1	.212	-2.32	.52
[day=2]*[condition=3]	[day=1]*[condition=1]	-12.47[a]	1.419	1	0.000	-15.25	-9.69
	[day=1]*[condition=2]	-2.49[a]	.809	1	.002	-4.07	-.90
	[day=1]*[condition=3]	-2.72[a]	1.176	1	.021	-5.02	-.42
	[day=2]*[condition=1]	-5.01[a]	.908	1	.000	-6.79	-3.23
	[day=2]*[condition=2]	.90	.723	1	.212	-.52	2.32

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable total errors

a. The mean difference is significant at the .05 level.

Overall Test Results

Wald Chi-Square	df	Sig.
305.714	5	0.000

The Wald chi-square tests the effect of day*condition. This test is based on the linearly independent pairwise comparisons among the estimated marginal means.

Overall Workload

Tests of Model Effects

Source	Type III Wald Chi-Square	df	Sig.
(Intercept)	1195.995	1	0.000
day	.000	1	.987
condition	208.695	2	0.000
day * condition	1.405	1	.236

Dependent Variable: NASA
Model: (Intercept), day, condition, day *

Parameter Estimates

Parameter	B	Std. Error	Interval Lower	Interval Upper	Hypothesis Test Wald Chi-Square	Hypothesis Test df	Hypothesis Test Sig.
(Intercept)	1.609	########	1.609	1.609	########	1	0.000
[day=1]	.172	.2859	-.389	.732	.361	1	.548
[day=2]	0[a]						
[condition=1]	.956	0.0000	.956	.956		1	0.000
[condition=2]	.470	.1179	.239	.701	15.905	1	.000
[condition=3]	0[a]						
[day=1] * [condition=1]	-.339	.2859	-.899	.222	1.405	1	.236
[day=1] * [condition=2]	0[a]						
[day=2] * [condition=1]	0[a]						
[day=2] * [condition=2]	0[a]						
[day=2] * [condition=3]	0[a]						
(Scale)	1						

Dependent Variable: NASA
Model: (Intercept), day, condition, day * condition

a. Set to zero because this parameter is redundant.

Estimated Marginal Means 1: day

Estimates

day	Mean	Std. Error	Interval	
			Lower	Upper
1	10.22	1.332	7.92	13.20
2	8.04	.316	7.45	8.69

Pairwise Comparisons

(I) day		Mean Difference (I-J)	Std. Error	df	Sig.	95% Wald Confidence Interval for Difference	
						Lower	Upper
1	2	2.18	1.369	1	.111	-.50	4.86
2	1	-2.18	1.369	1	.111	-4.86	.50

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable NASA

Overall Test Results

Wald Chi-Square	df	Sig.
2.540	1	.111

The Wald chi-square tests the effect of day. This test is based on the linearly independent pairwise

Estimated Marginal Means 2: condition

Estimates

condition	Mean	Std. Error	Interval Lower	Interval Upper
1	11.96	.000	11.96	11.96
2	8.72	1.246	6.59	11.54
3	5.00	.000	5.00	5.00

Pairwise Comparisons

(I) condition		Mean Difference (I-J)	Std. Error	df	Sig.	95% Wald Confidence Interval for Difference Lower	Upper
1	2	3.24[a]	1.246	1	.009	.80	5.68
	3	6.96[a]	.000	1	0.000	6.96	6.96
2	1	-3.24[a]	1.246	1	.009	-5.68	-.80
	3	3.72[a]	1.246	1	.003	1.28	6.16
3	1	-6.96[a]	.000	1	0.000	-6.96	-6.96
	2	-3.72[a]	1.246	1	.003	-6.16	-1.28

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable NASA

a. The mean difference is significant at the .05 level.

Overall Test Results

Wald Chi-Square	df	Sig.
6.760	1	.009

The Wald chi-square tests the effect of condition. This test is based on the linearly independent

Estimated Marginal Means 3: day* condition

Estimates

day		Mean	Std. Error	Interval Lower	Interval Upper
1	1	11.00	.000	11.00	11.00
	2	9.50	2.475	5.70	15.83
2	1	13.00	.000	13.00	13.00
	2	8.00	.943	6.35	10.08
	3	5.00	.000	5.00	5.00

Pairwise Comparisons

(I) day*condition		Mean Difference (I-J)	Std. Error	df	Sig.	95% Wald Confidence Interval for Difference	
						Lower	Upper
[day=1]*[condition=1]	[day=1]*[condition=2]	1.50	2.475	1	.544	-3.35	6.35
	[day=2]*[condition=1]	-2.00[a]	.000	1	0.000	-2.00	-2.00
	[day=2]*[condition=2]	3.00[a]	.943	1	.001	1.15	4.85
	[day=2]*[condition=3]	6.00[a]	.000	1	0.000	6.00	6.00
[day=1]*[condition=2]	[day=1]*[condition=1]	-1.50	2.475	1	.544	-6.35	3.35
	[day=2]*[condition=1]	-3.50	2.475	1	.157	-8.35	1.35
	[day=2]*[condition=2]	1.50	2.648	1	.571	-3.69	6.69
	[day=2]*[condition=3]	4.50	2.475	1	.069	-.35	9.35
[day=2]*[condition=1]	[day=1]*[condition=1]	2.00[a]	.000	1	0.000	2.00	2.00
	[day=1]*[condition=2]	3.50	2.475	1	.157	-1.35	8.35
	[day=2]*[condition=2]	5.00[a]	.943	1	.000	3.15	6.85
	[day=2]*[condition=3]	8.00[a]	.000	1	0.000	8.00	8.00
[day=2]*[condition=2]	[day=1]*[condition=1]	-3.00[a]	.943	1	.001	-4.85	-1.15
	[day=1]*[condition=2]	-1.50	2.648	1	.571	-6.69	3.69
	[day=2]*[condition=1]	-5.00[a]	.943	1	.000	-6.85	-3.15
	[day=2]*[condition=3]	3.00[a]	.943	1	.001	1.15	4.85
[day=2]*[condition=3]	[day=1]*[condition=1]	-6.00[a]	.000	1	0.000	-6.00	-6.00
	[day=1]*[condition=2]	-4.50	2.475	1	.069	-9.35	.35
	[day=2]*[condition=1]	-8.00[a]	.000	1	0.000	-8.00	-8.00
	[day=2]*[condition=2]	-3.00[a]	.943	1	.001	-4.85	-1.15

Pairwise comparisons of estimated marginal means based on the original scale of dependent variable NASA

a. The mean difference is significant at the .05 level.

Overall Test Results

Wald Chi-Square	df	Sig.
10.492	2	.005

The Wald chi-square tests the effect of day*condition. This test is based on the linearly independent pairwise comparisons among the estimated marginal means

Appendix D

Consent Form and Script

RESEARCH SUBJECT INFORMATION AND CONSENT FORM

TITLE: Evaluation of a Novel Myoelectric Training Device

PROTOCOL NO: HM20004508

INVESTIGATOR: Peter Pidcoe, PhD, DPT, PT

If any information contained in this consent form is not clear, please ask the study staff to explain any information that you do not fully understand. You may take home an unsigned copy of this consent form to think about or discuss with family or friends before making your decision.

In this consent form, "you" always refers to the research participant.

PURPOSE OF THE STUDY:

The purpose of this research study is to find an equation that matches the natural behavior of muscles in the forearm during rest and activity.

PROCEDURES

If you decide to be in this research study, you will be asked to sign this consent form after you have had all your questions answered.

At your first study visit (Visit 1), you will begin the study for data collection. This visit is considered training, so you can become familiar with the system. You will be asked to wear braces on your forearms during the study to make sure the data being collected is from the correct muscles. Then you will push the ends of your fingers against the braces to control a toy car and move it through an obstacle course. The total time for you to finish the course as well as the number of mistakes you make will be recorded. Mistakes include backing up, hitting a wall, or hitting a cone.

For your second visit (Visit 2), which should be scheduled within 48 hours of Visit 1, you will go through the procedure again for comparison purposes.

Your participation in this study will last up to 120 minutes for each visit. Approximately 10 individuals will participate in this study.

RISKS AND DISCOMFORTS

You may feel tired or uncomfortable during the study due to the braces, but the risk is small and you can take a break at any time. There is also a small chance of skin irritation from the electrode gel.

BENEFITS

The information gathered during the study may lead to a better understanding of the behavior of muscle activation, which has the potential to make advanced hand replacements feel more natural.

COSTS

There are no charges for the study visits. You will not be paid to participate.

ALTERNATIVE TREATMENT

Your alternative is not to participate in this study.

CONFIDENTIALITY

Data is being collected only for research purposes. Your data will be identified by ID numbers, not names, and stored separately from other records in a locked research area. All personal identifying information will be kept in password protected files and these files will be deleted five (5) years after the completion of the study. Other physical records will be kept in a locked file cabinet for five (5) years after the study ends and will be destroyed at that time. Access to all data will be limited to study personnel.

You should know that research data about you may be reviewed or copied by Virginia Commonwealth University.

Although results of this research may be presented at meetings or in publications, identifiable personal information pertaining to participants will not be disclosed.

VOLUNTARY PARTICIPATION AND WITHDRAWAL

Your participation in this study is voluntary. You may decide to not participate in this study. Your decision not to take part will involve no penalty or loss of benefits to which you are otherwise entitled. If you do participate, you may freely withdraw from the study at any time.

Your decision to withdraw will involve no penalty or loss of benefits to which you are otherwise entitled.

Your participation in this study may be stopped at any time by the researcher without your consent. The reasons might include:
- the researcher thinks it necessary for your health or safety;
- you have not followed study instructions; or
- administrative reasons require your withdrawal.

QUESTIONS

If you have any questions, complaints, or concerns about your participation in this research, contact:

Peter Pidcoe, 804-628-3655, pepidcoe@vcu.edu
West Hospital, Basement, Room 100
1200 E Broad St, West Hospital
P.O. Box 980224
Richmond, VA 23298-0224
or
Joshua Arenas, 757-567-3827, arenasja2@vcu.edu

The researcher/study staff named above is the best person(s) to call for questions about your participation in this study.

If you have general questions about your rights as a participant in this or any other research, you may contact:

Office of Research
Virginia Commonwealth University
800 East Leigh Street, Suite 3000
P.O. Box 980568
Richmond, VA 23298
Telephone: (804) 827-2157

Contact this number for general questions, concerns, or complaints about research. You may also call this number if you cannot reach the research team or if you wish to talk to someone else. General information about participation in research studies can also be found at http://www.research.vcu.edu/irb/volunteers.htm.

Do not sign this consent form unless you have had a chance to ask questions and have received satisfactory answers to all of your questions.

CONSENT

I have been provided with an opportunity to read this consent form carefully. All of the questions that I wish to raise concerning this study have been answered.

By signing this consent form, I have not waived any of the legal rights or benefits, to which I otherwise would be entitled. My signature indicates that I freely consent to participate in this research study. I will receive a copy of the consent form once I have agreed to participate.

____

Participant Name, printed

____ _______________

Participant Signature Date

____

Name of Person Conducting Informed Consent
Discussion / Witness
(Printed)

____ _______________

Signature of Person Conducting Informed Consent Date
Discussion / Witness

____ _______________

Principal Investigator Signature (if different from above) Date

Script

1. Introduction

In this experiment I am going to use an EMG, which senses the electrical activity of your muscles, to allow you to drive a remote control car. I will place pairs of electrodes over muscles in your lower arm and then brace your arms so that the muscles will be in a constant position while we conduct the trial. Then, I will ask you to contract those muscles in order to control the toy car and drive it through a course I have prepared. If you are ready now, I will begin placing the electrodes on your arm.

2. Calibration

With the electrodes now in place, we are going to calibrate the system. I am going to ask you to rest and then contract each of the braced muscles as hard as you can in order to get a baseline reading for the system. It is best that you flex using your fingertips and extend using your fingernails in order to get the most accurate reading for the maximum activation of the muscle.

3. Control Training

Your dominant arm will be used to control the steering of the car, while your other arm will be used to control the forward and backward motion of the car. You may now try moving your arms to move the wheels left and right, as well as move the car forward and back.

I am now going to place the car inside the box. In order to learn to drive the car using this specific algorithm, I am going to ask you to drive the car through a full 360° of rotation from one full turn in one direction. Please let me know if you feel that any adjustments should be made to the sensitivity of the controls. When you have completed this, I will have you take the NASA TLX survey to rate how difficult you felt this task was. After that we will move on to the driving course.

Before you begin, I will read the rating scale definitions of the survey so you can keep them in mind as you complete the task.

4. Functional Training/Testing

When I tell you to begin, I want you to navigate through the course and cross the blue tape at the end. You should pass through each of the gates marked by the white tape and avoid hitting the cones and the walls. If you hit a cone, three seconds will be added to your total time.

5. NASA TLX

Now that you have completed the course using this algorithm, I am going to have you take the NASA TLX survey to rate how difficult you felt this task was.

Appendix E

NASA TLX Survey

Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

RATING SCALE DEFINITIONS

Title	Endpoints	Descriptions
MENTAL DEMAND	*Low/High*	How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?
PHYSICAL DEMAND	*Low/High*	How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?
TEMPORAL DEMAND	*Low/High*	How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?
PERFORMANCE	*good/poor*	How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?
EFFORT	*Low/High*	How hard did you have to work (mentally and physically) to accomplish your level of performance?
FRUSTRATION LEVEL	*Low/High*	How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Effort or Performance	Temporal Demand or Frustration
Temporal Demand or Effort	Physical Demand or Frustration
Performance or Frustration	Physical Demand or Temporal Demand
Physical Demand or Performance	Temporal Demand or Mental Demand

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Frustration or Effort	Performance or Mental Demand
Performance or Temporal Demand	Mental Demand or Effort
Mental Demand or Physical Demand	Effort or Physical Demand
Frustration or Mental Demand	

Subject ID: ______________ Date: ______________

SOURCES-OF-WORKLOAD TALLY SHEET		
Scale Title	*Tally*	*Weight*
MENTAL DEMAND		
PHYSICAL DEMAND		
TEMPORAL DEMAND		
PERFORMANCE		
EFFORT		
FRUSTRATION		

Total count = ______________

(NOTE - The total count is included as a check. If the total count is not equal to 15, then something has been miscounted. Also, no weight can have a value greater than 5.)

Subject ID: ___________ Task ID: ___________

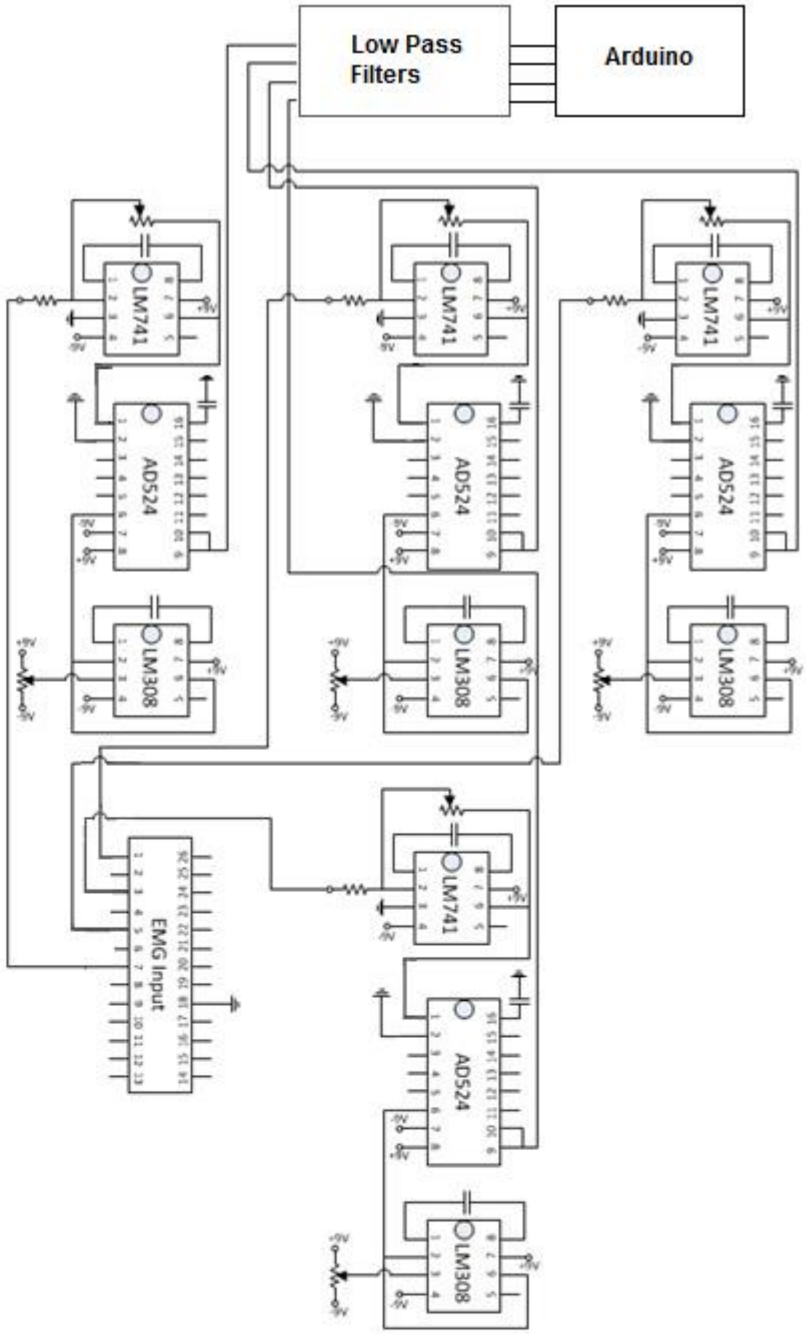
WEIGHTED RATING WORKSHEET			
Scale Title	*Weight*	*Raw Rating*	*Adjusted Rating (Weight X Raw)*
MENTAL DEMAND			
PHYSICAL DEMAND			
TEMPORAL DEMAND			
PERFORMANCE			
EFFORT			
FRUSTRATION			

Sum of "Adjusted Rating" Column = ______

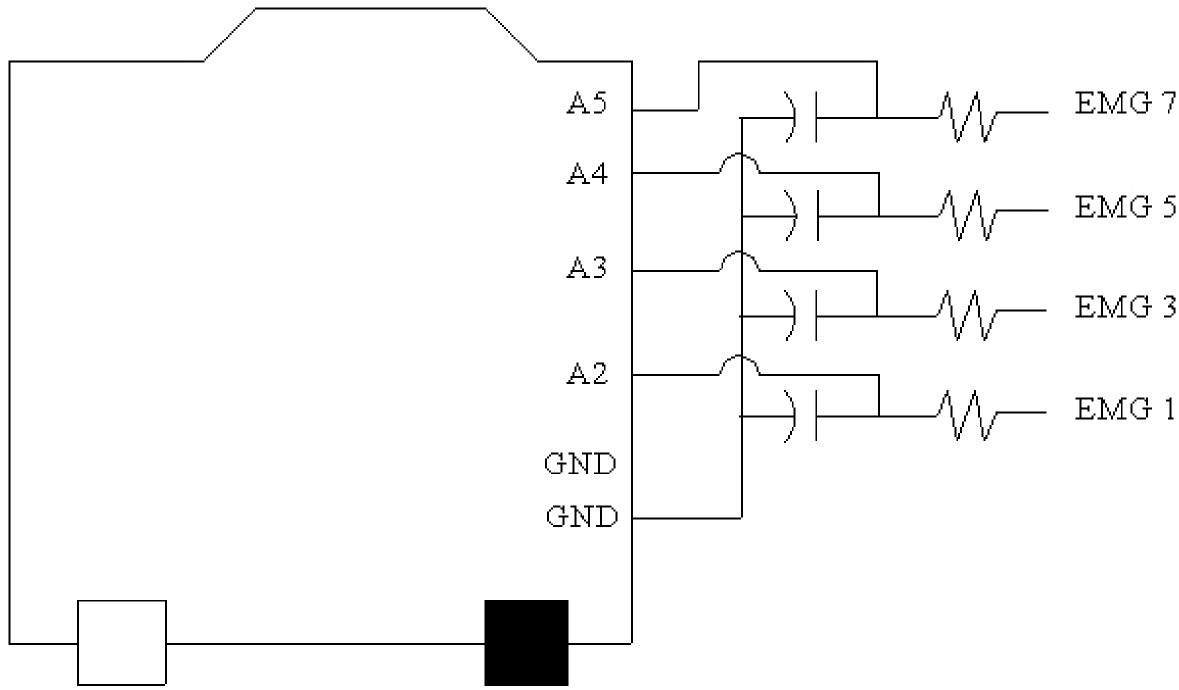
WEIGHTED RATING =
[i.e., (Sum of Adjusted Ratings)/15]

Appendix F: Schematics

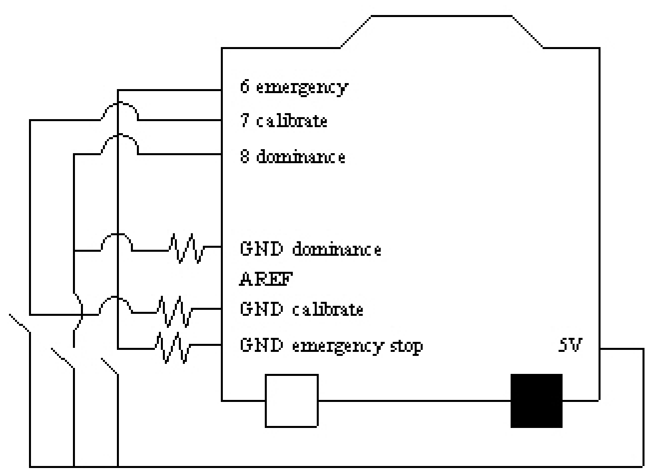
EMG Amplifying Board



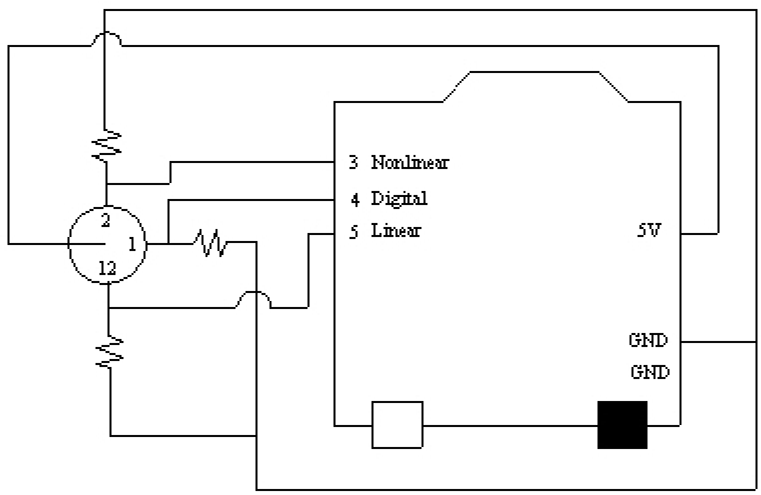
EMG Filters



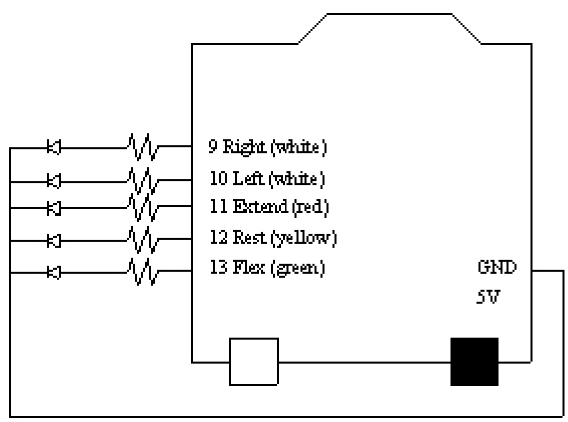
Switch Circuit



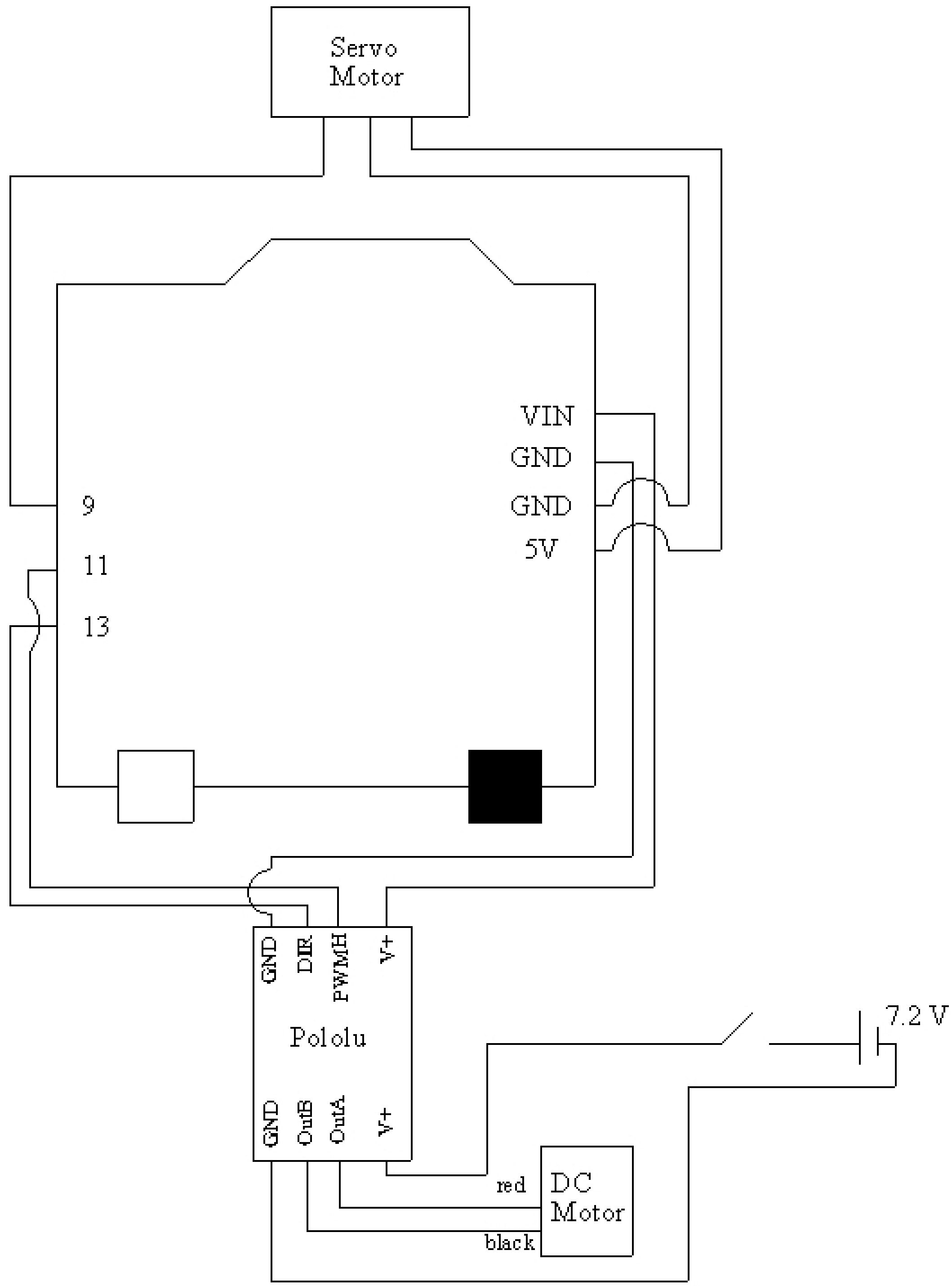
Dial Switch



Led Circuit



Remote Control Car Arduino Circuit



Appendix G: Arduino Code

Code used to process EMG data and transmit to car.

```
#include <EasyTransfer.h>
EasyTransfer ET;

struct SEND_DATA_STRUCTURE{
  int angle;
  int carspeed;
  int cardirec;
};

SEND_DATA_STRUCTURE txdata;

/*--------------------------------------------------
  variables for LEDs and push button
--------------------------------------------------*/
const int ledFlex = 13;
const int ledRest = 12;
const int ledExtend = 11;
const int ledLeft = 10;
const int ledRight = 9;
const int ArmPin = 8;
const int CalibratePin = 7;
const int EmergencyPin = 6;
const int LinearPin = 5;
const int DigitalPin = 4;
const int NonlinearPin = 3;
int buttonState = 0;
int emergencyState = 0;
int armState = 0;
int linearState = 0;
int digitalState = 0;
int nonlinearState = 0;
int ledActive;
```

```
/*---------------------------------------------------
  pins for EMG channels
---------------------------------------------------*/
const int Channel1 = A2;
const int Channel2 = A3;
const int Channel3 = A4;
const int Channel4 = A5;

/*--------------------------------------------------------------------
  variables for the original and mapped values of the sensor pins
--------------------------------------------------------------------*/
int C1sensorval;
int C2sensorval;
int C3sensorval;
int C4sensorval;
int C1mapval;
int C2mapval;
int C3mapval;
int C4mapval;

/*--------------------------------------------------------------------
  variables for calibration method and calculation of channel averages
--------------------------------------------------------------------*/
const int calib_array_size = 200;
float sumRest;
float sumActive;
float C1Rest;
float C1Active;
float C2Rest;
float C2Active;
float C3Rest;
float C3Active;
float C4Rest;
float C4Active;
int C1LinMax;
int C2LinMax;
int C3LinMax;
```

```
int C4LinMax;
const float gain = 1.00;

/*---------------------------------------------------------------------------
  variables to determine position for servo and stepper motors
---------------------------------------------------------------------------*/
int steerdiff;
int speeddiff;
int leftmap;
int rightmap;
int forwardmap;
int backmap;
const int thresh = 10;
const float leftslope = 0.4333;
const float rightslope = -0.4333;
const float forwardslope = 0.7111;
const float backslope = 0.7111;
int straight = 81;
float degreeconv;
int degree;
float spdconv;
int spd;
int direc;
float degree1;
int degree2;
int debug = 0;

void setup() {
  Serial.begin(9600);
  analogReference(INTERNAL);
  setupCalibration();
  /* code below reads data from each sensor pin for 2 seconds to prevent erroneous
     data due to analog Reference being changed*/
  int C1test = analogRead(Channel1);
  int C2test = analogRead(Channel2);
  int C3test = analogRead(Channel3);
  int C4test = analogRead(Channel4);
  delay(2000);
```

```
  ET.begin(details(txdata), &Serial);
}



void loop() {
  emergencyState = digitalRead(EmergencyPin);
  if (emergencyState == HIGH) {
    digitalWrite(ledExtend, HIGH);
    spd = 0;
    degree = straight;
    txdata.angle = degree;
    txdata.carspeed = spd;
    ET.sendData();
  }

  if (emergencyState == LOW) {
    digitalWrite(ledExtend, LOW);
    buttonState = digitalRead(CalibratePin);

    if (buttonState == HIGH) {
      armState = digitalRead(ArmPin);
      C1Rest = 0;
      C1Active = 0;
      C2Rest = 0;
      C2Active = 0;
      C3Rest = 0;
      C3Active = 0;
      C4Rest = 0;
      C4Active = 0;

      digitalWrite(ledRight, HIGH);
      ledActive = ledExtend;
      calibration(Channel1);
      C1Rest = sumRest / calib_array_size;
      C1Active = sumActive / calib_array_size;
      C1LinMax = round(C1Active * gain);
      delay(1000);
```

```
  ledActive = ledFlex;
  calibration(Channel2);
  C2Rest = sumRest / calib_array_size;
  C2Active = sumActive / calib_array_size;
  C2LinMax = round(C2Active * gain);
  delay(1000);
  digitalWrite(ledRight, LOW);

  digitalWrite(ledLeft, HIGH);
  ledActive = ledFlex;
  calibration(Channel3);
  C3Rest = sumRest / calib_array_size;
  C3Active = sumActive / calib_array_size;
  C3LinMax = round(C3Active * gain);
  delay(1000);

  ledActive = ledExtend;
  calibration(Channel4);
  C4Rest = sumRest / calib_array_size;
  C4Active = sumActive / calib_array_size;
  C4LinMax = round(C4Active * gain);
  delay(1000);
  digitalWrite(ledLeft, LOW);
}

if (buttonState == LOW) {
  linearState = digitalRead(LinearPin);
  digitalState = digitalRead(DigitalPin);
  nonlinearState = digitalRead(NonlinearPin);

  if (armState == LOW) {
    leftmap = C4mapval;
    rightmap = C3mapval;
    forwardmap = C2mapval;
    backmap = C1mapval;
    steerdiff = C4mapval - C3mapval;
    speeddiff = C2mapval - C1mapval;
```

```
}

else {
  leftmap = C2mapval;
  rightmap = C1mapval;
  forwardmap = C3mapval;
  backmap = C4mapval;
  steerdiff = C2mapval - C1mapval;
  speeddiff = C3mapval - C4mapval;
}

C1sensorval = analogRead(Channel1);
C1mapval = constrain(map(C1sensorval, C1Rest, C1LinMax, 0, 100), 0, 100);
C2sensorval = analogRead(Channel2);
C2mapval = constrain(map(C2sensorval, C2Rest, C2LinMax, 0, 100), 0, 100);
C3sensorval = analogRead(Channel3);
C3mapval = constrain(map(C3sensorval, C3Rest, C3LinMax, 0, 100), 0, 100);
C4sensorval = analogRead(Channel4);
C4mapval = constrain(map(C4sensorval, C4Rest, C4LinMax, 0, 100), 0, 100);

if (linearState == HIGH) {
  digitalWrite(ledFlex, HIGH);
  digitalWrite(ledRest, LOW);
  if (steerdiff > thresh) {
    degreeconv = ((leftslope * leftmap) + 76.6667);
    degree = constrain(degreeconv, straight, 120);
  }
  else if (steerdiff < -thresh) {
    degreeconv = ((rightslope * rightmap) + 85.3333);
    degree = constrain(degreeconv, 42, straight);
  }
  else {
    degree = straight;
  }
  if (speeddiff > thresh) {
    spdconv = ((forwardslope * forwardmap) - 7.1111);
    spd = constrain(spdconv, 0, 64);
    direc = 1;
```

```
  }
  else if (speeddiff < -thresh) {
    spdconv = ((backslope * backmap) - 7.1111);
    spd = constrain(spdconv, 0, 64);
    direc = 0;
  }
  else {
    spd = 0;
    direc = 0;
  }
}

if (digitalState == HIGH) {
  digitalWrite(ledRest, HIGH);
  digitalWrite(ledFlex, LOW);
  if (steerdiff > thresh) {
    degree = 120;
  }
  else if (steerdiff < -thresh) {
    degree = 42;
  }
  else {
    degree = straight;
  }
  if (speeddiff > thresh) {
    spd = 64;
    direc = 1;
  }
  else if (speeddiff < -thresh) {
    spd = 64;
    direc = 0;
  }
  else {
    spd = 0;
    direc = 0;
  }
}
```

```
  if (nonlinearState == HIGH) {
   digitalWrite(ledFlex, HIGH);
   digitalWrite(ledRest, HIGH);
   if (steerdiff > thresh) {
    degree1 = ((pow(2.71828, ((-46*(leftmap-10))*0.001))) - 1) / ((pow(2.71828, (-
0.02950*46))) - 1);
    degree2 = round((degree1 * 29.50) + 81);
    degree = constrain(degree2, straight, 120);
   }
   else if (steerdiff < - thresh) {
    degree1 = ((pow(2.71828, ((-46*(rightmap-10))*0.001))) - 1) / ((pow(2.71828, (-
0.02950*46))) - 1);
    degree2 = round((degree1 * -29.50) + 81);
    degree = constrain(degree2, 42, straight);
   }
   else {
    degree = straight;
   }
   if (speeddiff > thresh) {
    spdconv = ((pow(2.71828, ((-46*(forwardmap-10))*0.001))) - 1) / ((pow(2.71828, (-
0.06102*46))) - 1);
    spd = round(spdconv * 61.02);
    spd = constrain(spd, 0, 64);
    direc = 1;
   }
   else if (speeddiff < -thresh) {
    spdconv = ((pow(2.71828, ((-46*(backmap-10))*0.001))) - 1) / ((pow(2.71828, (-
0.06102*46))) - 1);
    spd = round(spdconv * 61.02);
    spd = constrain(spd, 0, 64);
    direc = 0;
   }
   else {
    spd = 0;
    direc = 0;
   }
  }
```

```
    if (linearState == LOW && digitalState == LOW && nonlinearState == LOW) {
      digitalWrite(ledFlex, LOW);
      digitalWrite(ledRest, LOW);
      spd = 0;
      degree = straight;
      direc = 0;
    }
    constrain(degree, 42, 120);
    constrain(spd, 0 , 64);
    txdata.angle = degree;
    txdata.carspeed = spd;
    txdata.cardirec = direc;
    ET.sendData();
  }
 }
}

/*----------------------------------------------------------------------
 method used to find the sum of resting and flexion/extension values for
 the specified EMG channel (sensorPin); the average is then calculated in
 the loop code
----------------------------------------------------------------------*/
void calibration(int sensorPin) {
 int calibrationArray[calib_array_size];
 int i = 0;
 int sensorval;
 sumRest = 0;
 sumActive = 0;

 blinkLED(ledRest);
 while (i < calib_array_size) {
  sensorval = analogRead(sensorPin);
  calibrationArray[i] = sensorval;
  sumRest = sumRest + calibrationArray[i];
  delay(15);
  i = i + 1;
 }
```

```
  if (i == calib_array_size) {
    digitalWrite(ledRest, LOW);
  }

  i = 0;
  delay(1000);

  blinkLED(ledActive);
  while(i < calib_array_size) {
    sensorval = analogRead(sensorPin);
    calibrationArray[i] = sensorval;
    sumActive = sumActive + calibrationArray[i];
    delay(15);
    i = i + 1;
  }


  if (i == calib_array_size) {
    digitalWrite(ledActive, LOW);
  }
}


/*----------------------------------------------------------------------
  initializes the pins for LEDs and the button of the calibration system
----------------------------------------------------------------------*/
void setupCalibration() {
  pinMode(ledLeft, OUTPUT);
  pinMode(ledRight, OUTPUT);
  pinMode(ledRest, OUTPUT);
  pinMode(ledFlex, OUTPUT);
  pinMode(ledExtend, OUTPUT);
  pinMode(ArmPin, INPUT);
  pinMode(CalibratePin, INPUT);
  pinMode(EmergencyPin, INPUT);
  pinMode(LinearPin, INPUT);
  pinMode(DigitalPin, INPUT);
  pinMode(NonlinearPin, INPUT);
```

```
  digitalWrite(ledLeft, LOW);
  digitalWrite(ledRight, LOW);
  digitalWrite(ledRest, LOW);
  digitalWrite(ledFlex, LOW);
  digitalWrite(ledExtend, LOW);
}

/*-------------------------------------------------------------------
  method used to blink the LEDs, signaling to the user which channel
  is being calibrated
-------------------------------------------------------------------*/
void blinkLED(int led) {
  digitalWrite(led, HIGH);
  delay(500);
  digitalWrite(led, LOW);
  delay(500);
  digitalWrite(led, HIGH);
  delay(500);
  digitalWrite(led, LOW);
  delay(500);
  digitalWrite(led, HIGH);
}
```

Code downloaded to car to receive transmission and control car.

```
#include <Servo.h>
Servo Steer;
#include <EasyTransfer.h>
EasyTransfer ET;
const int speedpin = 11;
const int dirpin = 13;
int servo;
int spd;
int dir;

struct RECEIVE_DATA_STRUCTURE {
  int angle;
  int carspeed;
  int cardirec;
};

RECEIVE_DATA_STRUCTURE txdata;
void setup() {
  Serial.begin(9600);
  setupMotor();
  ET.begin(details(txdata), &Serial);
  Steer.attach(9);
}
void loop() {
  if(ET.receiveData()){
    servo = constrain(txdata.angle, 42, 120);
    spd = constrain(txdata.carspeed, 0, 127);
    dir = constrain(txdata.cardirec, 0, 1);
    Steer.write(servo);
    Drive(dir, spd);
  }
}

void Drive(int dir, int spd) {
  digitalWrite(dirpin, dir);
  analogWrite(speedpin, spd);
```

```
}

void setupMotor() {
 pinMode(speedpin, OUTPUT);
 pinMode(dirpin, OUTPUT);
 digitalWrite(speedpin, LOW);
 digitalWrite(dirpin, LOW);
}
```