A Pilot Study on the Impact of Colors on Human Performance within a Multitasking Simulation Environment

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Abstract

Numerous research studies have formulated abstract assertions concerning how the human perception of color can stimulate a physiological response that enhances cognitive concentration. Within the framework of the color-in-context theory, interpretations and impacts of color are contingent on specific contexts; a single color can convey divergent or contrasting meanings in alternative settings. This pilot investigation seeks to enhance the experimental design for assessing the impact of different background colors using the U.S. Army Aeromedical Research Laboratory's Multi-Attribute Task Battery (USAARL MATB) simulation software. In this study, 8 participants undertook tasks of varying difficulty levels, with alterations to the background colors—specifically red, blue, grey, yellow, and green. To evaluate mental workload, pupillometry data, including average pupil diameter and average duration of fixation, were collected using the Tobii eye-tracking device. Additionally, subjective measures utilized in this study are the NASA task load index (TLX) and instantaneous self-assessment (ISA). The performance results derived from this research were anchored in accuracy and time metrics, and these were subjected to statistical tests aimed at ascertaining significant differences. The findings revealed noteworthy disparities in task difficulty levels concerning both performance outcomes and subjective assessments. Moreover, the physiological data exhibited significant differences as determined through paired tests. Notably, the three mental workload evaluation discrepancies can be attributed to the relatively small sample size, as anticipated.

Keywords
Human performance, Color, Multitasking, Pupillometry, Task difficulty level.

1. Introduction
Human performance measures serve multiple functions, encompassing the evaluation of attained performance levels, identification of performance strengths and weaknesses, establishment of expertise indices, and prediction of future performance outcomes. These measures are not only instrumental in assessing training program effectiveness and pinpointing areas that require enhancement but also find application in the endeavors of research and development teams striving to advance technologies and methodologies for performance enhancement (Ness et al. 2004).

Color constitutes a pivotal element in the design of human systems. It is recognized to exert a significant influence on psychological responses, impacting mood and emotional states. Warm colors have the potential to evoke stimulation, while cool colors are renowned for their calming effects (Mehrabian 1994). Empirical research underscores the favorable impact of effective color space on emotions and behavior, suggesting that appropriately chosen colors can substantially alleviate an operator's cognitive workload (Long et al. 2021a). Furthermore, a study by Küller et al. in 2009 highlights that workplace colors possess the capability to modulate physiological responses such as heart rate, anxiety, and comfort levels (Küller et al. 2009). Numerous studies advocate that color holds sway over task outcomes, impacting human performance, productivity, and creativity (Mehta and Zhu 2009).

The effects of color on individuals' psychology can be categorized as direct and indirect impacts. The direct effect pertains to the physiological responses triggered by light, affecting heart rate, blood pressure, and hormones.

Conversely, the indirect effect concerns the psychological perception of colors influenced by life experiences and cultural backgrounds, leading to emotions, attitudes, and behavior. Color psychology is a multifaceted field, with varying impacts based on individual and contextual factors. Effective utilization of color psychology in design and marketing necessitates considering these factors to align color choices with audience perception. Researchers have devised a physical space model, rooted in emotional adaptation's color perception model, to enhance workplace design simulation (Long et al. 2021b).

Numerous studies highlight the substantial influence of color on perceived room dimensions. Warm colors like red, yellow, and orange tend to make spaces appear smaller, while neutral colors like white and gray create a sense of spaciousness. Employees prefer combinations of cool and warm colors, while neutral colors mixed with cool tones enliven perception. Neutral colors stand out positively in space perception, inducing feelings of spaciousness, openness, simplicity, and order (Küller et al. 2009). Neutral color schemes outperformed other color combinations in creating perceptions of spaciousness, openness, simplicity, and order within workspaces (Savavibool and Moorapun, 2017).

2. Literature Review

Ergonomics, the study of designing work environments and tasks for human use, encompasses classical ergonomics and cognitive ergonomics. Classical ergonomics emphasizes physical aspects, while cognitive ergonomics delves into the psychological aspects of work (Helaers and Milinkovitch 2010)). Classical ergonomics emerged to match human capabilities with technology, focusing on physical aspects, which neglected the role of the mind. Cognitive ergonomics, on the other hand, acknowledges human-computer interaction and emphasizes work conceptualization, work environment impact, and control maintenance (Hollnagel 1997).

Cognitive ergonomics aims to improve system design by managing mental workload. A reliable system must perform well under varying conditions, minimize unwanted variance, and maintain a balance between physical and cognitive demands. Different measurement methods are employed to assess workload, including subjective, physiological, and performance measures (Megaw 2005). Subjective measures, like the NASA Task Load Index (NASA TLX) and Instantaneous Self-Assessment (ISA), offer practical insights into perceived workload (Hart and Staveland 1988; Tattersall and Foord 1996), among other subjective measures. Physiological measures, such as pupillometry, cardiac function, and brain function, help analyze changes in responses (Badiru and Bommer 2017). Performance measures encompass task time, accuracy, and unconscious cognition, aiding in estimating mental workload and learning curves (Badiru and Bommer 2017).

The Multiple Resource Theory (MRT) predicts interference between tasks in high-demand multitasking settings. It identifies shared cognitive resources that tasks compete for, leading to interference when demands exceed resources (Liu and Wickens 1988). MRT employs dimensions like processing stages, perceptual modalities, visual channels, and processing codes to explain time-sharing performance variations. It aids in predicting performance levels, guiding design decisions, and recommending strategies to manage resource overload (Wickens 2002).

Practical applications of MRT and cognitive ergonomics require a thorough understanding of human information processing and resource allocation. Despite challenges in modeling and validation, these concepts provide valuable insights for designing efficient and safe human systems (Sarno 1995). Combining subjective, physiological, and performance measures along with the principles of MRT can aid in effectively addressing cognitive demands in system design.

3. Methodology

3.1. Sampling Technique

For inclusion in this study, participants need to meet specific criteria: they must be students, faculty, or staff members. The recruitment process involved distributing flyers and reaching out through personal connections. As part of the initial screening, a color blindness test will be administered. The participation count for this pilot study is 8 individuals (7 males and 1 female). Inclusive requirements encompass individuals aged 18 to 34, whereas those who are color-blind, utilize medical devices, or have susceptibility to photosensitive epilepsy are excluded from participation. The full experiment research lasts about 50 minutes, with each experimental scenario taking 5 minutes. Participants were given the opportunity to familiarize themselves with the simulation software through practice sessions before starting the actual experimental scenarios.

3.2. Study Material and Specifications

The experiment involves utilizing the computer-based Multi-Attribute Task Battery – USAARL, which is an updated version of the MATB-TSU. The interface for the USAARL MATB is depicted in Figure 1. Initial parameter generation is required, while subsequent runs utilize prior parameter files. This feature enables users to input desired parameters such as demand levels, active tasks, automation reliability, color profiles, and resource management. The "open color lab" button opens a separate window to customize element colors for active task and automation modes, which are integral for configuring colors within the workspace interface. The USAARL MATB Color Lab controls color information via a GUI-based color picker. Color profiles are designed for automation ON and OFF modes. The color of the text can be customized globally, and tanks have varying colored levels to indicate fuel units. The MATB Color Lab accommodates color vision deficiencies and supports exporting profiles for use in the MATB Parameter Generation GUI.

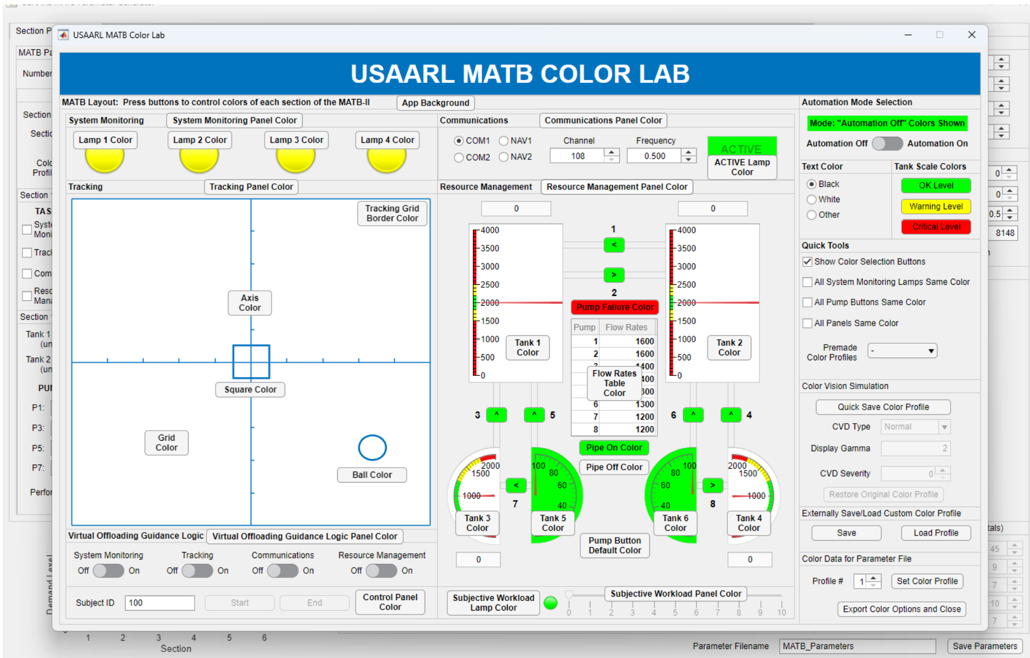

Figure 1. USAARL MATB Color Lab GUI

For the experiment, an Acer Aspire 5 Notebook Laptop with specifications, including an Intel Core i7-1165G7 and 36GB RAM, is employed to run the USAARL MATB software. This setup is connected to a TECKNET Bluetooth wireless mouse and a Logitech G Extreme 3D Pro joystick. The mouse facilitates responses to the USAARL MATB communication and resource management tasks. Additionally, the laptop's speakers relay audible audio communication, while the joystick is pivotal for the tracking and system monitoring tasks. All tasks within the MATB are used, with the background color varying for each experiment. Subsequent subjective evaluations of mental workload are conducted after each experiment. The system monitoring task involves responding to lights by pressing buttons within a specified time frame. The tracking task necessitates using a joystick to maintain a target's center, while the communication task involves adjusting radio settings in response to auditory cues. In the resource management task, participants manage fuel tank levels.

Utilizing the Tobii Pro Spectrum device enhances accuracy in tracking eye movements. The experiment maintains the original colors for the tracking task while altering other panel colors for the MATB simulation. For careful color selection, yellow, green, and red indicators on the fuel tank gauge convey different conditions. The study targets warm (red, yellow) and cool (blue, green) colors, along with the default grey background, based on their arousal and calming effects. The goal is to assess how these colors impact participants' performance in aviation tasks, considering their psychological influences.

Experimental subjective measurement involves using the NASA Task Load Index (NASA-TLX) and instantaneous self-assessment embedded in the USAARL MATB. NASA-TLX involves participants rating perceived workload across six dimensions. Additionally, the USAARL MATB includes real-time workload assessments to identify fluctuations throughout tasks. These subjective measures provide insights into participants' perceptions of mental workload and aid in task optimization and resource allocation.

3.3. Selection of colors

In this experiment, the colors used in the tracking task remain unaltered, as they have been intentionally chosen by the system designer. The white background is utilized for the tracking task, while the fuel tank gauge incorporates a combination of yellow, green, and red indicators to signify warnings, acceptable conditions, and failures in the fueling system respectively. However, for this experiment, all other panel colors, which make up approximately 60% of the overall MATB simulation interface, are considered background colors and will be modified.
Based on the literature review, red, green, blue, and yellow are the fundamental color senses that cannot be represented as a mixture of two or more colors and are described as psychological primary colors to evoke anxiety state (Halpin and Morgan 2010; Hering 1964; Jacobs and Suess 1975). In addition, it has been established that red and yellow are categorized as warm colors that tend to have arousing effects on individuals. On the other hand, blue and green are considered cool colors that generally have calming effects. Taking this information into account, the study will specifically focus on these five colors: red, yellow, blue, green, and the default background color - grey. By utilizing these specific colors, the study aims to examine whether the arousal or calming effects associated with warm and cool colors have any discernible influence on participants' performance during the simulated aviation tasks.

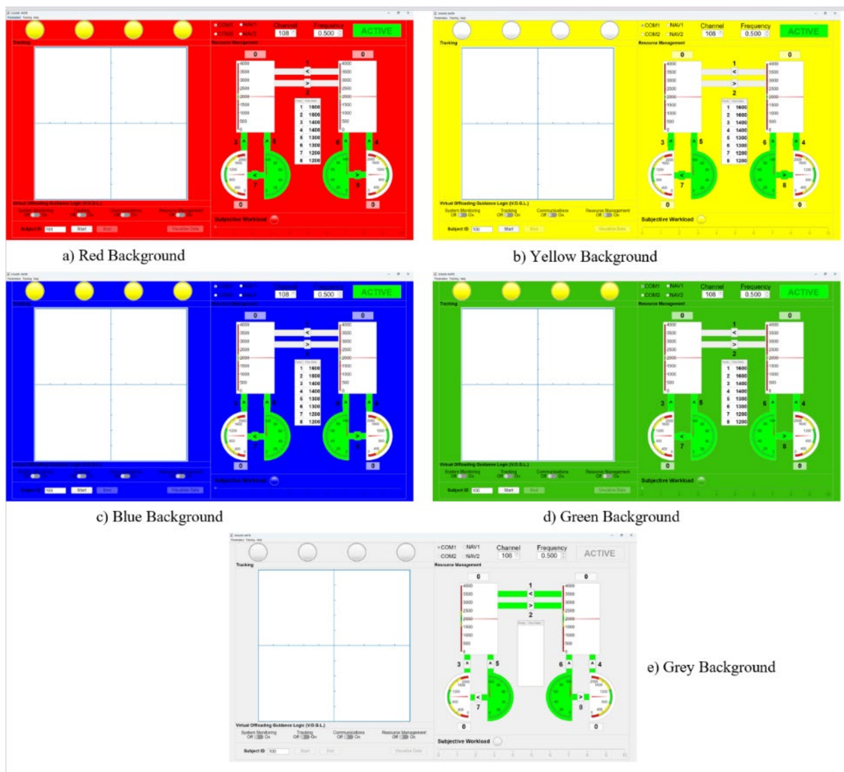

Figure 2. Utilized USAARL MATB Background Color Interfaces

3.4. Experiment procedures

Before commencing the experiment, participants went through a brief color blindness test to ensure their normal color vision, as this might impact their subsequent task performance. Successful completion of the test requires participants to accurately identify the precise number pattern enclosed within a circle, distinguished by a distinct color, within a predefined timeframe. Following this, participants were presented with a consent form, which they read and signed as an indication of their willingness to take part in the experiment. A demographic survey was also conducted, gathering information about participants' age, gender, ethnicity, and other relevant personal details. The brief introduction and tutorial provided to participants encompass navigation and interaction with the software, ensuring participants grasp its fundamental functions and operations. In preparation for the experiment's commencement, the Tobii Pro Spectrum eye-tracking device will be initialized. This device recorded participants' eye movements and gaze patterns throughout the simulation across all experimental scenarios. The concurrent extraction and analysis of eye-tracking data during each simulation scenario will facilitate the precise evaluation of participants' visual attention and allocation of cognitive resources. With the setup completed, the simulation began, involving participants in diverse tasks engineered to gauge their monitoring, resource management, communication, and tracking proficiencies. These tasks are meticulously crafted to emulate real-world scenarios necessitating multitasking and decision-making abilities. After each experimental scenario, participants are prompted to complete a NASA Task Load Index (TLX) questionnaire. This questionnaire, conducted for both low and high task difficulty levels, serves the purpose of assessing perceived task difficulty.

3.5. Statistical Analysis Technique

The experiment is divided into 2 groups, which employ a within-subjects design, which means that all participants in each group will be exposed to all conditions of the experiment. This design allows for multiple testing sessions, with each session involving different treatments or conditions. By using this design, the variability among participants is reduced, resulting in increased statistical power. Each group comprised 4 participants, yielding a total of 8 participants overall. The study employed distinct experimental scenarios and employed a Latin Square technique to randomize color presentation within each Task Difficulty Level (TDL) as shown in Table 1. The experimental scenarios for each group are as follows:

Table 1. Experimental Scenario

Group 1	Group 2
A = Red Background, Low TDL	A = Yellow Background, Low TDL
B = Blue Background, Low TDL	B = Green Background, Low TDL
C = Grey Background, Low TDL	C = Grey Background, Low TDL
D = Red Background, High TDL	D = Yellow Background, High TDL
E = Blue Background, High TDL	E = Green Background, High TDL
F = Grey Background, High TDL	F = Grey Background, High TDL

The expected outcomes of this study, involving performance data, will be subjected to analysis using repeated measures analysis of variance (MANOVA) in the JMP statistical tool while the pupillometry data will be analyzed using the XLSTAT tool. Consequently, the findings are likely to contribute substantially to the refinement of design strategies for the core experiment, taking into account the role of color in mental workload analysis.

4. Result and Discussion

4.1 Performance Measure of MWL

The outcomes show how these factors significantly impacted group 1's response/ performance in the MANOVA study that was done. The overall least-squares (LS) means range from 38.31 to 67.33 based on the observed responses for the various tasks presented. Blue has LS means between 30.91 and 66.46 when looking at the effects of color, grey ranged from 32.63 to 68.63, and red varied from 39.23 to 68.38. Additionally, for task difficulty level (TDL) effects, low TDL conditions produced LS means from 26.93 to 78.22, whereas high TDL conditions yielded LS means between 37.36 and 61.78. Regarding parameter estimates, the intercepts for different TDL and colors were computed, with values ranging from 36.95 to 67.82.

Table 2. Least Squares Means for Group 1

GROUP 1					
Factors		RESMAN	Tracking	Monitoring	Comm
Color	Blue	30.91	66.46	62.75	38.98
	Grey	35.85	68.63	62.29	32.63
	Red	51.43	68.38	59.39	39.23
TDL	Low	41.44	78.22	61.18	26.93
	High	37.36	57.43	61.78	46.96
Overall Means		38.31	38.31	67.33	61.50

An overall test for within-subject interactions demonstrated a significant effect on response, suggesting that the TDL combinations and their interactions indeed influenced the outcomes. The interactions between response and color were assessed through different multivariate tests. While some tests indicated relatively low significance, overall, the color's impact on performance was not significantly strong. Similarly, the interactions between response and TDL were tested, revealing a significant difference. Moreover, the combined interaction of response, color, and TDL was also examined, and the results indicated that the three-way interaction did not have a highly significant impact on performance/ response.

Between subjects, the analyses focused on the intercept, color, TDL, and color-TDL interactions. The intercepts demonstrated a strong overall effect, with a significant difference among subjects. However, the effects of color, TDL, and the interaction between color and TDL were found to be less significant. The results suggest that TDL

conditions and their interactions played a significant role in influencing performance outcomes, while the effects of color and their interactions were less pronounced.
However, in the analysis of Group 2 performance data using the MANOVA (Multivariate Analysis of Variance) fit model in JMP, the overall least square (LS) means for the different tasks were as follows: Resource Management (52.73), Tracking (79.03), Monitoring (59.80), and Communication (32.35). When considering the impact of color, the LS means were observed for different colors and TDL. As an example, the LS means for the Tracking task with the green color is 78.70, with the grey color as 78.68, and the yellow color as 79.71.

Table 3. Least Squares Means for Group 2

GROUP 2					
Factors		RESMAN	Tracking	Monitoring	Comm
Color	Green	49.45	78.70	66.55	34.80
	Grey	58.08	78.68	63.24	36.75
	Yellow	50.65	79.71	49.61	25.50
TDL	Low	53.95	86.85	56.91	25.99
	High	51.51	71.22	62.69	38.72
Overall Means		52.73	79.03	59.80	32.35

Moreover, the response across tasks was divided into "Low" and "High" difficulty levels. The LS means for these categories were as follows: Resource Management - Low (53.95) and High (51.51), Tracking - Low (86.85) and High (71.22), Monitoring - Low (56.91) and High (62.69), Communication - Low (25.99) and High (38.72). Additionally, color effects were evaluated, showing how different colors impacted different tasks. The interaction between color and TDL was also examined. For example, the LS means for the interaction of Green and Low TDL were as follows: Resource Management (42.46), Tracking (86.66), Monitoring (62.93), and Communication (31.85). Overall response interactions were tested, resulting in significant effects (F Test = 15.56, $p < 0.0001$). Interaction effects were evaluated for response and color (Wilks' Lambda = 0.52, $p = 0.0902$), response and TDL (F Test = 1.89, $p = 0.0006$), as well as the combined interaction of response, color, and TDL (Wilks' Lambda = 0.58, $p = 0.1541$). Between-subjects analysis was also conducted. The intercept showed significant effects (Intercept: F Test = 53.24, $p < 0.0001$; while color tests showed insignificant effects (F Test = 0.19, $p = 0.2092$). Also, TDL and color-TDL interactions did not yield significant results. Hence, the MANOVA FIT analysis of Group 2's performance/ response considered the influence of color and TDL.

4.2 Physiological Measure of MWL

Average pupil diameter data (pupillometry) and average fixation durations for each participant and experimental scenarios were obtained from the eye-tracking device. The obtained results were classified based on color and Task difficulty level, TDL (i.e., Red, Low = RL), and subjected to the Shapiro-Wilk Test to determine the normality of the raw data distribution. The obtained result from Shapiro-Wilk as shown in Table 4, demonstrated a non-normal distribution for group 1, while only grey-high task difficulty level for average pupil diameter has a significant difference in group 2 as shown in Table 5. Due to the non-normal distribution which can be attributed to the small sample size, the data were subjected to a non-parametric Friedman ANOVA.
As depicted in Figure 3, when applying the Friedman paired t-test to compare on group 1 (red, blue, and grey), there was no significant impact observed on the average duration of fixation. Notably, only the red and grey backgrounds exhibited a significant p-value < 0.05 for both low and high task difficulty level, based on the average pupil diameter data. Similarly, when analyzing pupillometry data from group 2 (yellow, green, and grey), no significant differences were found in the average duration of fixation. The only significant results were observed in the case of green and grey backgrounds for both low and high TDL, as illustrated in Figure 4. It is worth noting that for both groups, the paired tests did not yield significant results for all other color backgrounds.

Table 4. Pupillometry Normality Test Using Shapiro-Wilk for Group 1

Experimental Scenarios	Mean of Average Duration of Fixation (SD), Significant/ Not Significant	Mean of Average Pupil Diameter (SD), Significant/ Not Significant
Red-LTDL	366.75 (81.98), NS	2.95 (0.26), NS
Blue-LTDL	353 (62.24), NS	2.88 (0.27), NS
Grey-LTDL	333.5 (62.23), NS	2.76 (0.28), NS

Red-HTDL	367.5 (79.01), NS	2.93 (0.22), NS
Blue-HTDL	377.5 (94.10), NS	2.82 (0.21), NS
Grey-HTDL	384.5 (109.4), NS	2.72 (0.23), NS

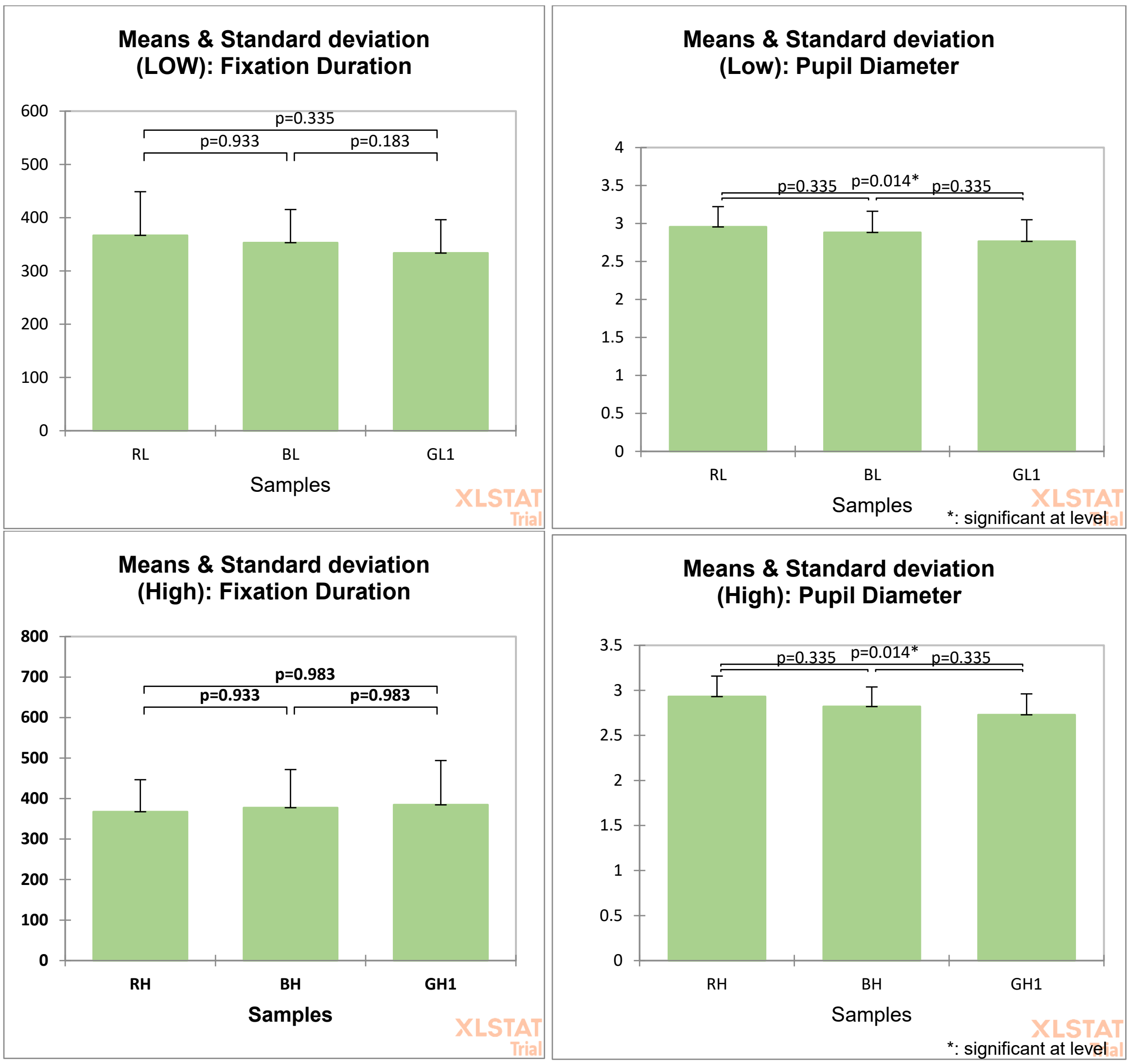

Figure 3. Pupillometry Friedman Paired Test for Group 1

Table 5. Pupillometry Normality Test Using Shapiro-Wilk for Group 2

Experimental Scenarios	Mean of Average Duration of Fixation (SD), Significant/ Not Significant	Mean of Average Pupil Diameter (SD), Significant/ Not Significant
Yellow-LTDL	261.25 (44.79), NS	2.76 (0.08), NS
Green-LTDL	261.50 (33.87), NS	2.87 (0.07), NS
Grey-LTDL	266.50 (33.16), NS	2.62 (0.05), NS
Yellow-HTDL	271.75 (53.87), NS	2.76 (0.07), NS
Green-HTDL	282.25 (46.84), NS	2.89 (0.11), NS
Grey-HTDL	304 (42.24), NS	2.62 (0.06), S

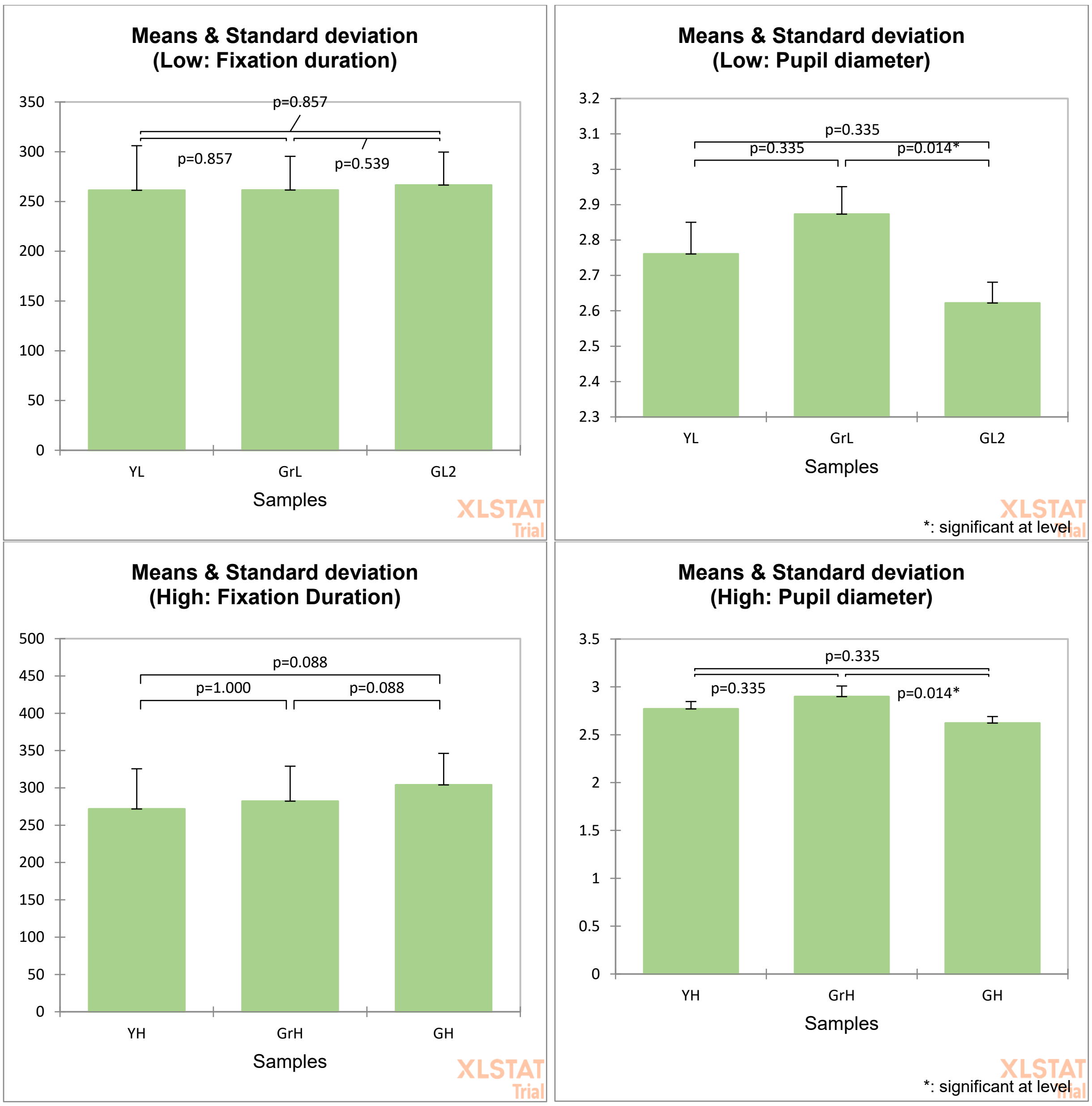

Figure 4. Pupillometry Friedman Paired Test for Group 2

4.3 Subjective Measure of MWL

The NASA TLX and Instantaneous Self-Assessment (ISA) embedded in the USAARL MATB were utilized to assess mental workload concerning task difficulty levels. In group 1, the overall weighted results were 64.42 for low task difficulty and 72.50 for high task difficulty. Specifically, within the low task difficulty, the mental demand dimension of NASA TLX yielded the highest sum of 272.50, closely followed by effort with a total of 242.50. Moving to high task difficulty, the effort dimension took precedence with a sum of 332.50, while the mental dimension followed with a total of 277.50.

For group 2, the results diverged slightly. The weighted score for low task difficulty was 57.17, with effort leading as the dominant dimension at 230, followed by mental demand with a sub-score of 212.50. In high task difficulty, the weighted score was 64, and the mental demand dimension stood out with a sub-score of 261.25, followed by temporal demand at 230. While the NASA TLX interpretation categorizes workload score values of 0-9 as low, 10-29 as medium, 30-49 as somewhat high, 50-79 as high, and 80-100 as very high (Prabaswari et al. 2019), it is reasonable to conclude that both groups perceived the workload of the low and high task difficulty level assigned as '*High*'.

Furthermore, the USAARL ISA rating scale spans from 1 to 10. In both groups, low task difficulty was rated at 6, while high task difficulty received a rating of 9. Remarkably, this subjective assessment aligns with performance measures, reinforcing the significance of task difficulty within this experiment.

5. Conclusion

The integration of mental workload analysis in human-machine interfaces is essential for engineering management as research has shown that color significantly impacts an individual's perception of task difficulty and cognitive processes. Hence, it is important to consider other factors, such as task complexity, individual differences, and environmental factors among others.

The pilot study holds significance in validating the proposed experimental design and methodology. Its purpose is to identify any necessary modifications that would ensure the attainment of valid results. Although the pilot study analysis focuses on mental workload evaluation by performance and pupillometry data, subjective measures evaluate mental workload within the context of task difficulty level. Based on the statistical analysis carried out, the task difficulty level factor is hypothetically significant based on both groups and none of the groups presented a significant color difference for performance measure.

However, it became evident from the pilot study results that participants displayed substantial continuous enhancement in their task performance which was anticipated but was expected to be mitigated by randomizing task order in the simulation software. In addition, the sample size used in this pilot study is very small, hence conclusions cannot be made yet.

Consequently, these insights gained from this work will be employed in future work to design a new methodology in procedure and randomization that minimizes the learning rate of subjects to determine the impact of color by introducing Latin square randomization across all experimental scenarios instead of within difficulty level. Also, the subjective rating will be employed to corroborate and ensure comprehensive computation of the mental workload perceived by subjects concerning changes in the background color.

Ultimately, this project aims to advance the knowledge within the domain of engineering management and facilitate the creation of future human-machine systems that prioritize safety, efficiency, and user effectiveness. Through the implementation of this experimental approach, we can explore the influence of various background colors and task complexity levels on performance, determining whether noteworthy statistical distinctions exist among the different scenarios.

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Biographies

Esther Omotola Adeyemi, a graduate student at the University of Dayton, is known for her dedication as a student and her exceptional leadership skills coupled with resourcefulness. Presently, she serves as a research assistant within the Human Performance and Cognition Lab. She obtained her bachelor's degree in civil engineering at the University of Ilorin, Nigeria, in the year 2018. With an extensive four-year professional background in the construction sector, she has amassed valuable work experience in the construction sector, specializing in areas such as structures, transportation, and marine work. Her time in the industry has honed her ability to solve practical problems encountered in the field. Her affiliations include esteemed professional organizations like the Nigerian Society of Engineers (NSE), and the National Society of Black Engineers (NSBE), among others.

Sharon Claxton Bommer is an Associate Professor in the Department of Engineering Management, Systems, and Technology at the University of Dayton. She earned a Ph.D. in Engineering in Industrial and Human Systems, specializing in human performance and cognition. Dr. Bommer holds a Bachelor of Science in Mechanical Engineering and two master's degrees: a Master of Business Administration and a Master of Science in Industrial Engineering. Before earning her Ph.D., she worked for over fifteen years in the automotive manufacturing industry in various engineering and operation roles, whereas her last position was as Plant Manager for a Tier 1 parts supplier. In addition, she has served as the Dean of the School of Business and Applied Technologies at Clark State College, providing leadership for business, information technology, agriculture, and engineering technology programs. Her research is in human systems integration, focusing on human performance and cognition for industrial and military operations.