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COGNITIVE ERGONOMIC-DRIVEN TECHNOLOGY: A PATHWAY TO IMPROVE MENTAL WORKLOAD, BODY POSTURE, AND WORK PERFORMANCE OF AGEING WORKERS IN OFFICE SETTING

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ABSTRACT

Ageing may reduce cognitive function, impacting thinking, reasoning, and memory. One of the potential solutions to address this issue is by utilizing Cognitive-Driven Technology (CEDT). The objective of this study is to investigate the impact of cognitive ergonomic-driven technology on the perceived mental workload, working posture, and task performance of ageing workers. Eight ageing workers were instructed to perform two types of tasks (arithmetic and typing) in two segments (i.e., Segment A (baseline) and Segment B (consisting of CEDT interventions). The accuracy and efficiency of tasks from both segments were evaluated. Mental workload measures (NASA-TLX and Heart rate) and body posture were recorded during the task execution. The recordings were utilized in developing the scenario in a design software, which then further analyzed the Rapid Upper Limb Assessment (RULA) score. One of the crucial findings has been achieved, which result of the correlation analysis shows that in segment B, there was a strong and significant negative correlation between the RULA score and task performance score ($r = -0{,}781$, $p = 0{,}022$). This means that as the RULA score decreases (indicating better working posture), the task performance improves. These findings emphasize CEDT's role in maintaining good posture for performance.

KEY WORDS

ageing, RULA, cognitive-driven technology, workload, office worker

CLASSIFICATION

JEL: I12, J81

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INTRODUCTION

Malaysia is experiencing notable trend of ageing phenomenon, with a growing number of elderly individuals. According to the latest statistical data by Department of Statistics Malaysia, the total population of elderly in Quartile 1 in 2023 is 6,2 million, while in 2024 the number has increased to 6,3 million. The trend of ageing phenomenon in Malaysia signifies the magnifying of ageing workforce in the country. Employers, policymakers, and society must adopt age-inclusive practices and policies so that they are able to address challenges faced by ageing workforce and exploit their potentials. Leveraging the potential of ageing workforce is a very demanding effort. As ageing processes took place, human body experienced degenerative changes [1, 2]. During the events, there will be physical and mental function deterioration, risk of sickness increases and eventually death occurs [3, 4].

Mental workload evaluation in work activities nowadays has caught the attention of researchers and industries to ensure safety, health, comfort, long-term productivity and efficiency of the worker [5, 6]. Subjective measurement is a self-rating method to evaluate the mental workload experienced when performing tasks. Examples of widely used self-rating tools include NASA Task Load Index (TLX), Subjective Workload Assessment Technique and Workload Profile [7]. Objective measurement is more towards measuring physiological responses observed when performing tasks. Some of the widely accepted and validated measurements are heart rate derived from the electrocardiogram (ECG), brain signal extracted from electroencephalogram (EEG), eye-blinks measured from electrooculogram (EOG) and skin conductance response involving electrodermal activity sensors [8, 9]. The third category is performance measurement where it is based on the task context. Some of the common examples are measurement of error rate, reaction and response time and counts of procedures and tasks completed [10, 11].

Executing office tasks either traditionally or with the assistance of advanced technologies would require appropriate workstation setup. An ideal workstation is one that is established with reference to ergonomic principles. Changes in working postures were reported to be significantly correlated to mentally demanding working situations involving time pressure, intensity, and duration of the task [12]. RULA is one of the reliable tools to evaluate posture during task execution involving workers' upper limb [13, 14].

Digital and virtual assistants have been part of our working routines, especially in the era of Fourth Industrial Revolution (4IR or Industry 4.0). Computers and systems were integrated with machine learning mainly to support the human cognitive aspects resulting in smart and automated applications. Cognitive ergonomics-driven technology (CEDT) is an innovative approach that combines the fields of cognitive science and ergonomics, aiming to enhance the work environment's comfort and efficiency. Areas utilizing CEDT applications are vast. One of the applications is Natural Language Processing (NLP) which assists in transmitting information from human to computer. Another popular machine learning application that facilitates cognitive functioning is optical character recognition (OCR). This technology enables the conversion of scanned paper documents into editable and searchable text data [15].

Main objective of this study is to investigate the impact of cognitive ergonomic-driven technologies on ageing workers' mental workload, working posture and task performance. Also, this study aims to determine the relationship between mental workload and working posture, and how these important variables affect task performance. The existing knowledge on ageing workers would gain new dimensions relating to the crucial role of cognitive ergonomics interventions in assisting ageing workers in office settings. Additionally, analyzing the relationship between mental workload and body posture will establish a foundation for future exploration into the influence of perceived mental workload over physical demands in the context of ageing workers. The main hypotheses guiding this work are as follows.

H_1: Interventions of cognitive ergonomic-driven technologies in work tasks will reduce perceived mental workload, improve working posture, and increase the task performance score.

H_2: There is a relationship between mental workload and working posture and it will affect the task performance of ageing workers.

METHODOLOGY

PARTICIPANTS

Eight participants (aged 50 and above, M = 60,63 year, SD = 8,19 year) were recruited via email and social media. The sample size was determined by power analysis to ensure an observed power of 0,95 with an alpha of 0,05 [16]. Participants met specific criteria, including age, computer literacy, normal or corrected vision, English proficiency, and a minimum of five years of work experience. Only participants without pre-existing conditions were selected to ensure the integrity of the findings related to heart rate and performance. All participants provided informed consent and received a token of appreciation for their involvement.

EXPERIMENTAL SETUP AND MEASUREMENT APPARATUS

Experimental setup consists of computer workstation components (such as desktop, keyboards, mouses, monitor, desk, and chair), assignment sheets, devices for OCR applications which were the Photomaths (Photomath, Inc.) and Microsoft Lens (Microsoft 2023), and the built-in NLP software (Microsoft 365 Proofing). For the OCR applications, the physical text was converted into a digital format which enabling seamless integration of the extracted text into the intended files on desktop. Measurements apparatus were the tools used to measure mental workload, body posture and task performance of the participants. Mental workload measurements in this study utilized the NASA-TLX, ECG device (Polar H10 chest strap) and Polar watch as in Figure 1, and video recorder to record the time and posture of the participants while performing the tasks.

FIGURE 1. Polar H10 chest strap and Polar watch.

EXPERIMENTAL DESIGN

This study was approved by the Ethics Committee for Research Involving Human Subjects, Ref. no. UPM/TNCPI/RMC/JKEUPM/1.4.18.2. The experiment was conducted at Malaysian Research Institute on Ageing (MyAgeing®) in a special set-up, temperature-controlled, quiet room. Participants completed repeated office tasks in two segments: Segment A (baseline) and Segment B (with CEDT interventions). Tasks, durations, and measurements were identical across segments, involving data entry and arithmetic tasks. Detailed procedures and measurements are provided in the following subsections.

EXPERIMENTAL PROCEDURE

The experiment was conducted on one participant at a time. Upon arrival, participants were briefed on the study and completed a consent form. Then, they answered a demographic questionnaire, after that, ECG devices were attached. Participants familiarized themselves with the workstation and adjusted the chair, monitor, keyboard, and mouse. The posture may not necessarily align with optimal ergonomic standards. This approach was intentional, as it was aimed to evaluate the habitual postures that ageing individuals typically use when performing tasks, rather than imposing ideal ergonomic guidelines. By doing so, the real-world conditions in which older adults operate can be captured, as these postures reflect their own way of adapting to tasks over time.

To induce mental workload, participants performed two tasks per segment, aiming for accuracy within a 10-minute timeframe. Task order was randomized. In the typing task, participants typed sentences from a hardcopy, with speed measured in words per minute and accuracy by correct words typed [17]. In the arithmetic task, they answered 350 questions, with performance based on correct answers [18, 19]. Heart rate and posture were recorded during tasks. After each segment, participants rated the NASA-TLX and took a 10-minute break. A token of appreciation was given for their participation, and the experimental procedure is shown in Figure 2.

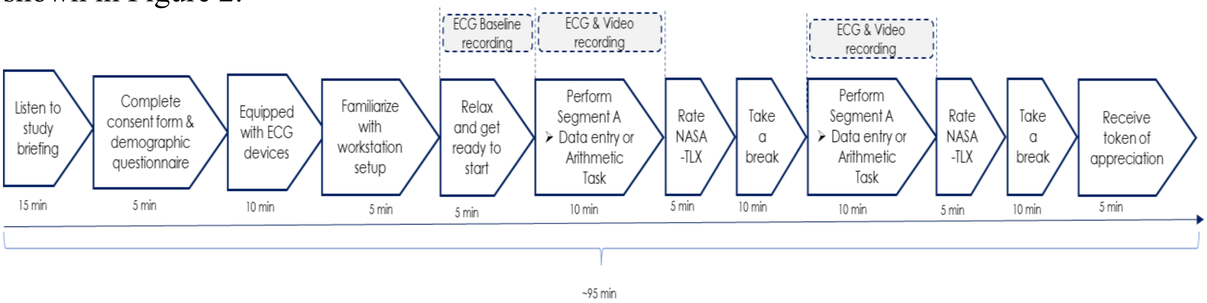

Figure 2. The flow of experimental procedure.

INDEPENDENT AND DEPENDENT VARIABLES MEASUREMENTS

This study outlined several independent and dependent variables based on two types of measurements namely subjective and objective. The summary of the variables of each measurement was shown in Table 1, while details were presented in following subsections.

Subjective measurement. The NASA-TLX was used to assess perceived mental workload across six subscales: Mental Demand, Physical Demand, Temporal Demand, Performance, Effort, and Frustration. Participants rated each subscale and completed pair-wise comparisons. Participants' postures, including neck bending, shoulder flexion, shoulder extension, elbow flexion, and back flexion (Figure 3), were recorded during tasks. These recordings were used to create scenarios in CATIA V5 for RULA analysis. The Human Builder module in CATIA V5, interacting with OCR devices, simulated the tasks and provided RULA scores, categorized as green (1-2; minimal risk), light yellow (3-4; low risk), yellow (5-6; moderate risk), and red (6+; high risk), Figure 4.

Objectives measurement. Multiple dependent variables were measured, including heart rate and task performance score (TPS). Heart rate was recorded using the Polar H10 chest strap and watch at a 1000 Hz sampling frequency, with lower rates indicating reduced mental workload. Participants relaxed and breathed normally before recording, and data were captured using Polar WebSync software. TPS was assessed through accuracy and efficiency metrics: accuracy was based on correct answers and net Words per Minute (WPM), while efficiency was calculated using a linear interpolation formula. The final TPS combined performance scores from each segment, as shown in Equation (1).

Table 1. Summary of study variables.

No.	Variables	Descriptions
	Fixed	
1	Task duration	10 minutes for each task
2	Time of tasks (ToT)	3 minutes each analysis segment
Independent		
1	Segment type	A & B
2	CEDT interventions	OCR & NLP
Dependent		
1	Weighted workload (WWL)	NASA-TLX
2	RULA score	RULA
3	Heart rate (bpm)	ECG
4	Task Performance Score (TPS) i) Accuracy score • Error count • Total number of words typed. • Total number of questions answered. ii) Efficiency score • Words typed per minute. • Questions answered per minute	Task performance measures

Figure 3. Non-Neutral Posture during the task execution.

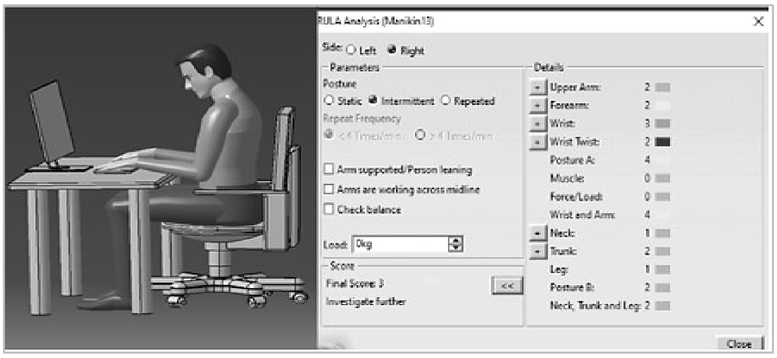

Figure 4. Non-Neutral posture with CATIA V5 RULA Analysis.

$$Task\ Performance\ Score\ (TPS) = \frac{Accuracy\ score + Efficiency\ score}{2}. \quad (1)$$

STATISTICAL ANALYSIS

Analysis was performed using IBM® SPSS® Statistics 29 (Armonk, NY: IBM Corp). To achieve the mentioned objectives, the T-test (WWL of NASA-TLX), ANOVA (Heart Rate, RULA and TPS) and Pearson correlation (relationship between Heart rate, RULA and TPS) were utilized.

RESULTS

DEMOGRAPHIC VARIABLES

A total of eight participants (3 male and 5 female) were involved in this study, with an average age of 60.63 years (SE = 2.90). All participants had significant work experience in their respective fields, with a mean of 32.75 years (SE = 3.30). These participants were selected based on their extensive professional backgrounds and relevance to the study's focus.

MENTAL WORKLOAD MEASUREMENT

Subjective Measurements – NASA-TLX. Figure 5 summarizes subjective NASA-TLX ratings for tasks in Segment A and B. The highest mean score was for Effort in both segments, while Physical Demand was the lowest, indicating minimal physical requirements. Segment A had a higher overall WWL score (12.6% higher than Segment B). However, the independent sample T-test revealed no significant difference between the WWL scores of the segments ($p > 0.05$). Hypothesis 1, which proposed that cognitive ergonomic interventions would reduce perceived mental workload, is supported by lower WWL scores in Segment B.

Objectives Quantification – Heart Rate. In Segment B, participants had lower mean heart rates during both typing and arithmetic tasks compared to Segment A (Table 2). Repeated measures ANOVA revealed a significant effect of segment type on heart rate (F (1,6) = 81.82, $p < 0.001$, $\eta^2 = 0.932$), with lower rates in Segment B ($p < 0.001$). There was also a significant interaction effect between segment type, task type, and task time (F (2,12) = 4.622, $p = 0.032$, $\eta^2 = 0.435$). Bonferroni-corrected pairwise comparisons indicated significant differences between segments A and B for all tasks and times, with the reported p-values being adjusted to account for multiple comparisons ($p < 0.01$).

Performance Measurement Based On TPS. Participants who made fewer errors had better performance scores. Among ageing participants, the highest mean Task Performance Score (TPS) of 97.73 was recorded in Segment B, while the lowest TPS was 31.91 in Segment A (Figure 6). Repeated measures ANOVA with Greenhouse-Geisser correction showed a significant difference in mean TPS between segments (F (1,7) = 28.441, $p = 0.001$, $\eta^2 = 0.802$), supporting Hypothesis 1, which predicted improved TPS in Segment B.

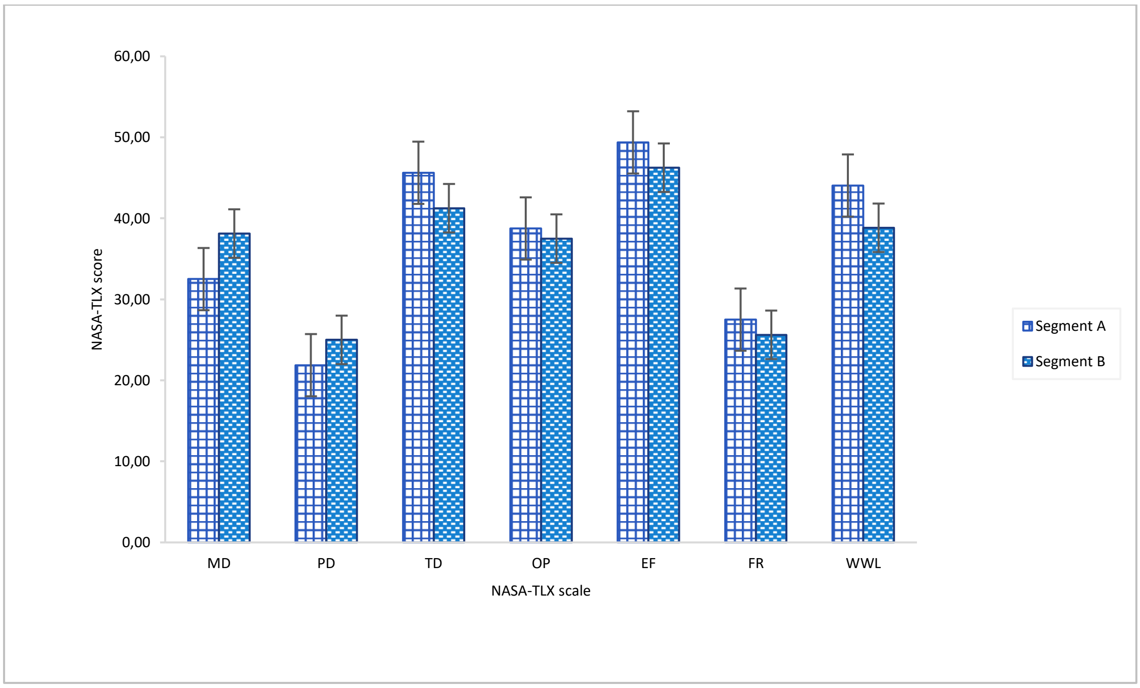

Figure 5. Subjective ratings of participants on workload measured by NASA-TLX (MD – Mental demand, PD – Physical demand, TD – Temporal demand, OP – Own performance, EF – Effort, FR – Frustration and WWL – Weighted workload).

Table 2. Mean heart rate (in bpm) in each segment.

Task	ToT	Segment A			Segment B		
		Mean	SD	SE	Mean	SD	SE
Typing	1	81.13	9.25	3.27	73.63	9.52	3.36
	2	80.50	10.09	3.57	73.50	9.34	3.30
	3	81.25	9.24	3.27	74.75	9.22	3.26
Arithmetic	1	81.63	10.24	3.62	75.57	9.34	3.53
	2	82.75	9.33	3.30	74.29	9.14	3.46
	3	82.25	9.51	3.36	73.71	8.58	3.24

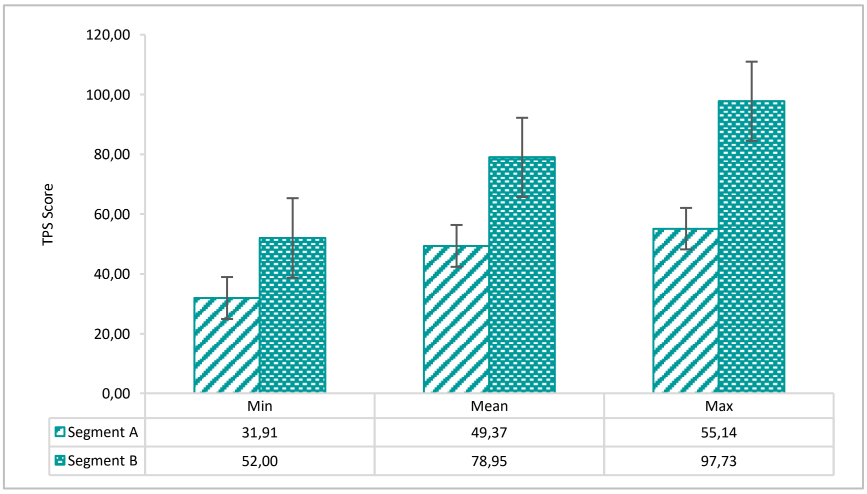

Figure 6. Summarize results of TPS.

BODY POSTURE BASED ON RULA SCORE

Participants' body postures during tasks were modelled in Human Builder for each segment. Figures 7(a) and 7(b) show the models and analysis for Segment A and Segment B, respectively. Figure 8 shows different RULA scores by segment. The highest mean RULA score was for the arithmetic task in Segment B (M = 4.50, SD = 0.53), followed closely by Segment A (M = 4.46, SD = 1.20). Repeated measures ANOVA revealed no significant main effect of segment type on RULA scores ($p > 0.05$). The maximum RULA score of 6 (Orange) was found in Segment A for the arithmetic task, indicating the need for immediate investigation and changes.

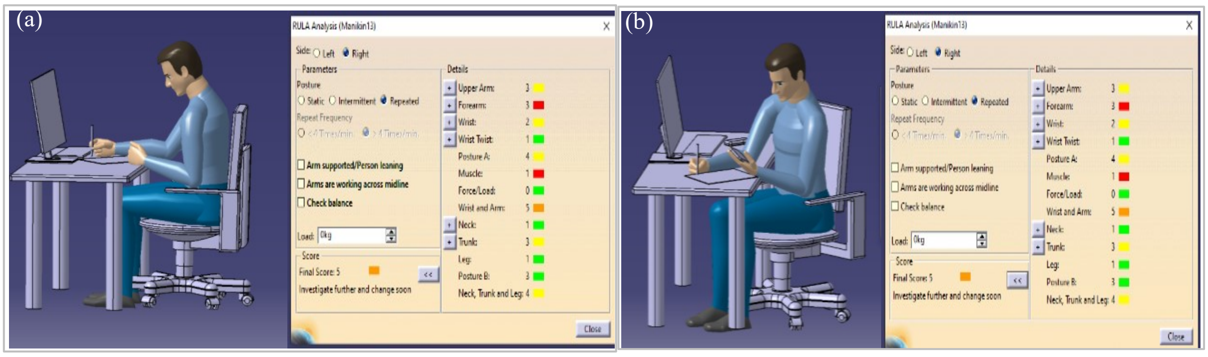

Figure 7. a) RULA builder model on Segment A – arithmetic task; b) RULA builder model on Segment B – arithmetic task.

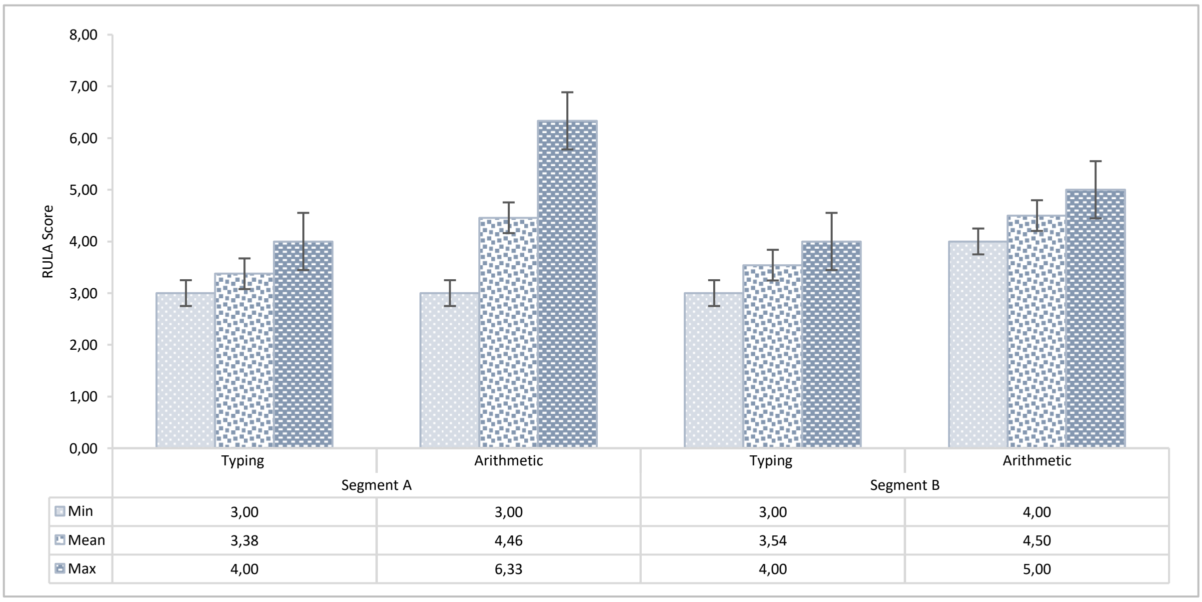

Figure 8. RULA score summary.

CORRELATION BETWEEN MENTAL WORKLOAD, WORKING POSTURE AND TASK PERFORMANCE

To test Hypothesis 2, Pearson correlation analysis was performed for both segments, examining the relationships between mental workload, posture, and task performance. Table 3 summarizes the results. In Segment B, there was a strong, positive correlation between heart rate and TPS ($r = 0.789$, $p = 0.020$), indicating that higher heart rates were associated with better performance. Additionally, Segment B showed a strong, negative correlation between RULA score and TPS ($r = 0.781$, $p = 0.022$), suggesting that better performance was associated with improved posture (lower RULA score).

Table 3. Correlation WWL, heart rate, RULA score and TPS.

Variables	Segment A				Segment B			
	1	2	3	4	1	2	3	4
1. WWL	-	0,065	0,303	–0,283	-	–0,364	–0,104	–0,370
2. Heart rate	0,065	-	–0,685	0,317	–0,364	-	–0,695	0,789*
3.RULA score	0,303	–0.685	-	0,091	–0,104	–0,695	-	–0,781*
4. TPS	–0,283	0.317	0,091	-	–0,370	0,789*	–0,781*	-

*significant correlation $p < 0,05$

DISCUSSION

This study investigated the impact of cognitive ergonomic-driven technology on perceived mental workload, working posture, and task performance of ageing workers in office setting lay the foundation for exploring the influence of ergonomic-driven technology over body posture and work performance specifically for ageing workers. The result of this study largely supports our hypotheses $\mathbf{H_1}$ and $\mathbf{H_2}$.

EFFECT OF COGNITIVE ERGONOMIC-DRIVEN TECHNOLOGY

One objective of this study was to assess the impact of CEDT interventions, such as OCR and NLP, on mental workload, posture, and task performance. We hypothesized that these interventions would positively affect mental workload as measured by NASA-TLX scores. Confirming this hypothesis would offer new insights into how aging office workers interact with CEDT and manage mental workload during work tasks.

The study results indicated that CEDT interventions reduced overall mental workload by 11,85% compared to no intervention, Figure 5. NASA-TLX scores showed higher mental workload in Segment B compared to Segment A, suggesting that without CEDT, workers in Segment A faced greater mental demands. However, Segment B’s higher scores for mental and performance demand imply challenges in adapting to CEDT tools (Figure 5) [20, 21]. Despite these challenges, proper guidance ensured they did not significantly affect overall results. Heart rate measurements supported the NASA-TLX findings, showing that increased workload corresponded with higher heart rates. Both subjective (NASA-TLX) and objective (heart rate) measures indicated that Segment A, without CEDT, had higher workload compared to Segment B.

In RULA, scores were similar for typing tasks in both segments. However, for arithmetic tasks, Segment A showed a rapid increase in RULA scores, indicating greater discomfort and strain compared to Segment B, where the increase was more gradual. This suggests participants in Segment A experienced higher levels of discomfort during arithmetic tasks, with posture becoming less comfortable over time, Figure 8.

Figure 6 shows that Segment B, with CEDT implementation, achieved a higher performance score. Technologies such as OCR and NLP enhance productivity by enabling faster and more accurate data entry, retrieval, and processing, benefiting aging office workers [22, 23]. CEDT not only speeds up task completion but also improves work quality by reducing errors and allowing focus on more complex tasks [24, 25].

WORK PERFORMANCE OF BAD BODY POSTURE AND HEAVY WORKLOAD

Correlation analysis of both segments, as shown in Table 3, explored the relationships between mental workload, body posture, and task performance using WWL from NASA-TLX, heart rate, RULA score, and TPS. In Segment B, a strong positive correlation (r = 0,789) between heart rate and TPS was statistically significant, suggesting that higher heart rates, associated with physical stimulation from CEDT, correlated with improved performance [26-28].

Additionally, a significant negative correlation (r = –0,781) was found between RULA score and TPS, indicating that better posture (lower RULA score) is linked to improved task performance [23]. This underscores the importance of maintaining good posture to enhance performance outcomes.

CONCLUSION

This study confirms that CEDT can reduce perceived mental workload, improve working posture, and enhance task performance. It underscores the significant links between mental workload, posture, and performance, highlighting the importance of good posture for optimal results. The findings suggest that CEDT offers opportunities for ergonomic interventions that balance physical and mental demands for aging workers. To fully realize these benefits, adequate training and support are essential. Implementing CEDT can help institutions and organizations boost productivity and manage mental workload while promoting better posture.

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