Interaction Effects of Physical and Mental Tasks on Auditory Attentional Resources

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ABSTRACT

Many tasks in the real world require simultaneous processing of mental information alongside physical activity. Whilst physical workload may have an impact on mental performance and attentional resources, most previous studies in ergonomics have not systematically investigated the impact of interactions between physical and mental demand on individual performance. The purpose of this study was to examine the influence of mental and physical workload interactions on auditory attentional resources and performance on verbal and spatial tasks. The moderate level of physical lifting improved the performance of auditory tasks under mental underlaod level. Surprisingly, rSO2 oxygenation changes were sensitive to changes in mental workload; also they were not sensitive to physical workload. The NIRS technique was valuable and sensitive in terms of reflecting the impact of mental and physical workloads on attentional resources and mental activities.

Keywords: physical workload; auditory mental workload; attentional resources; performance; brain activity

1 INTRODUCTION

Most researchers have focused on the examination of physical and mental demand impacts on individual's performance, separately. The mental workload has increased more than the physical workload in many jobs due to the rapid increase in technology in recent years; however, there are many jobs that require physical activities combined with mental tasks (e.g., firefighting, manufacturing, and assembly jobs) that can place stress on cognitive functions (Mozrall and Drury 1996). However, the authors who studied the effects of physical activity on cognitive function have found inconsistent and non-uniform results (Didomenico and Nussbaum 2008; Tomporowski 2003). Furthermore, researchers have focused on the effect of physical exercise on simple mental tasks (reaction time tasks) (Perry et al., 2008). According to some researchers, the optimum cognitive performance occurs under a medium level of physical exercise due to increased level of arousal (Audiffren et al., 2008). On the other hand, other researchers postulate that some levels of physical effort, such as a moderate level, can facilitate the mental process by increasing the percentage of blood flow, and thus oxygen, to the brain (Antunes et al., 2006), creating a defense toward any reduction in available oxygen in the brain due to mental stress and resulting in improvement in cognitive functions. Furthermore, Wilson and Russell (2003) said that the correlation between mental workload and performance is the same as between arousal level and performance, i.e., U-inverted. Therefore, it seems important to investigate the impacts of various physical and mental workload combinations on attentional resources performance.

NIRS, a recent method in neuroergonomics science, measures the impact of workload on brain activities (Parasuraman et al., 2008; Perry et al., 2009). Furthermore, the voluntary control of human actions or physical tasks combined with mental load (cognitive, perceptual, and affective processes) is one of the primary functions of the brain (Karwowski and Siemionow, 2003). As a result, the tasks, which include physical and mental demands, might place a heavy load on the brain function capacity of the operator. The purpose of this experiment is to examine the effects of physical lifting and mental workload interactions on auditory mental tasks (verbal and spatial).

2 METHODS

2.1 Design

The current study involves two experiments to investigate the effect of the interaction of physical workload (PWL) and mental workload (MWL) on individual attentional resources in the performance of auditory-verbal (arithmetic) and auditory-spatial (tone localization) tasks. The experiment used a 3×3 full factorial repeated measures design. Table 1 illustrates the nine conditions of interactions between the physical and mental arithmetic tasks. Table 4.2 presents the combination between physical demand and spatial figures at nine different levels.

Repeated measure analysis was used *within subject factors* (three physical and mental workload levels of interaction) and *between subject factors* (types of auditory mental tasks, i.e., verbal and spatial tasks).

Table 1 The nine conditions of interaction physical load and mental arithmetic tasks.

		Mental Auditory Verbal/Spatial Workload (MWL)		
		Low mental load	**Medium mental load**	**High mental load**
Physical Workload (PWL)	**Low lifting load (8% body weight)**	Performance will decrease under this condition due mental underload	Poor performance	Poor performance
	Medium lifting load (14% body weight)	Improves Performance	Acceptable performance	Poor performance
	High lifting load (20% body weight)	Poor performance	Poor performance	Performance will decrease under this conditions (overload)

The mental arithmetic tasks (auditory verbal task) included three levels of difficulty: low level (addition/subtraction numbers between 1 and 10), medium level (addition/subtraction problems with two numbers between 3 and 35) and high level (addition/subtraction problems with two numbers between 20 and 150 for the subtraction operation and between 20 and 105 for the addition). The tone localization tasks (auditory spatial task) included three levels of difficulty: low level (participants were asked to determine the sources of tones between two activated speakers placed at 270^o and 30^o), medium level (intermediate level, participants were asked to find the source of the tones from four speakers located in different positions (270^o, 30^o, 60^o and 90^o) and high level (difficult level, participants were asked to catch the auditory tone with six speakers, (270, 30, 60, 90, 120 and 150 degrees). Physical lifting (8%, 14% and 20% of body weight) was as illustrated in Table 1; this physical task was similar to physical levels used by Didomenico and Nussbaum (2008).

2.2 Output measures

Dependent variables were included, namely: performance (number of correct responses, speed and accuracy), physiological indices (heart rate (HR) and regional cerebral oxygen saturation (rSO2)), and subjective assessments of overall workload (observed by using the NASA-TLX scores) (Hart and Staveland, 1988).

2.3 Particpants

The participants for each experiment were divided into two groups of 15 (one group for mental verbal task- experiment 1 and another for mental spatial task- experiment 2, in a between-subjects design), aged 25-35, with an equal balance of male and female participants in each group. In addition, the standard hearing test questionnaire (Self-Assessment of Communication, Schow and Nerbonne, 1982) was used to evaluate the hearing health of the participants; all participants had normal hearing. All subjects were healthy and did not have any history of back or musculoskeletal disorder. All participants were selected from the Brunel University staff and students.

2.4 Procedures

At the beginning, the participants were given a short introduction to the experiment in order to familiarize them with the steps. Also, the participants were provided instructions and advice on how to perform a lifting task and arithmetic mental task. The participants were then asked to affix the chest electrodes for the heart rate monitor on their chests so we could record the HR at baseline (rest) and measure the HR during the experimental conditions. The experiment included nine conditions, and counterbalancing between conditions was considered in order to reduce potential carryover effects and fatigue. Additionally, the NISR was fixed on the foreheads of the participants to measure the oxygenation (rSO2) of the brain.

At first, the participants' standing position was in the center of the experiment room; the dimensions of the chamber room were 3.30m×3.0m×2.68m this was used to isolate the outside noise. In addition, the room sound intensity level was nearly 33 dB(A) The participants were required to lift boxes from the floor to a 69-cm high table. They were required to do 4 lifts/min, and were free to select either of two methods of posture. The boxes were supported with two handles, and their dimensions were 35×35×30 cm. The table was placed in front of the subject and the boxes on the floor. The subjects were asked to keep their bodies and faces facing forward. The subjects were asked to lift the boxes onto the table and then place them back on the floor. Concurrently, they verbally answered the arithmetic problems given by the experimenter within an allotted fixed time (5 sec), to reduce the variation between each subject's speed in answering. The arithmetic sound was generated from the speaker at 70 dB (A) sound intensity (male voice).

Each volunteer completed nine conditions, and each condition was of 6 min duration. Also, each volunteer completed 25 questions at each level as accurately and quickly as possible in the allotted 6 minutes. The number of correct responses and the actual time required to complete the section was recorded directly by the software. Between each condition, each participant was given 5 min rest and the participant's NASA-TLX score was computed.

In the second experiment (i.e., tone localization task), the participants used the identical measure and equipment to the previous experiment. The tone generator software (NCH) was used to generate the tone and white-noise. The speakers were placed in the room at different positions and were each assigned a number. The speaker placed at 270° from the participant was assigned number 1; at 30°, number 2; at 60°, 3; at 90°, 4; at 120°, 5; and at 150°, 6. Two sounds were presented concurrently from two different speakers. For example, the pure tone and white noise were presented simultaneously from Speakers 1 and 2 for low auditory workload (two speakers active) with 400 ms duration. The participant responded to the pure tone concurrently with the lifting task and the experimenter recorded the answer in the program. Each condition level included 25 problems, and participants were given 6 minutes to complete each level. In addition, they took 5 minutes to rest and complete the NASA-TLX Score between each condition.

3 RESULTS

3.1 Perfromance

The ANOVA technique showed that the levels of difficulty of both factors separately—the physical and mental workloads—highly and significantly impacted the participants' answer accuracy in both visual mental tasks ($F(2,52) = 84.81$, $p<0.01$ and $F(2,52) = 57.21$, $p<0.01$, respectively). There was no interaction impact on accuracy ($p=0.332$). In addition, when the task levels (arithmetic and tone localization) increased, the accuracy decreased, except that the accuracy at low mental level and medium lifting load of interactions in both tasks was improved. In addition, there were no significant differences between both tasks under all levels of interactions ($p>0.05$)

According to contrast analysis, a significant difference was observed between all levels of physical workload ($p=0.027$). Additionally, the analysis showed a significant difference between mental workload levels in both tasks ($p=0.014$).

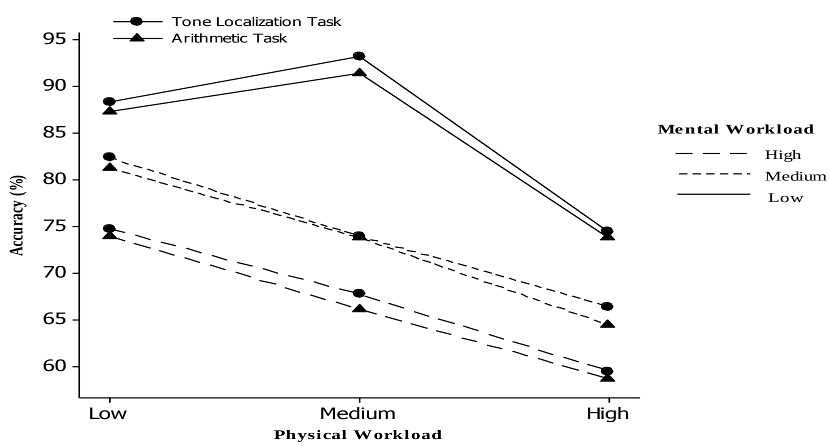

Figure 1 Means of accuracy of tone localization and arithmetic mental auditory tasks responses against physical and mental workload interaction.

The ANOVA technique showed that the mental workload factor highly and significantly impacted participants' time to provide correct responses ($F(2,52) = 4153.25$, $p<0.01$). In addition, the physical workload factor had a significant impact on participants' time to provide correct responses ($F(2,52) = 798.51$, $p<0.01$). Moreover, the effects of physical and mental workload interactions on time for correct responses were significant ($p=0.01$). In addition, when the mental tasks levels (arithmetic and tone localization) and lifting weight increased, the average time for correct responses increased. The lowest time of correct responses appeared at medium lifting level × low mental demand of arithmetic and tone localization tasks. Auditory arithmetic while lifting consumed more time than the tone localization task. There were significant differences between tone localization tasks and arithmetic tasks at high level of mental load versus medium lifting load (p=0.038) and high mental load versus high lifting physical load (p=0.031), see Figure 2.

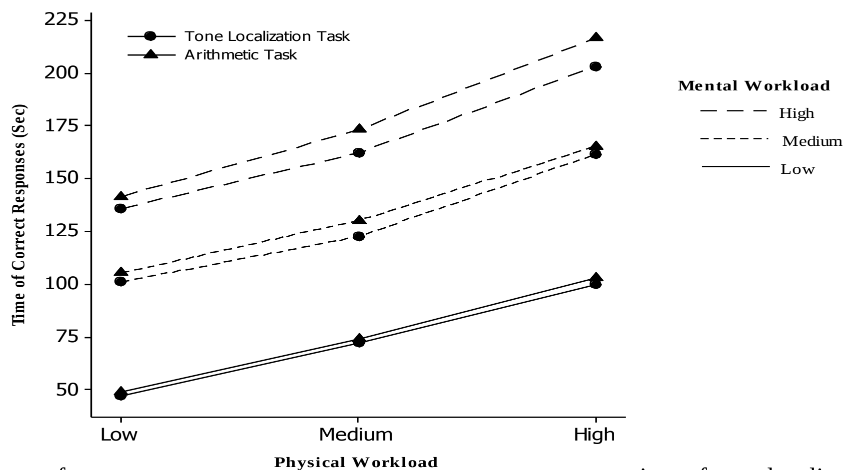

Figure 2 Means of correct responses time of tone localization and arithmetic mental auditory tasks responses against physical and mental workload interaction.

3.2 Physilogical measures

There was a significant impact of mental workload on participants' HRs ($F(2,52) = 1210.02$, $p<0.01$) in both tasks. Furthermore, lifting workload levels in both auditory tasks (arithmetic and tone localization) had a significant effect on HRs of participants ($F(2,52) = 3120.51$, $p<0.01$). In contrast, the influence of lifting levels and mental workload tasks was not significant ($p>0.05$). Generally, the HRs' mean significantly increased when the physical and mental workload increased ($p<0.05$); see Figure 3. Moreover, the physical and mental workload interaction had not significant influence on HRs ($F(4,104) = 1.85$, p=0.43). Tone localization and physical lifting produced lower physiological stress than the arithmetic task condition, but there were no significant differences between both tasks ($p>0.05$).
As expected, the ANOVA technique showed that the mental workload factor highly and significantly influenced the participants' percentage of blood oxygenation in the frontal cortex of the brain (rSO2) ($F(2,52) = 153.86$, $p<0.001$). In addition, the physical workload factor had a significant impact on the percentage of oxygenation ($F(2,52) = 59.82$, p=0.012). Moreover, the effect of physical and mental workload interaction on rSO2 was not significant (p=0.63). However, the percentage of oxygenation in the brain increased when both mental task levels (arithmetic and tone localization) increased, whereas it decreased when the physical workload increased; see Figure 4. There were significant differences between both mental tasks at high mental workload while interacting with low, medium and high physical lifting tasks (p=0.013, p=0.022 and p=0.026, respectively).

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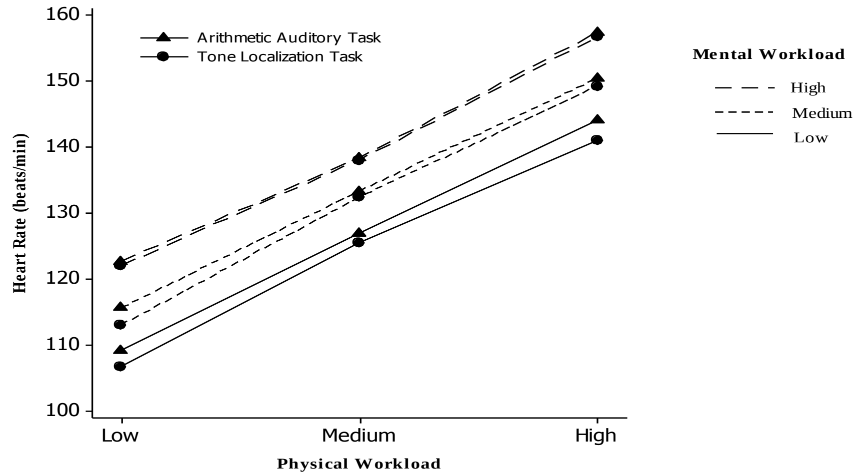

Figure 3 Heart rate means of tone localization and arithmetic mental auditory tasks responses against lifting boxes and mental workload

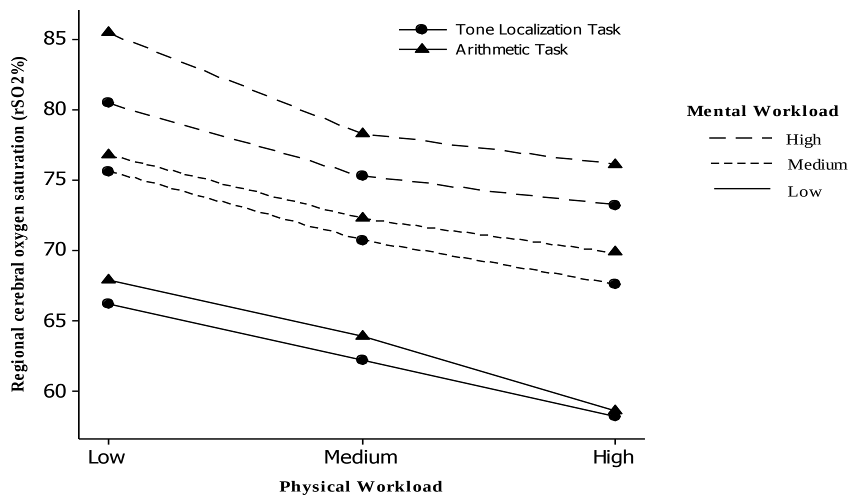

Figure 4 Brain oxygenation changes means of both tasks arithmetic and tone localization under nine levels of physical and mental workload interaction.

3.3 Subjective Assessment Tool (NASA-TLX)

The ANOVA technique showed that the mental workload factor highly and significantly impacted the NASA-TLX scores (p<0.01). In addition, the physical workload factor had a significant impact on the ratings (p<0.01). Moreover, the effects of the physical and mental workload interaction on NASA-TLX were not significant (p=0.24). The NASA-TLX score showed significant differences among mental workloads in both mental task levels and physical workloads (p<0.05). There were no significant differences between arithmetic and tone localization tasks among all levels of interactions (p>0.05).

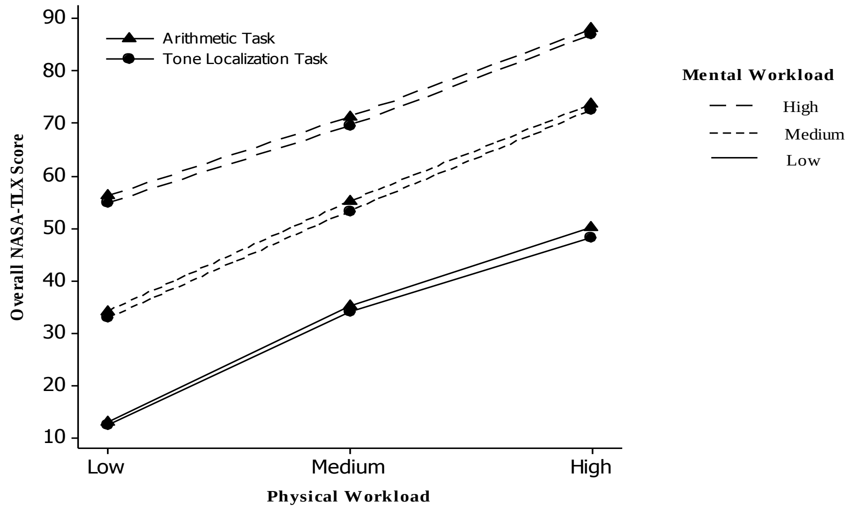

Figure 5 Overall workload assessment of arithmetic and tone localization mental task against physical and mental workload interactions, using the NASA-TLX rating.

4 DISCUSSION

The effects of physical and mental workload interactions on auditory tasks were investigated in this study. The findings of this experiment in terms of performance impact were that the accuracy and time of correct responses were impacted by the physical and mental workloads. Unexpectedly, optimum performance did not occur under medium level of physical and mental workload interactions in both auditory mental task conditions. Moreover, increased intensity in physical and mental workload (overload) led to poor accuracy and increased time of correct responses in arithmetic and tone localization tasks that increased stress on auditory attentional resources. That may be because the moderate level of arithmetic and tone localization tasks used in this study was complex for participants. However, the exciting result was that a moderate level of physical workload (14% of body mass) improved the cognitive information process under auditory mental underload level in tone localization and arithmetic tasks. Because the incremental increases in physical activity led to increased arousal level, performance increased. This is consistent with a previous study by Audiffren et al. (2008) that found that moderate cycling level improved performance of tone auditory reaction time tasks due to increased level of arousal. That is not consistent, however, with Didomenico and Nussbaum (2008), who found that increased levels of physical and mental workload did not impact arithmetic tasks performance. However, the differences between their study and current study may be because the auditory tasks that were used in the current study were more complex.

Heart rate was sensitive to physical and mental workload changes, since it increased significantly when workloads increased. In addition, a rise in rSO2 percentage was associated with mental workload increases in both mental tasks. That means that increased auditory mental demands increased the percentage oxygenation changes in brain (brain activation), since increased brain activation indicate an imbalance between the amount of oxygen in the brain and the amount needed to meet high mental workload. That is consistent with Kikukawa et al. (2008), who found that increasing the level of mental demand in a pilot task (takeoff situation) leads to poor performance. On the other hand, the increase level of physical activity from low level to medium led to reduction the activation of brain since; the more of blood translated to brain so that the delivered oxygen to the brain was increased that reduced oxygenation changes percentages in the brain. As a result of that, it may the performance was facilitated at moderate physical level. This is similar to Antunes et al (2006) those suggested that the auditory cognitive functions supports by some physical exercise since, the physical activity makes a lot amount of blood flows to brain so, the amount oxygen increases which assess the mental information process. NASA-TLX increased significantly while physical and mental workloads increased and showed significant differences between physical levels and mental demands in both mental tasks conditions.

5 CONCLUSIONS

The balance between individual attention capacity and task workload was necessary, since some physical activity workload, such as moderate level, facilitates the low-level auditory cognitive information process and make it faster. In addition, high intensity levels of physical and mental workload led to poor responses. Increased physical activity did cause an increase in physiological arousal, which may improve performance. Significantly, an increased level of physical workload (to medium level) led to increased arousal level, which supported the cognitive task performance at low mental workload. Furthermore, this study supports the use of the NIRS technique that reflects the effects of physical and mental workload on brain activity and presents the percentage of oxygenation changes in the brain during workload interactions.

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