Research Paper: The Relationship Between Helmet Weight, Cognitive Performance, and Mental Workload

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ABSTRACT

Introduction: This study sought to examine the effects of helmet weight on cognitive performance and mental workload. Twenty participants were studied in 3 one-hour sessions.

Methods: The study participants were requested to read and work with computers under the following 3 conditions: wearing no helmets, wearing a helmet that weighed 800 g (A), and a helmet weighing 1500 g (B). "N-back" task and Continuous Performance Test (CPT) were employed to assess cognitive performance. At the same time, NASA-TLX and Thermal Comfort and Fatigue Perception Scale were used to evaluate mental workload and comfort. At the end of the intervention sessions, perceived mental workload, thermal comfort, and fatigue in the head were measured. Moreover, the research participants' cognitive performance was gauged before and after the sessions.

Results: The present study findings revealed that helmet weight significantly impacted cognitive performance ($P<0.001$). However, no significant difference was detected in the participants' mental workload before and after the intervention.

Conclusion: Helmet weight could affect cognitive performance. Therefore, in designing helmets, the helmet's weight should be considered an essential factor.

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Highlights

- Helmet weight significantly impacted cognitive performance.
- The results showed that the perceived mental workload was not influenced by helmet weight.
- Designing helmets, the helmet's weight should be considered an essential factor.

Plain Language Summary

This study examined the effect of helmet weight on brain performance. The results showed that the perceived mental workload was not influenced by helmet weight. However, brain performance declined as a result of wearing heavier helmets. Furthermore, the perceived local fatigue in the shoulders and neck increased after wearing heavier helmets. Thus, manufacturers should consider helmet weight while designing helmets and developing the relevant standards.

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1. Introduction

The head is among the most vulnerable body parts in motorcycle accidents. Overall, 75% of mortalities in motorcycle accidents are caused by skull damages (Deck & Willinger, 2006). Numerous countries have made it obligatory to wear helmets (Rueda, Cui, & Gilchrist, 2009). Motorcycle riding requires utmost mental attention as a complex and dynamic mental activity. This indicates that failure in mental performance and cognitive errors constitute primary reasons for motor riders' damages. Indeed, 34% of mortalities among motor riders are caused by cognitive errors (Di Stasi et al., 2009).

Given that helmet is used to protect the head against mechanical damages, multiple ergonomic studies have focused on optimizing helmets to protect against mechanical impact (Liu, Ivers, Norton, Boufous, Blows, & Lo, 2008). Conversely, limited studies have concentrated on helmet's impact on mental performance. To the best of our knowledge, no attempt has been made to improve the interaction between humans and the helmet from a mental and cognitive perspective.

Limited studies have revealed that increased temperature in the head caused by wearing a helmet might lead to lower cognitive performance. Some research projects have also displayed that skin temperature rise can lower complicated performances and hinder decision-making processes (Gaoua, Grantham, Racinais, & El Massioui, 2012). It has also been demonstrated that wearing a helmet might increase the reaction time and decline mental performance (Hancock, 1983; Neave, Emmett, Moss, Ayton, Scholey, & Wesnes, 2004). However, some other studies have failed to detect any association between wearing helmets and cognitive performance. Bogerd, Walker, Brühwiler and Rossi (2014) stated that wearing a helmet covering the entire face had a boundary effect on reducing cognitive performance even in hot environments (Bogerd et al., 2014).

Overall, the existing studies have attributed lowered cognitive performance to the heat on the scalp region. These studies, however, failed to take other factors into account. Helmet weight, for example, is an essential parameter in this regard. This factor, i.e., reported among the reasons for riders' reluctance to use helmets, leads to fatigue naturally (Faryabi, Rajabi, & Alirezaee, 2014). Although new technologies have been applied to manufacture lighter helmets, numerous motor riders worldwide use heavy helmets. The helmet's weight may result in fatigue in the neck and shoulders. Given the direct relationship between physical load and cognitive workload, heavy helmets may reduce mental performance among riders (Şahana, Ermana, & Meneka, 2015). However, studies concerning the effects of helmet weight on cognitive performance and mental workload are scarce. Therefore, the current study aimed to examine the impact of motor riders' helmet weight on their cognitive performance and mental workload in a laboratory setting.

2. Methods

The sample size was estimated using G*Power 3.1. With an input at .05, a medium effect size of .15, power of .90, the minimum sample size required for this study was 20. In this study, 20 healthy male adults with the Mean±SD age of 26.4±3.3 years and head circumference of 49-55 cm participated. The individuals were excluded from the study if they used medications regularly or suffered from claustrophobia or attention disorder. The participants were requested not to use alcohol, drugs, or caffeine for at least 12 hours before each test session. In the familiarization sessions, the participating individuals were asked to adjust their clothing to feel thermally comfortable. The participants' sleep schedules were also checked before each stage. Moreover, we ensured that they had slept for 7-9 hours before the study. Furthermore, each participant used the same clothing during the three experimental sessions to observe homogeneity. Before the study, written informed consent forms were obtained from the study participants. Moreover, the necessary approval was gained from the Ethics Committee of Shiraz University of Medical Sciences.

The study participants were seated in front of an air-blowing fan to minimize the impact of the thermal condition. Then, a 16-inch LCD screen with a resolution of 386*768 pixels was positioned opposite the participants. The horizontal distance between the air-blowing fan and each participant's forehead was 70 cm, while the distance between their forehead and the LCD was 50 cm. The room where the measurements were carried out had an ambient temperature of 24±2°C and 46±3% relative humidity. Besides, the wind speed (VW) was set at 0.6±0.1 ms^{-1}. During the experiments, the participants were alone and had no contact with others.

In each experimental session, the examination time was kept constant to avoid the impact of the circadian rhythm. The participants took part in two familiarization sessions to reduce learning effects on the results. This was found sufficient for avoiding the learning effect in a pilot study. Subsequently, each participant underwent three experimental sessions in a balanced order. Each session occurred on a particular day of a week, with the three experiments being conducted within three consecutive weeks.

The participants completed the experiment in the control session without wearing any helmets. However, in the two experimental sessions, they wore two different helmets weighing 800 gr and 1500 gr. Before the experiments, the participants' head circumferences were measured following ISO8559 (1989). Moreover, they were provided with helmets corresponding to their head circumferences (Beazley, 1997). The visor and vents of the helmets remained closed during the experiments.

Before starting the experiments, the participants completed a mood questionnaire (Monk, 1989). Furthermore, sleep duration and quality were measured for the night leading to the experiment using two Petersburg Sleep Quality Index (PSQI) items. These items included "How many hours did you sleep last night" and "How well do you assess your sleep quality during this period".

At the end of each session, the participants' whole body temperature perception, thermal comfort, and fatigue perception in the head, neck, and shoulders were measured by the visual analog scale. Moreover, the participants self-evaluated their mental workload through the NASA-TLX index (Vitório, Masculo, & Melo, 2012).

The baseline phase, i.e., the initial 7 minutes per session, was allocated to providing some instructions, familiarizing the participants with the procedure for completing each particular experiment (Table 1). The research participants also completed the cognitive tests (1-back and reaction time) during the familiarization time. Following the familiarization phase, the equilibration phase began, which lasted for 40 minutes and aimed at achieving a thermal and physical load steady state. During this time, the participants were involved in reading or doing unrelated computer work. Eventually, the participants completed the cognitive test battery. The cognitive tests were as follows:

The N-back task: To assess working memory, use was made of the n-back test, frequently used to evaluate memory performance (Cook, Choobineh, Taheri, & Rastipishe, 2018). This instrument is used to determine the individuals' ability to process, select, and save information in a short period. The Persian version of N- back was used in this study. Cronbach α of the test was 0.76 in the previous survey (Hatami et al., 2018). In the current study, the computer type and n=1 were employed since previous research had indicated that the 1-back test was sensitive to motorcycle helmet intervention (Cook, Choobineh, Taheri, & Rastipishe, 2018). In this test, 120 digits were displayed at the center of a computer screen with 1500 ms intervals, with the entire process lasting for three minutes. The study participants were required to press the answer button on the keyboard immediately if two consecutive numbers were the same. The number of correct answers and the response time (ms) were considered to be dependent variables.

The continuous performance test: As a reliable, standardized computer test, a continuous performance test has been widely used to assess sustained attention over time. Cronbach α of the test was 0.76 in the previous study (Kasaeian, Kiamanesh, & Bahrami, 2014). This test contained 150 visual stimuli (shapes and numbers) displayed on a computer screen, 20% comprised the target stimuli. The participants were required to identify these stimuli by pressing the keyboard's space button.

Every stimulus was displayed for 150 ms, with 500 ms intervals between two consecutive stimuli. Commission error, omission error, and reaction time (ms) were regarded as the dependent variables of the test how do you.

Mental workload: NASA-TLX is sensitive to variations in mental workload and presents the most accurate information on mental workload. The face validity and reliability of the Persian version of the NASA-TLX technique have been approved (α=0.897) (Mohammadi, Mazloumi, & Zeraati, 2013). This technique contained 6 subscales: mental and physical requirements, time requirement, effort, performance, and stress. Subjective scores ranging from 1 to 20 were attributed to these subscales. Subsequently, load source was computed through conducting 15 pairwise comparisons of the subscales (Vitório et al., 2012). Finally, the index number of mental workload was calculated based on the weighted average of the given scores and the index values.

Thermal comfort and fatigue perception: A five-point thermal comfort scale (ranging from 0: comfortable to 4: extremely uncomfortable) was used to assess the participants' thermal comfort perception on the scalp region. The details of this scale have been presented elsewhere (ISO10551, 2001). Additionally, a 10 cm visual analog scale measured local fatigue in the head, neck, and shoulders.

The collected data were analyzed using SPSS. The Kolmogorov-Smirnov test was used to assess the normality of the data. The effect of the intervention (helmet) on cognitive performance, mental workload, and subjective fatigue was tested by repeated measures Analysis of Variance (ANOVA). Besides, repeated-measures Analysis of Covariance (ANCOVA) was performed to control the influence of thermal comfort perception as the covariate on cognitive performance. For further analysis, pairwise comparisons using Bonferroni correction were calculated. The statistical significance was set at 0.05.

3. Results

According to Table 2, the helmet's reaction times on the working memory task were not significantly affected. In other words, there was no significant difference among no-helmet, helmet A (800 g), and helmet B (1500 g) modes. Furthermore, neither considerable 'time' effects nor any 'helmet * time' interactions on the reaction times could be observed.

Concerning the indices of the accuracy of the working memory task, Table 2 indicated that the intervention type significantly influenced the mean number of correct responses ($F_{2,56}$=14.29, P<0.01). In contrast, the helmet type did not affect the mean number of incorrect responses.

The results of Bonferroni correct factor revealed a significant difference between helmet A and non-helmet modes (P=0.05) and between helmet B and non-helmet modes (P=0.01) regarding the mean scores of correct responses. There was a significant difference between helmet A and helmet B (with a lower mean) concerning the mean scores of correct responses (P=0.01).

Considering the sustained attention task, Table 2 revealed that the helmet type did not affect mean reaction times. In this respect, no significant differences were found among non-helmet, helmet A, and helmet B modes. In addition, there was no significant 'time' effects or 'helmet * time' interactions effect on reaction times.

As for accuracy on the sustained attention task, Table 2 indicated that the mean number of correct responses was significantly affected by the helmet type (F=3.21, P<0.05) and time (F=8.84, P<0.05). However, no significant 'helmet * time' interaction effect was found for reaction times indices. In contrast, wearing helmets had no significant impact on the sustained attention task's mean number of errors.

Table 1. The study protocol in an experimental session

Baseline Phase	Equilibration Phase	Final Phase	
N-Back and continuous performance test	Reading and computer work	N-Back and continuous performance test	NASA-TLX, heat comfort scale and fatigue scale
7 min	40 min	min 7	

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Table 2. Results of repeated-measures ANCOVA on the helmet- and time-independent variables

Performance Variables		Helmet		Time		Helmet * Time	
		F	P	F	P	F	P
Working memory	Reaction time	0.34	0.56	0.21	0.81	1.27	0.29
	Correct responses	14.29	0.001	1.12	0.33	4.98	0.01
	False responses	0.28	0.59	1.65	0.20	5.01	0.01
Sustained attention	Reaction time	0.42	0.52	1.98	0.15	0.99	0.38
	Correct responses	3.21	0.01	8.84	0.03	0.69	0.51
	Error	0.15	0.70	0.28	0.71	1.60	0.22

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The results of post-hoc analysis using the Bonferroni correction factor revealed a significant difference between helmet A and helmet B (P=0.04) and between non-helmet and helmet B modes in terms of correct responses (P=0.04). However, no significant differences were observed between non-helmet and helmet A modes in this regard.

Mixed ANOVA analyzed the average rates (raw TLX) of NASA TLX. The obtained results addressed no significant intervention effects ($F_{2,38}$=2.30, P=0.11). Moreover, the results of analyses on the ratings of the single dimensions of NASA TLX suggested no significant effects for NASA–TLX subscales (Mohammadi et al., 2013)

An overview of the results of fatigue perceptions under the three different helmet modes has been presented in Figure 1. Accordingly, significant differences were found among these three modes ($F_{2,38}$=58; P<0.05). The collected results indicated that the fatigue perception value under the non-helmet mode was significantly lower than that of helmet A (P<0.001) and helmet B modes (P<0.001). Indeed, fatigue perception under helmet A was significantly lower than that under helmet B (P<0.001).

4. Discussion

As a primary attempt, the current research sought to examine the effect of helmet weight on cognitive performance and mental workload. It was hypothesized that heavier helmets could enhance perceived mental workload and reduce cognitive performance. The study results indicated that perceived mental workload was not associated with the helmet weight. Nonetheless, the cognitive performance test findings revealed that working memory performance and sustained attention were influenced by helmet weight. It further had a significant impact on the local fatigue of the shoulders and neck. These results were in line with previous investigations (Bogerd et al., 2014; Neave et al., 2004). For example, Nick Neave et al. (2007) demonstrated that using helmets by cricketers reduced their cognitive performance.

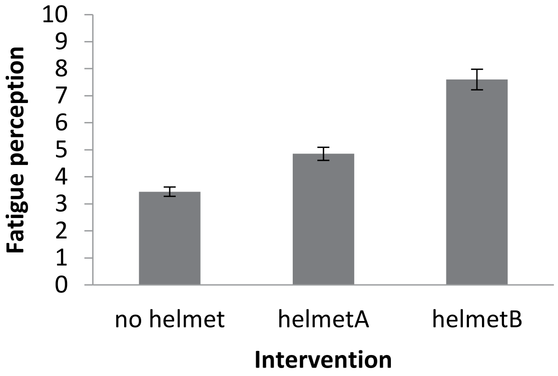

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Figure 1. Changes in fatigue perception across the three conditions. Error bars indicate standard errors of the mean

The significant distinction between the present study and the one mentioned above is that the latter attributed the reduced cognitive performance to local temperature rise in the scalp region caused by wearing helmets. However, in the present study, attempts were made to moderate the heat created by wearing helmets through ventilation.

Moreover, the effect of thermal comfort (as perceived by the participants) was considered a covariate in the statistical analyses. The reduced cognitive performance could only be attributed to the independent variable, i.e., helmet weight. Considering the absence of studies in this area, the impact of helmet weight on decreased cognitive performance can be justified in two ways: first, helmet weight causes local fatigue in the shoulders and neck, and second, it leads to reduced blood circulation in the cerebral cortex. Therefore, wearing heavier helmets increases local fatigue in the neck and shoulders, eventually decreasing cognitive performance (Şahana, Ermana, & Meneka, 2015). Indeed, research has revealed that physical load and fatigue affect cognitive performance. For instance, Asuman Sahana et al. blamed physical fatigue for reduced blood circulation in the prefrontal cortex, which decreased working memory performance (Şahana et al., 2015). On the other hand, wearing helmets could disturb blood supply to the cortex. Some studies have indicated that reduced blood supply to the cortex might decline cognitive performance (Yew, Nation, & Initiative, 2017).

Although a significant decline was observed in the participants' cognitive performance, no significant differences were detected in their mental workload. This might be due to the subjective procedure used to measure mental workload. In other words, NASA-TLX used to measure the participants' perceptions of mental workload is more sensitive to the task rather than the physical features or the work environment (Galante et al., 2018). On the other hand, the lack of changes in mental workload further supports the findings related to reduced cognitive performance. More precisely, different levels of cognitive performance were registered in the three sessions, while the participants were using the same memory capacity. This further approves that helmet weight could affect working memory performance.

Like any other study, the present research suffered from some limitations. Firstly, the study was conducted in a simulated (rather than natural) environment. Therefore, interested researchers are recommended to investigate the effect of helmets with various weights in natural settings. Secondly, although some studies have mentioned the reliability and validity of the tests used, the most critical limitation is the uncertainty of the validity and reliability of tests used because it was not re-examined in the present study. Third, only cognitive tests were used in this study. It is better to use objective tests such as Electroencephalography (EEG) and Electromagnetography (EMG) to validate the results in further future studies.

5. Conclusion

This study examined the effect of helmet weight on cognitive performance and mental workload in a laboratory setting. Inspired by the findings of the previous studies, attempts were made to moderate the impact of heat (caused by wearing helmets) on cognitive performance. The results showed that the perceived mental workload was not influenced by helmet weight. However, cognitive performance significantly declined as a result of wearing heavier helmets. Furthermore, the perceived local fatigue in the shoulders and neck increased after wearing heavier helmets. Thus, manufacturers should consider helmet weight while designing helmets and developing the relevant standards. This study can be regarded as the launchpad for similar investigations in this area.

Ethical Considerations

Compliance with ethical guidelines

All ethical principles are considered in this article. The participants were informed of the purpose of the research and its implementation stages. They were also assured about the confidentiality of their information and were free to leave the study whenever they wished, and if desired, the research results would be available to them. A written consent has been obtained from the subjects. principles of the Helsinki Convention was also observed.

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Authors' contributions

Conceptualization and supervision: Reza Kazemi and Alireza Choobineh; Methodology: Reza Kazemi; Investigation, writing – original draft, and writing – review & editing: All authors; Data collection: Mojgan Zoaktafi; Data analysis: Mojgan Zoaktafi and Matin Rostami; Funding acquisition and resources: Reza Kazemi

Conflict of interest

The authors declared no conflict of interest.

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