Title: Can Helmet Weight Affect Cognitive Performance and Mental Workload? An Experimental Study

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To appear in: Basic and Clinical Neuroscience

Received date: 2019/04/7
Revised date: 2020/10/24
Accepted date: 2020/08/23

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Please cite this article as:

Choobineh, A., Rostami, M., Zoaktafi, M., & Kazemi, R. (In Press). Can Helmet Weight Affect Cognitive Performance and Mental Workload? An Experimental Study. Basic and Clinical Neuroscience. Just Accepted publication Oct. 24, 2020. Doi: http://dx.doi.org/10.32598/bcn.2021.1773.1

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Abstract

This study sought to examine the effect of helmet weight on cognitive performance and mental workload. Twenty participants were studied in three one-hour sessions. The participants were asked to read and work with computer under three conditions: while wearing no helmets, while wearing a helmet that weighed 800 g (A), and while wearing a helmet weighing 1500 g (B). “N-back” task and Continuous Performance Test (CPT) were employed to assess cognitive performance, while 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 as well as thermal comfort and fatigue in the head were measured. Moreover, the participants’ cognitive performance was gauged before and after the sessions. The findings revealed that helmet weight had a significant impact on cognitive performance (p<0.001). Nonetheless, no significant difference was detected in the participants’ mental workload before and after the intervention. It was thus argued that helmet weight could affect cognitive performance. Therefore, in designing helmets, the weight of the helmet should be considered as an important factor.

Keyword: Helmet, Cognition, Ergonomics, Workload, Mental fatigue
1. Introduction

Head is one of the most vulnerable body parts in the event of motorcycle accidents. In fact, 75% of mortalities in motorcycle accidents are caused by skull damages (Deck & Willinger, 2006). To prevent such damages, many countries have made it obligatory to wear helmets (Rueda, Cui, & Gilchrist, 2009). As a complex and dynamic mental activity, motorcycle riding requires utmost mental attention. This shows that failure in mental performance and cognitive errors constitute one of the major 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, many ergonomic studies have focused on optimizing helmets to protect against mechanical impact (Liu et al., 2008). Conversely, limited studies have concentrated on the impact of helmet 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.

A limited number of 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 the rise of skin temperature can lower complicated performances and hinder decision-making processes (Gaoua, Grantham, Raemaix, & El Massiou, 2012). It has also been demonstrated that wearing a helmet might increase the reaction time and decline mental performance (Hancock, 1983; Neave et al., 2004). Yet, some other studies have failed to detect any association between wearing helmets and cognitive performance. In the latest study, Bogerd et al. (2014) showed that wearing a helmet covering the entire face had a boundary effect on reducing cognitive performance even in hot environments (Bogerd, Walker, Brühwiler, & Rossi, 2014).

Taken together, the existing studies have attributed lowered cognitive performance to the heat on the scalp region. These studies, however, have failed to take other factors into account. Helmet weight, for example, is an important parameter in this regard. This factor, which has been reported as one of the reasons for riders’ reluctance to use helmets, leads to fatigue naturally (Faryabi, Rajabi, & Alirezaee, 2014). Although new technologies have been utilized to manufacture lighter helmets, many motor riders across the world still use heavy helmets. The weight of the helmet 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). To date, nonetheless, no studies have investigated the effect of helmet weight on cognitive performance and mental workload. The current study, therefore, aims to examine the impact of motor riders’ helmet weight on their cognitive performance and mental workload in a laboratory setting.

2. Materials and Methods

The sample size was estimated using G*Power 3.1. With an input a at .05, a medium effect size of .15, power of .90 the minimum sample size required for this study was 20. Twenty healthy male adults with the mean (SD) age of 26.4 (3.3) years and head circumference of 49-55 cm participated in this study. The individuals were excluded from the study if they used medications on a regular basis 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 so that they would feel thermally comfortable. The participants’ sleep schedules were also checked prior to each stage and attempts were made to ensure that they had slept for 7-9 hours before the study. Furthermore, to observe homogeneity, each participant used the same clothing during the three experimental sessions. Before the study, written informed consents were obtained from the participants and approval was gained from the Ethics Committee of Shiraz University of Medical Sciences.

2.2. Setup

The participants were seated in front of an air blowing fan in order to minimize the impact of thermal condition. Then, a 16-inch LCD screen with the resolution of 386*768 pixels was positioned opposite to 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 in which the measurements were carried out had an ambient temperature of 24(2) °C and a relative humidity of 46(3)%. Besides, the wind speed (vw) was set at 0.6 (0.1) ms⁻¹. During the experiments, the participants were alone in the room and had no contact with others.

2.3 Protocol and procedure

In each experimental session, the time of examination was kept constant to avoid the impact of the circadian rhythm. In order to reduce learning effects on the results, the participants took part in two familiarization sessions. 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 certain day of a week, with the three experiments being conducted within three consecutive weeks.

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 |
| 7 min | 40 min | 7 min |

NASA-TLX, heat comfort scale and fatigue scale

In the control session, the participants completed the experiment without wearing any helmets. In the two experimental sessions, however, they wore two different helmets weighing 800 gr and 1500 gr. Prior to the experiments, the participants’ head circumferences
were measured following ISO8559 (1989) and they were provided with helmets that corresponded to their head circumferences (Beazley, 1997). The visor and vents of the helmets remained closed during the experiments.

Before starting the experiments, the participants filled out a mood questionnaire (Monk, 1989). Furthermore, sleep duration and quality were measured for the night leading to the experiment using two items on Petersburg Sleep Quality Index (PSQI). 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 visual analogue scale. Moreover, the participants self-evaluated their mental workload through NASA-TLX index (Vitório, Masculo, & Melo, 2012).

The baseline phase; i.e., the initial seven minutes of each session, was allocated to providing some instructions, hence familiarizing the participants with the procedure for completing each particular experiment (Table 1). The participants also completed the cognitive tests (1-back and reaction time tests) 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. At the end, the participants completed the cognitive test battery.

2.4 Cognitive tests

2.4.1 N-back task

To assess working memory, use was made of the n-back test, which has been frequently used to evaluate memory performance (Cook, 2000). In fact, this instrument is used to determine the individuals’ ability to process, select, and save information in a short time period. The Persian version of N-back was used in this study. Cronbach α of the test was 0.76 in the previous study (Hatami, J., Hemmatian Borujeni, B., Abdekhodaie, E 2018). In the current study, the computer type and n=1 were employed since a previous research had indicated that 1-back test was sensitive to motorcycle helmet intervention (Cook, 2000). 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 participants were required to press the answer button on the keyboard immediately in case two consecutive numbers were the same. The number of correct answers and the response time (ms) were considered to be dependent variables.

2.4.2 Continuous performance test

Continuous performance test, as a reliable standardized computer test, has been widely used to assess sustained attention in the course of time. Cronbach α of the test was 0.76 in the previous study (Kasaeian, K., Kiamanesh, A., & Bahrami, H 2014). This test contained 150
visual stimuli (shapes and numbers) displayed on a computer screen, 20% of which comprised the target stimuli. The participants were required to identify these stimuli via pressing the space button on the keyboard. Every stimulus was displayed for 150 ms, with 500 ms intervals between every two consecutive stimuli. Commission error, omission error, and reaction time (ms) were regarded as the dependent variables of the test.

2.4.3 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 has been approved (α=0.897)(Mohammadi, Mazloumi, & Zeraati, 2013). This technique contained six subscales, namely 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, D. M., Masculo, F. S., & Melo, M. O, 2012). Finally, the index number of mental workload was calculated in the light of the weighted average of the given scores and the index values.

2.5 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 analogue scale was used to measure local fatigue in the head, neck, and shoulders.

2.6 Statistics and data processing

The collected data were analyzed by Statistical Package for the Social Sciences (SPSS), version 21 (SPSS Inc., Chicago, IL, USA). 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

3.1 Working memory

According to Table 2, the reaction times on the working memory task were not significantly affected by the helmet. In other words, there was no significant difference among no-helmet, helmet A (800 g), and helmet B (1500 g) modes. Furthermore, neither any significant ‘time’ effects nor any ‘helmet * time’ interactions on the reaction times could be observed.
Table 2. The results of repeated measures ANCOVA on helmet- and time-independent variables

| Performance variable       | Helmet F | Helmet p | Time F | Time p | Helmet * time F | Helmet * time 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            |

Concerning the indices of accuracy of the working memory task, Table 2 indicated that the mean number of correct responses was significantly influenced by the intervention type (F(2; 56) = 14.29, p<0.01). In contrast, the mean number of false responses was not affected by the helmet type.

The results of Bonferroni correct factor revealed a significant difference between helmet A and non-helmet modes (p=0.05) as well as between helmet B and non-helmet modes (p=0.01) regarding the mean scores of correct responses. Additionally, 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).

3.2 Sustained attention

Considering the sustained attention task, Table 2 revealed that the mean reaction times were not affected by the helmet type. In this respect, no significant differences were found among non-helmet, helmet A, and helmet B modes. In addition, there were 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 impacts on the mean number of errors for the sustained attention task.

The results of post-hoc analysis using Bonferroni correction factor revealed a significant difference between helmet A and helmet B (p=0.04) as well as 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.
3.3 Mental workload

The average rates (raw TLX) of NASA TLX were analyzed by mixed ANOVA. The results showed no significant effects of the intervention (F2, 38 = 2.30, p=0.11). Moreover, the results of analyses on the ratings of the single dimensions of NASA TLX showed no significant effects for NASA–TLX subscales (Mohammadi et al., 2013).

3.4 Fatigue perceptions

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 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).

![Figure 1. Changes in fatigue perception across the three conditions. Error bars indicate standard errors of mean.](image-url)

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 findings of cognitive performance test 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 those of the previous investigations (Bogerd et al., 2014; Neave et al., 2004). Nick Neave et al., (2007) for example, demonstrated that using helmets by cricketers reduced their cognitive performance. The major distinction between the present study and the above-mentioned one is that the latter attributed reduced cognitive performance to local temperature...
rise in the scalp region caused by wearing helmets. In the present study, however, 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 taken into account as a covariate in the statistical analyses. This means that 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 considerably, which eventually reduces cognitive performance (Şahana et al., 2015). Indeed, research has revealed that physical load and fatigue affected cognitive performance. For instance, Asuman Sahana et al. blamed physical fatigue for reduced blood circulation in the prefrontal cortex, which in turn 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, 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.

Limitations of the study and suggestions for further research

Like any other study, the present research suffered from some limitations. Firstly, the study was conducted in a simulated (rather than real) environment. Therefore, interested researchers are recommended to investigate the effect of helmets with various weights in real settings. Secondly, although some studies have mentioned the reliability and validity of the tests used, the most important limitation is the uncertainty of the validity and reliability of tests used in the study because it was not re-examined in the present study. Third, only cognitive tests were used in this study, and it is better to use objective tests such Electroencephalography (EEG) and Electromagnetography (EMG) to further validate the results in 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 take helmet weight into account while designing helmets and developing the relevant standards. This study can be regarded as the launch pad for similar investigations in this area.

Acknowledgement

This study was financially supported by the Health Sciences Research Center affiliated to Shiraz University of Medical Sciences. Hereby, the authors would like to thank Ms. A. Keivanshekouh at the Research Improvement Center of Shiraz University of Medical Sciences for improving the use of English in the manuscript.

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