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The Effect of Different Levels of Mental Fatigue on the Performance of Throwing of Skilled Handball Players

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Background: The speed and accuracy of performance are affected by various factors, including mental fatigue. The current study investigated the effect of two durations of 15 and 30 minutes' mental fatigue on the speed and accuracy of throwing performance in skilled men handball players.
Methods: The present study was semi-experimental with the participating of 45 skilled players (24.98 ± 3.66 years) who were randomly assigned to 15-minute, 30-minute mental fatigue, and the control group. Mental fatigue was induced by the Stroop task, and the accuracy of the throwing, hit percent, and speed of performance were measured before and after the induction of mental fatigue. Data were analyzed using mixed analysis of variance with repeated measure.
Results: Throwing speed and accuracy, as well as the Hit percent, decreased in both groups after 15 and 30 minutes of mental fatigue ($P<0.05$). In the two groups of 30 and 15 minutes of mental fatigue, no significant difference was observed in the decrement of throwing accuracy ($P<0.05$).
Conclusion: The impact of mental fatigue goes beyond specialized technical performance in a sport, and any decline in performance due to mental fatigue is likely related to motivational issues. Also, mental fatigue causes attention to be diverted from target stimuli to stimuli that are irrelevant to task performance, leading to a reduced capacity to tight control over the primary task. To protecting the accuracy of performance in tasks require speed, mental activity of the athlete should be avoided before the performance.

1. Introduction

Speed and accuracy have permanently been an integral part of success in sports performance of team and ball sports and are known as the distinguishing property of superior athletes (Magill, Richard, Anderson, 2022). In sports with ever changing environments, players often required to make quick and accurate decisions based on the location of the ball and the actions and movements of teammate and opposing players, while their decisions and action are depends on mental, physical, technical, and tactical factors and other environmental factors context that influencing performance in different ways (Magill, Richard, Anderson, 2022; Shahbazi et al., 2012; van der Linden et al., 2003). These require long-term vigilance, decision-making and continuous information acquisition and processing, which seems to be influenced by fatigue. Considering the cognitive nature of the mentioned components, it seems that the mental aspect of fatigue that may arise during the game has a more special effect on performance (Marcora et al., 2009; Pageaux & Lepers, 2018). Fatigue is defined as a decrease in the ability and efficiency of mental and/or physical activities caused by excessive activities (Pageaux & Lepers, 2018; Phillips, 2015). In other words, fatigue refers to a decrease in energy level and is divided into two types: physical and mental fatigue (Ishii et al., 2014). Mental fatigue is a psychobiological state that is caused by continuous periods of cognitive activities that require mental effort and a feeling of fatigue and lack of energy (Dahl, 2013; Phillips, 2015). For fatigue, regardless of its type, have several underlying mechanisms, including energy reduction and hormonal changes and functional mechanisms (Boksem & Tops, 2008), physiological responses of the nervous structures (Kunrath, Cardoso, et al., 2020) and many other factors(Ishii et al., 2014). Although the underlying neural mechanisms of physical fatigue and diseases or syndromes related fatigue are known to some extent, knowledge about the underlying neural mechanisms of mental fatigue is more limited and still debatable (Habay et al., 2021; Tanaka et al., 2012). The regressive effect of mental fatigue on technical sport performance was confirmed in research literature(Badin et al., 2011; Smith et al., 2016, 2017). Studies has reported that mental fatigue threaten executive functions and the ability to maintain attention to key cues, performance adjustments, rapid and accurate response, and interpretation of meaningful cues in the visual field (Boksem & Tops, 2008). Therefore, mental fatigue can be a threat to athletes' performance in team sports, like handball, because in such sport, the athlete's technical performance is based on interpersonal coordination, decision-making, and speed in executing skills (Marino, 2019).

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Previous studies showed that mental fatigue impairs specific physical, technical, and perceptual-cognitive performance of athletes in different fields (Van Cutsem et al., 2017), endurance performance, movement skills performance, and decision-making performance (Ishii et al., 2014; Martin et al., 2018; Russell, Jenkins, Rynne, et al., 2019; Russell, Jenkins, Smith, et al., 2019). Even though, in other studies; it has been shown that-for example-maximum power was not affected by mental fatigue (Budini et al., 2014). The study of Penna et al. (2018) did not show the effect of mental fatigue on the heart rate and blood lactate of elite handball players (Penna et al., 2018). Results show that mental fatigue reduced peripheral vision and limited offensive and defensive tactical behaviors of soccer players (Kunrath, Nakamura, et al., 2020). Also, Various technical, tactical and physical indicators of football in small field games more or less indicate a tangible reduction due to mental fatigue (Kunrath, Cardoso, et al., 2020; Kunrath, Nakamura, et al., 2020; Moreira et al., 2018).

In general, most researches examine football performance, and often performance indicators have been examined as a dependent variable (see the review study by Kunrath et al., 2020). In some other sport, including table tennis (Le Mansec et al., 2018), basketball (Moreira et al., 2018), and cricket (Veness et al. 2017), the effect of mental fatigue has been investigated too and their results have been somewhat different. Smith et al. (2017) showed that mental fatigue does not hinder the passing speed, but it decreases its accuracy and the performance error increases due to cognitive effort (Smith et al., 2017). In another study, the effect of mental fatigue was not seen on some functional motor tasks (Veness et al., 2017). Thoroughly, in previous studies, the duration of fatigue induction has been induced in different durations and intensities; 90 minutes (Le Mansec et al., 2018; Marcora et al., 2009), 60 minutes (Kosack et al., 2020), 40 minutes (Fortes et al., 2021) or 40 minutes (Badin et al., 2016; Smith et al., 2017).

Generally, it seems that the impact of mental fatigue at different levels should be compared in a single experiment in order to compare its separate effects with more certainty. On the other hand, the measurement of throwing accuracy and speed as a dependent variable have been investigated distinctly in previous researches (Izadi et al., 2020). To investigate the effect of mental fatigue on these two variables, a concurrent task must be designed and the measurement of both variables in one task. Handball, as a sport where the success is largely depended on speed and accuracy of throwing (Wagner et al., 2014) as a upper limb motor task, has received less attention, unlike previous studies that examine football task that used lower limbs than required a gross movement to run. Therefore, we intend to investigate these issues in the present study. Subsequently, reviewing the available literature, most of the studies considered football performance and there are many articles that have examined these skills and various performance indicators in handball. It seems that due to the difference in the characteristics and skills required among different team sports, it is not indisputable to generalize the aforementioned results to other sports with certainty. Therefore, it is necessary to conduct a study in sport that requires the implementation of open skills, and the present study examines this issue in handball.

2. Materials and Methods

2.1. Subjects

The participants were 45 male handball players (24.98 ± 3.66 years) who volunteered to participate in the study and were randomly assigned to two experimental groups- 30-minute and 15-minute mental fatiguegroups, and a control group (n=15 players for each group). Communication with the participants was done through their club coaches. The entering criteria of study include physical and mental health, participation and activity in handball practice, the covid-19 vaccination card, and the exclusion criteria also include injury, having symptoms of the disease (especially symptoms of Covid19), and unwillingness to participate voluntarily. The participants were asked to have regular sleep patterns on the days of the experiments. All participants signed the written consent form. Random distribution of participants in groups was done with the help of "www.randomizer.org" website (Gantois et al., 2020). Research Ethics Committee certificate of Islamic Azad University of Ahvaz Branch, approved the study procedures and interventions (approval ID: IR.IAU.AHVAZ.REC.1401.150). All Participants gave written, informed consent to participate in the experiment according to the guidelines of aforementioned Committee.

2.2. Apparatus and task

Measurement of the throwing Performance. To measure the accuracy of the handball throwing, the test adopted from the study of Nuño et al. (2016) was used (Nuño et al., 2016). In these six circles targets with circular dimensions were designed on the wall of the court and the participants had to throw the ball towards the target at 7 meters distance. The target consists of three concentric circles, the outset circle is a circle with a diameter of 150 cm and the central is a 50 cm circle, between these two there is a circle in diameter of 100 cm. The ball was thrown to each target twice, and move to next target clockwise until doing a total of 12 consecutive throws. The accuracy of the throw relative to the target was recorded by the assessors, with a score between 1 and 3 (hitting the center circle was given 3 points, hitting the middle and outer circle 1 and 2 point respectively and missing the target were given zero points).

To measure the speed of performance in total 12 throws, the participants were asked to throw the balls towards the target with no stop as quickly as possible. Once the first ball hits the target (or wall), the timer starts and it stops when the last ball hits. The total time of completing 12 trials was recorded as duration and speed score in millisecond. Furthermore, another variable was computed as the hit percentage or the percentage of successful throw which included the number of passes that hit the target compared to the total number of passes sent (12 throws) (Veness et al., 2017). Standard ball was used, according to the standards of the World Handball Federation (with a circumference of 58 cm and a mass of 475 grams). Tests were conducted in a standard handball court and participants used to wear appropriate handball clothe. Before performing the field tests, the participants had 10 minutes to warm up and prepare for the tests under the supervision of the sports coach and the research associate.

Inducing mental fatigue. Mental fatigue was induced using modified Stroop color–word task and through playing words and colors. During this intervention, participants would say the color of words (red, blue, green, and yellow) that were presented in random order (Mun et al., 2014). Research's examiner monitored the participants' verbal responses. Participants were asked to answer as many correct words as possible. In case of making a mistake, the examiner warned and resume the activity (Badin et al., 2016; Smith et al., 2017). Control group players watched 30 minutes of a documentary film. This documentary was selected based on its attractive yet emotionally neutral content and was technically unrelated to the research objectives, according to previous studies (Badin et al., 2016).

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Subjective Measurement of the mental fatigue. Before and after the fatigue inducing intervention, mental fatigue was measured through a subjective estimation by participants. Mental fatigue of the participants was assessed similar to previous studies in an Visual analogue scale (VAS) method (Badin et al., 2016) used in the study of Badin et al. (2016) and Smith et al. (2016, 2018). The 100 mm analog line for estimating mental fatigue is marked at one end "not at all" and at the other end with "max." The participant should mark his mental fatigue on the line. They assigned a point to their mental fatigue from 0 to 100 with 10 value intervals (Smith et al., 2018).

2.3. Procedure

After the participants were identified regarding the criteria for entering the study, they were present at the place where the tests were implemented. The participants were asked to avoid vigorous exercise at least 24 hours before the experiments and to eat a regular meal at least 2 hours before the experiments time. Before the beginning of the tests, the participants have the opportunity to warm up for 10 minutes on the handball court under coaching of the qualified coach. The warm-up of the participants was general and specific using ball. After the warm-up, they got ready and completed 10 familiarization throw and then performed a pre-test consisting of making 12 throws to 6 determined circle goals in the shortest possible duration.

After the pre-test, participants were randomly assigned to the groups. Then, corresponding to their experimental group, they took part in the mental fatigue induction activities or control condition. The experimental groups should perform the word and color Stroop task for the determined durations for each experimental group (15 and 30 minutes). The control group also watched an irrelevant neutral movie (Badin et al., 2016). After participating in this mental fatigue intervention, the participants estimated their mental fatigue using an analog line. After the mental fatigue induction intervention, the participants were again performed the test as they did in pre-test. The scores of each section were entered into statistical analysis.

2.4. Data Analysis

All dependent variables were expressed as a mean ± standard deviation. Prior to analysis, the normality of data distribution was checked using the Shapiro-Wilk test and also data examined for homogeneity using Levene's test. One-way ANOVA was used to compare groups in pre-test. 3 (fatigue) ×2 (time) mixed ANOVA were used at the depended variables (accuracy score, hit percent, and speed of performance). In case of a significant F value was detected for interaction between factors, one way ANOVA was used to compare groups in post-test. Tukey post-hoc test was used to pairwise comparisons. The data analysis was performed using the IBM SPSS Statistics software (v. [26], New York, U.S.A.) at significance level of $P \leq 0.05$.

3. Results

To ensure groups homogeneity in the pre-test, a comparison was made using. The results of one-way ANOVA showed that difference between the groups in the pre-test in the variables of throwing accuracy score ($f_{(2, 42)} = 0.07$, $p=0.93$), hit percent ($f_{(2, 42)} = 0.36$, $p= 0.69$), and speed of performance ($f_{(2, 42)} = 0.01$, $p= 0.98$) was not significant. VAS rating of mental fatigue of experimental groups before and after inducing Stroop task was reported in table 1.

A significant group × time interaction existed for VAS estimation of subjective mental fatigue ($F (2, 42) = 4.34$; $P = 0.019$; $\eta^2_p = 0.17$). Result of one way ANOVA showed no difference between group in pretest subjective rating of mental fatigue ($f_{(2, 42)} = 2.14$, $p= 0.13$) but one-way ANOVA revealed higher post-test ratings of subjective mental fatigue ($f_{(2, 42)} = 19.77$, $p= 0.001$) in the experimental group than control group (30 min. group vs control $p=0.001$, 15 min. group vs control $p= 0.001$) and no difference between tow durations of mental fatigue ($p= 0.37$) (table 1).

Table 1.
Descriptive statistics (Mean± S.D) of dependent variables in the pretest and posttest.

Variables	Groups	Pre-test (M± Sd)	Post-test (M± Sd)
Accuracy score	30-min mental fatigue	70.33±11.57	50.67±10.33
	15-min mental fatigue	70.67±8.21	55.33±14.57
	control	69.33±10.50	70.33±10.26
Hit percent	30-min mental fatigue	77.22±10.19	61.67±7.59
	15-min mental fatigue	77.22±8.01	64.44±9.69
	control	76.67±11.87	76.67±8.45
Speed of performance (S)	30-min mental fatigue	14.64±2.71	17.41±2.38
	15-min mental fatigue	14.67±2.74	17.28±2.76
	control	13.96±2.21	13.41±2.77
VAS	30-min mental fatigue	22.33±9.80	43.00±12.07
	15-min mental fatigue	23.33±10.15	34.67±10.08
	control	23.0014.61	22.00±12.07

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Throwing accuracy. The results of 3 ×2 (fatigue × time) mixed ANOVA showed significant main effect of time ($f_{(2, 42)} = 178.78$, p= 0.001, η^2_p= 0.82) and the interaction effect of fatigue and time ($f_{(2, 42)} = 58.44$, p= 0.001, η^2_p= 0.73). Post hoc comparisons showed no difference between two mental fatigue groups (p=0.90) but both mental fatigue groups were have lower scores than control in post test (p=0.01, p=0.001).

Hit percent. The results of 3 ×2 (fatigue × time) mixed ANOVA showed a significant main effect of time ($f_{(2, 42)} = 39.59$, p= 0.001, η^2_p =0.48) and interaction effect of fatigue and time was also significant ($f_{(1, 42)} = 4.53$, p= 0.01, η^2_p= 0.18). Post hoc comparisons showed no difference between two mental fatigue groups (p=1.00) but both mental fatigue groups were have lower hit percent than control in post test (p= 0.009, p=0.003).

Speed. Total duration that all 12 throws lasted was used as index for speed of performance. The results of 3 ×2 (fatigue × time) mixed ANOVA showed a significant main effect of time ($f_{(2, 42)} = 58.28$, p=0.001, η^2_p =0.58) and interaction effect of fatigue and time was also significant ($f_{(1, 42)} = 26.83$, p=0.01, η^2_p = 0.56). Post hoc comparisons showed no difference between two mental fatigue groups (p= 0.99) but both mental fatigue groups were slower than control in post test (p=0.001, p=0.001).

4. **Discussion and Conclusion**

The present was aimed study was to investigate the effect of mental fatigue on the throwing technical performance of expert handball players, emphasizing the two components of performance, including accuracy and speed. Too many factors are modulate human motor performance in sport sets at different level of analysis (Pashabadi & Jamshidi, 2021). According to the findings, both accuracy and speed components of handball throwing showed a significant decrement attributable to fatigue. In literature of this area, outside the laboratory, motor control is traditionally investigated with tests that include the implementation of specialized sports-technical skills in a specific sport. Since mental fatigue alters accuracy and speed, it is likely that more complex technical-sports skills such as throwing handball, soccer or shooting are also impaired. Previously, Smith et al. (2016) observed a decrease in shooting speed and accuracy in soccer players (Smith et al., 2016). Other studies also confirmed the decline in technical performance due to mental fatigue (Badin et al., 2016; Smith et al. 2016, 2017). Another important issue is that the effect of mental fatigue goes beyond specialized technical performance in one sport; Previous studies showed decrease in ball speed and accuracy in the table tennis forehand (Le Mansec et al., 2018), decrease in the performance of technical skills in cricket (Veness et al., 2017), and in soccer (Smith et al., 2016).

Players also had a significant decrease in throwing accuracy after participating in mental fatigue-inducing tasks in both fatigue durations of 30 and 15 minutes. In the comparison of two groups of 30 and 15 minutes of mental fatigue, no significant difference was observed in the decrement of throwing accuracy and both mental fatigue groups were have lower scores than control in posttest. It can be suggested, performing the Stroop task requires more mental demands and requires more mental effort than watching a neutral movie, so significantly caused mental fatigue (Boksem et al., 2006; Hopstaken et al., 2015; Rozand et al., 2015). However, mental fatigue caused by being active in the Stroop task in two different periods of 30 and 15 minutes did not show a significant difference in the amount of decrement in throwing accuracy. Cognitive effort can lead to a decrease in performance by decline motivation (Hopstaken et al., 2015; Marcora et al., 2009). However, to rely on this statement, one should be more cautious and it is necessary to emphasize that the motivational changes affecting performance due to states of mental fatigue may depend on the activity or skill is performed, the interest and expertise of the participants and the individual differences. In any case, the study of Smith et al. (2017) suggests that any drop in performance due to mental fatigue can be attributed to motivational factors, although the current study does not confirm such a claim but it seems that factors other than motivational factors could be the reason for this destructive effect. On the other hand, regardless of throwing speed, participants made more aiming errors during their 12 throws after mental fatigue. In fact, although different participants completed the specified number of throws at different times, they missed a greater number of these throws. This finding supports previous suggestions by researchers such as Badin et al. (2016) that mental fatigue may exacerbate the decline in short passing performance observed during competition (Badin et al., 2016). Also we our findings suggest that handball throwing accuracy may have decreased due to the speed-accuracy trade-off, as players faced this performance drop by maintaining speed at the cost of losing accuracy(Rozand et al., 2015).

Despite the lack of research on mental fatigue and performance based on specific skills in handball, research near to this study points to some potential mechanisms behind the observed performance impairments. For example, mental fatigue is strongly related to the capacity of attention and concentration. Indeed, mental fatigue has been shown to refocus attention from target stimuli to stimuli that are irrelevant to task performance, leading to a reduced capacity for greater control over the primary task (Smith et al., 2016). Therefore, in the present study, it is possible that performance under mental fatigue was impaired due to a reduction in the amount of attention devoted to the task. Central resource capacity theories of attention suggest that when concurrent activities compete for attention, it ensures that attention is focused on completing the primary task (Magill, Richard, Anderson, 2022). This theory appears to be consistent with the findings of the current research, whereby mentally fatigued participants were unable to maintain their performance accuracy at an optimal level.

The present findings on the decrease in speed due to mental fatigue were in contrast with the recent research of Smith et al. (2017) and similar to the findings of Rozand et al. (2015). While in the current study, both accuracy and speed components faced a significant drop. In the findings of Rozand et al. (2015), that investigated the effects of mental fatigue on the speed-accuracy trade-off in tasks with different difficulty indexes, mental fatigue increased actual and perceived movement time (decreased speed). There are inconsistencies between the above mentioned studies and the present study, among which the important difference between the two studies was the emphasis on speed and accuracy (Gantois et al., 2020). Although participants in both studies were asked to complete the respective trails of task as quickly and accurately as possible, task constraints likely resulted in an emphasis on speed or accuracy. As an example of the study of Rozand et al. (2015), in the hitting tasks, if he made two consecutive errors in hitting the target and missed the target ball, the test was canceled. In contrast, in Smith et al.'s (2017) experiment, final score was a time-based measure, and Slowing down in performing the trials with the intention to enhance accuracy, resulted in additional penalty time, and as a result, participants knew that if they -in order to emphasize the accuracy-, they reduce the speed of their actions and perform more slowly, they will lose score totally, so they emphasized on speed and they already knew that it is better to complete the various efforts of the task faster in order to get maximum points. In the

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present study, the speed of completing the trials was considered as a distinct variable and the participants had a separate time score in terms of speed in addition to accuracy. Altogether, these findings suggest that there is a speed–accuracy trade-off when completing skills requiring speed–accuracy under conditions of mental fatigue, in which the performance of one task goal is not at the expense of the other goal. Therefore, the participants of the present study, like the study of Rozand et al. (2015), should keep a middle ground between accuracy and speed during the continuous effort and not sacrifice one for the other.

Future research should directly assess whether handball and competition in this sport are mentally tiring? However, it is recommended that players avoid mentally exhausting activities before a match to maintain their ability to make accurate throws that are critical to success. By summarizing the results obtained from this study and the experiments mentioned in the literature section of the current research (including the review study by Pageaux and Lepers (Pageaux & Lepers, 2018) studies that focus on things such as the performance of the upper limbs (such as blows table tennis and cricket and handball) as well as lower limbs (such as soccer Kick accuracy), had been done. It seems clear that mental fatigue impairs the execution of certain sports-related techniques. With the interpretation that mental fatigue differentiates the performance of both upper and lower limbs, it is possible that the reducing effects of mental fatigue can be extended to other sports/motor skills. Therefore, thoroughly we suggest avoiding long-term cognitive tasks before competitions. We also suggest that to prevent the negative impact of mental fatigue on performance during sports events, coaches should consider specific technical training in the presence of mental fatigue to train athletes to cooperate with the presence of mental fatigue.

It is also possible that training in the condition of mental fatigue reduces its negative effect on performance. Indeed, recent research has shown that professional athletes, such as cyclists, are more resistant to mental fatigue, possibly due to their constant exposure to situations that require self-regulation (Nuño et al., 2016). Therefore, the effectiveness of training in mentally exhausting conditions to improve technical performance in handball should be investigated in future researches. This finding has significant implications for executive settings during sports performance where players have limited time to control and throwing the ball due to game pressure. This issue can be the source of mental fatigue of handball players. Therefore, if a player is under pressure from the opponent and is mentally tired at the same time, the drop in accuracy and speed in his throws and shots is more expected. Therefore, it can be suggested that towards the end of a match, when players are likely to be mentally fatigued, a more conservative strategy (i.e. throwing to a player whom not under pressure from the opponent, rather than risking a throw to a teammate is in a pressured position) is possible. Conversely, a team that does not have possession of the ball may benefit from implementing a strategy of increasing pressure time on the player in possession, could take advantage. Current findings also recommend the importance of training under mental fatigue conditions and variety in different situations of handball game. Especially the conditions that require the players to perform precise movements while under the pressure of space and time are emphasized more.

Conflicts of interest

The authors declare there is no conflict of interest.

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