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Errorless Training Improves Performance Even Under Conditions of Cognitive and Physical Fatigue

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A B S T R A C T

Background: For many years the negative effects of fatigue on performance have been studied. Fatigue can deteriorate different factors in the performance of learned motor skills. This research was undertaken to elucidate the effect of errorless training on the performance of a throwing task in non-fatigued, cognitively fatigued, and physically fatigued conditions.
Methods: 16 subjects (males: n= 6 and female: n=10) (age mean: 29 ± 5.63) participated in the acquisition phase, the participants performed 5 blocks of 30 trials of a two- step ball throwing task, starting close to the target, and gradually moving away. 48 hours later, the participants first took part in a retention test of 10 throws, and then, after a mental fatigue protocol of 30 minutes of word-color Stroop test, the first transfer test (10 trials) was taken. 48 hours later, the participants made another 10 trials (transfer 2) after the physiological fatigue protocol (maintaining 50% MVC for 2 minutes).
Results: The results of ANOVA with repeated measure showed a significant difference between performance in the retention test and the two transfer tests ($p<0.05$). Bonferroni test showed better performance in the transfer 1 ($p= 0.002$) and transfer 2 ($p= 0.003$) tests compared to the retention). No significant difference was observed between the two transfer tests ($p=1.000$).
Conclusion: Not only did the performance of the throwing task learned through errorless training not deteriorate with fatigue, but it also improved compared to the non-fatigued condition. It is suggested that people specially athletes and coaches to leverage the errorless training method when designing training courses to prevent the deterioration of performance.

1. Introduction

For many years the negative effects of fatigue on performance have been analyzed and studied (Davey, Thorpe, & Williams, 2002; Penna et al., 2018). Fatigue has mostly been considered as an external imposition on the central nervous system, or lower level structures, such as muscular efficiency and cardiac output, causing a decrease in motor performance. Fatigue can be classified into cognitive, physical, central, local, global, and environmental types. Cognitive fatigue is defined as a drop in cognitive resources, caused by prolonged time on task, and increasing with time (Boksem & Tops, 2008). This psychobiological state is known by feeling the loss of energy (Marcora & Staiano, 2010). Cognitive Fatigue increases the rate of perceived Exertion (PRE) by affecting Anterior Cingulate Cortex (ACC) region (Daskalakis, Lehrner, & Yehuda, 2013). The ACC takes part in some cognitive control tasks like attention allocation, anticipation, decision-making and error detection which would be disrupted by cognitive fatigue. Physical fatigue is defined as any decrease in force produced by a muscle or muscle group, as a result of chemical and metabolic changes, caused by long task durations or repetition of a task (Taylor, Amann, Duchateau, Meeusen, & Rice, 2016). It could also be defined as the inability to preserve recalled power or continue the specific intensity of sports activity (Booth & Thomason, 1991).

Since fatigue is an inescapable response of the body to task repetition and long task duration, mitigating its effects is a hot research topic. Cognitive fatigue results in a drop in the performance of learned skills, as a result of a decrease in neuro-motor commands from the motor cortex to motor units, and muscular efficiency (Bishop, 2012). Furthermore, cognitive fatigue results in high cognitive loads on the working memory, deteriorating accuracy, and response time (Penna et al., 2018). It has been observed in numerous studies that cognitive fatigue can deteriorate different factors in the performance of learned motor skills, e.g. Speed, accuracy, coordination (Coutinho et al., 2018). Moreover, in physical fatigue conditions, after prolonged motor tasks, the serotonin accumulated in neural synapses extends muscle contractions (Perrier & Delgado-Lezama, 2005). Further extension of activities results in the overproduction of serotonin and inhibition of muscle contractions, deteriorating performance. Fatigue induced deterioration of performance is also caused by physiological factors, such as high lactate concentrations in blood, Adenosine Tri Phosphate (ATP) deficiency, and dehydration. These factors are directly related to psychological conditions, such as perceptual narrowing, which deteriorates motor performance in its own right (Poolton, Masters, & Maxwell, 2007). In this research, we aim to analyze the effects of

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a well-known training method on performance under fatigue conditions.

Errorless training, which results from designing training courses in such a way that would minimize errors and hypothesis testing while learning, taps into implicit memory resources. The reasoning behind the selection of errorless learning for this study is its relative advantages over some other implicit learning methods. For instance, performing secondary tasks is another implicit learning method which makes it more difficult for the learner to obtain explicit knowledge. The errorless method, in comparison, accesses implicit memory resources by limiting task errors, resulting in an easier training method (A. Lola, Giatsis, Pérez Turpin, & Tzetzis, 2021). This method prevents the accumulation of explicit knowledge by limiting errors, enabling subjects to store information in an implicit, non-declarative manner (Gentile, 1998). The "reinvestment theory" (Masters, 1992) states that minimizing conscious processes during the preliminary steps of learning decreases performance deterioration and the probability of regression and conscious processing, under pressure or after a period of not exercising, resulting in a smaller deterioration of performance (Masters & Maxwell, 2004). These conditions are created using different practice methods, including errorless training.

The resilience of implicit processes against high cognitive loads has been verified time and time again in the learning under pressure literature (Hardy, Mullen, & Jones, 1996; Lam, Maxwell, & Masters, 2009). One recent study has shown that extreme mental fatigue can facilitate a sequence generation task learned using the procedural learning method (Borragán, Slama, Destrebecqz, & Peigneux, 2016). Since the effects of fatigue on motor performance has not been studied as much as the its effects on the performance of cognitive tasks, in this research, we analyze the performance of a two-step ball throwing task under fatigue conditions. Furthermore, even though cognitive and physical fatigue are structurally and causally different, the effects of this difference on performance have not been analyzed before, we aim to analyze the difference in performance under these two different fatigue conditions. The results of this study are expected to help coaches and athletes design suitable training courses, especially for sports that involve ball throwing.

2. Materials and Methods

2.1. Subjects

16 males (n= 6) and female (n=10) (age mean: 29± 5.63) took part in this study. All participants were right handed, and healthy in terms of vision, movement, and psychological profile. The sleep quality of the participants was controlled using the Pittsburgh sleep quality questionnaire. People who did not obtain satisfactory scores on the sleep quality questionnaire or had a history of psychological or physical problems were removed from the study. The participants were informed about all of the study steps, and written informed consent was obtained from them before the study. This research was approved by the ethics committee of Shahid Beheshti university (Ethical code: IR.SBU.REC.1399.056).

2.2. Apparatus and Task

Two step ball throwing task: The two step ball throwing task, validated by Singer was utilized to implement the research protocol (Singer, Lidor, & Cauraugh, 1993). The test consists of two target areas. The first one was on the ground and the second one was the target board with 10 concentric circles. The ball had to make contact respectively to the both of target areas. The participant received 1 to 10 points, depending on the point the ball made contact with the second target.

Modified color-word Stroop test software: The Stroop test is based on the observation that individuals can read words much faster than they can identify and name colors. In order to induce cognitive fatigue according the pilot test, 30 minute of Stroop task was utilized.

N-back test software: The n-back task is a continuous performance task that is commonly used as an assessment in psychology and cognitive neuroscience to measure a part of working memory and working memory capacity. In order to ensure cognitive fatigue, this test was used before and after the cognitive fatigue protocol (Lorist et al., 2000).

Visual analogue scale of fatigue (VAS-F) self-report index: To assess subjective levels of cognitive fatigue (Lee, Hicks, & Nino-Murcia, 1991).

SAEHAN manual dynamometer: According to (Khalkhali, Bazrafkan, Khademi Kalantari, & Rezasoltani, 2012) the maintaining 50% of the maximum voluntary contraction (MVC) of their dominant hand, in elbow extension was used in order to induce physical fatigue.

Borg scale of perceived exertion: To assess subjective levels of physical fatigue we used of self-report scale Borg (Borg, 1998).

Camera: iPhon 5s mobile camera to record and score the task.

Pittsburgh sleep quality index (Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989): Because of important effect of sleep quality on cognitive functions, Pittsburgh index was used to ascertain the sleep quality of the participants.

2.3. Procedure

A pilot test was undertaken before the main study protocol in order to validate the test and accustom the experimenter with it. Two participants (one male, one female) took part in the pilot study which contained all the steps of the main study. During this pilot study, a 30 minute stroop test was deemed enough to induce cognitive fatigue. Furthermore, we used this pilot study to ascertain the effectiveness of the physical fatigue protocol.

The two step ball throwing task, utilized two target areas. The first target area was a 60cm by 60cm designated area on the ground, with which the ball had to make contact before hitting the second target (the target board). The first target area and the target board were 80cms apart. The target board was comprised of 10 concentric circles, each with a diameter 3cms larger than the one before it. The ball had to hit both the first target area and the target board, and if it failed to hit either of the two, the participant received no points. If the ball hit both the first target area and the target board, the participant received 1 to 10 points, depending on the point the ball made contact with the target board. The whole process was filmed by a camera and after the session the recorded film was reviewed precisely then scored based on contacted point. In order to prevent ceiling effects, and considering the fact that the participants were all amateurs, pre-testing was foregone in this study (Maxwell, Masters, Kerr, & Weedon, 2001). The rationale for this was the fact that pre-testing from small distances to bull's eye (less than 2.50 m) would give the participants explicit knowledge of the task.

The protocol for this study included one acquisition session and two test sessions included retention and two transfer tests (under cognitive and physical fatigue), with 48 hours between every two sessions. During the first session, the participants were given 5 warm-up throws, and then proceeded to make 5 blocks of 30 throws, starting from 2.5m away from the bull's eye, and gradually moving away, with the final block of throws performed from 3.50 m away from the bull's eye. During the second session, the participants took part in a retention test (10 throws from 3m away from the bull's eye) and proceeded to the first transfer test after 30 minutes of stroop testing (to induce cognitive fatigue, as per the cognitive fatigue

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protocol). 3 minutes of N-back tests, along with the VAS-f scale were used to verify cognitive fatigue. A decrease in N-back performance, as well as the VAS-f results, were taken as validation of the cognitive fatigue protocol.

During the third session, the participants were told to hold 50% of the maximum voluntary contraction (MVC) of their dominant hand, in elbow extension (Khalkhali, Bazrafkan, Khademi Kalantari, & Rezasoltani, 2012). The MVC of the participants was assessed before and after the fatigue protocol using the same dynamometer. They had been encouraged to do their best power compared to the other participant. A drop of 18% or more in MVC was taken as a validation of physical fatigue (Lepers, Maffiuletti, Rochette, Brugniaux, & Millet, 2002). Borg self-report scale was utilized in conjunction with MVC measurements to improve the accuracy of the study. Finally, after the induction of fatigue in the participants, they took part in the second transfer test (10 throws, 3m away from the target board).

2.4. Data analysis

Descriptive and inferential statistics were used to analyze the data obtained from this study. analysis of variance (ANOVA) with repeated measures was utilized to compare the retention, transfer 1 (Cognitive Fatigue) and transfer 2 (Physical Fatigue) test results. Also repeated measures ANOVA was utilized to compare between the 5 acquisition blocks.

3. Results

The Shapiro-Wilk test was utilized to ascertain the normality of the data (p= 0.15), and the Levene test was used to assess the equality of variances (p>0.05).

3.1. Cognitive and Physical Fatigue

Dependent t-test results showed the significance decrease on MVC and N-back after the physical fatigue protocol **(Table 1).**

Table 1.
Average (Mean±SD) *MVC and N-back Measurement before and after the Fatigue Protocols*

Measurement	Pre	Post	Df	t	Sig
MVC	26.90 ± 4.69	21.03 ± 3.69	16	17.985	0.0001
N-back	0.92 ± 0.16	0.72 ± 0.02	16	3.07	0.004

3.2. The Acquisition Phase

Repeated measures ANOVA between the 5 acquisition blocks did not demonstrate significant difference between the blocks (p=0.330, F=1.177, eta= 0.073). In the comparison between the blocks, it was observed that the best results were obtained in the second block and the worst results were obtained in the fifth block. Considering that the test becomes more difficult in higher blocks, these results can be justified (**Figure 1**).

3.3. The retention and the two transfer tests

The results of ANOVA repeated measure demonstrated a significant difference between the performance of the participants in these tests ($F_{(2,30)}$=11.169, p=0.000237). The Bonferroni test results showed significant difference between the performance of the participants in retention with transfer 1 (p=0.002) and transfer 2 (p= 0.003). However, no significant difference observed between two transfer tests (p=1.000). The performance of the participants during the three tests is presented in **figure 2**.

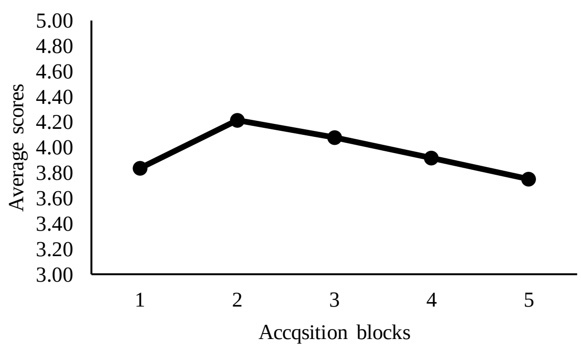

Figure 1. *Average scores in the acquisition blocks*

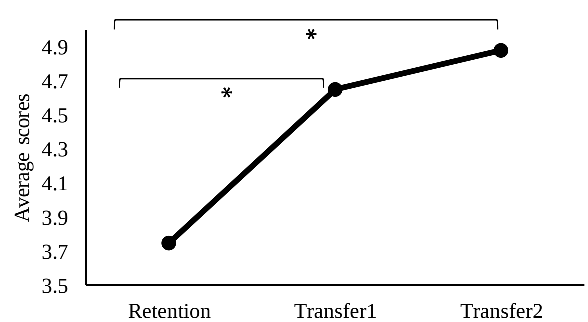

Figure 2. *Average scores in the retention, transfer1 (Cognitive Fatigue) and tranfer 2 (Physical Fatigue)*

Note*: * significant difference at the P≤0.05*

4. Discussion and conclusion

The results of this study demonstrate no deterioration in performance and are in line with learning under pressure literature (Borragán et al., 2016; Hardy et al., 1996). This research shows that with an increase in cognitive loads of a task (e.g. with stress or fatigue) and accumulation of information in working memory, the implicit memory resources can keep up performance, resulting in no deterioration in performance. Furthermore, (A. Lola et al., 2021; A. C. Lola & Tzetzis, 2021) show the independence of the implicit memory from working memory resources, and the versatility of non-declarative processing mechanisms against cognitive load, confirming the findings of this study. Evolutionarily older processes are intrinsically more robust against disruptions in comparison to younger processes. The neural processing behind implicit learning are evolutionary older and more robust than those behind explicit processes. Hence, the fact that implicitly learned skills are unaffected by fatigue is justified (Poolton et al., 2007).

The similarities between cognitive and physical fatigue mechanisms in affecting the central nervous system can explain the similarity in their effects on performance, and the insignificance of the difference between the two fatigued transfer tests. A study on magnetoencephalographic (MEG) brain imaging showed a decrease in the activity of left hemisphere basal ganglia by increasing stimulation, as a result of physical fatigue. This study confirms the relationship between physical fatigue and psychological factors (Tanaka, Ishii, & Watanabe, 2016). On the other hand, Masters et. al. showing the relationship between physical fatigue and the production of cortisol and physiological stress (Poolton et al., 2007). After this process, the sympathetic nervous system activates, and accessible working memory capacity drops, resulting in deterioration of explicit processes and performance, while leaving implicit processes intact. In general, these analyses can explain the similar effects of cognitive and physical fatigue.

The improvement in the performance of the participants in the two fatigued tests compared to the retention test was an interesting finding of this research. Not only did the participants not suffer a loss in performance under cognitive and physical fatigue, but also they improved compared to non-fatigued states. From a neurobiological perspective, human brain has different memory systems for different information types. Brain imaging shows the correlation between the working memory and brain areas such as the pre-motor cortex, Broca's area, the occiptal lobe, and the Fronto-parietal lobe, which are responsible for activities that require conscious attention (Baddeley, 2003). On the other hand, other parts of the brain, like the Striatum and the Amygdala in Corpus Striatum, cerebellum and the spinal cord are related to the non-declarative and implicit memory systems (Rose & Christina, 1997), and are responsible for habit formation, automated recognition of task organization, and some learning processes (Peigneux et al., 2000; Yin & Knowlton, 2006). Boragan et.al demonstrate adversarial and compensative relationships between different memory systems. Removing one memory system from processing and storing information improves the performance of other memory systems (Borragán et al., 2016). For example, overloading the accessible working memory resources with cognitive loads such as fatigue removes working memory from this process. This competition between the working memory and implicit memory can benefit implicit memory. We believe that this adversarial and compensative relationship helps memory processes, especially implicit processes, keep up and even improve performance under cognitive and physical fatigue conditions.

In general, the improvements observed in the performance of the participants in cognitive and physical fatigue conditions, in comparison to non-fatigued condition, shows the effectiveness of implicit processes under fatigue and duress, supporting the superiority of errorless training. In order to further justify the advantage of errorless training observed in the present study, it could be said that even though performing secondary tasks frees up memory resources, it appears that other methods such as errorless training or analogy learning are less taxing on memory resources, by reducing training complexity (Ewolds, Bröker, De Oliveira, Raab, & Künzell, 2017). On the other hand, as a result of the limitations imposed by the COVID-19 pandemic, the author did not have access to controlled laboratory conditions, and could only oversee one acquisition session. It is therefore suggested to repeat this study with more acquisition sessions, and controlled laboratory conditions. Also, to better understand the relationships between different memory systems, it is suggested to record brain activity. Furthermore, it is suggested to repeat this study on different age and gender groups, since age and gender differences are likely to affect learning and resilience against fatigue. Finally, since people are affected by different forms of fatigue in performance, and this research has demonstrated the positive effects of errorless training on fatigued performance, we suggest athletes and coaches to leverage the errorless training method when designing training courses to prevent the deterioration of performance.

Authors' contribution

Conception and design of study: R.B, B.A; data collection: R.B; Data analysis and/or interpretation: R.B, M.K; Drafting of manuscript and/or critical revision: R.B, B.A, M.K; Approval of final version of manuscript: R.B, B.A, M.K.

Conflict of interest

There are no conflicts of interests for any of the authors to report.

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