



Effects of Limb-Specific Fatigue on Motor Learning during an Upper Extremity Proprioceptive Task

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Abstract

Background: The effects of limb-specific fatigue on motor skill acquisition and retention are not clear.

Objective: To investigate the impact of limb-specific fatigue on acquisition and retention of an upper extremity proprioceptive task.

Methods: Twenty-two right-handed participants were randomly and equally assigned to either fatigued or non-fatigued protocols. Acquisition phase for the upper extremity task consisted of 5 blocks each with 12 trials. After 48 hours, all participants performed 1 block retention test (12 trials) with the left arm followed by 1 block transfer test (12 trials) with the right arm. Performance for each block was analyzed using a one-way analysis of variance (ANOVA). Performance differences between groups for acquisition was analyzed using a 2 x 5 (group x block) ANOVA with repeated measures on the blocks. The performance on retention-transfer was analyzed by separate ANOVAs. Statistical significance set at $p < 0.05$.

Results: The fatigued condition displayed significantly more E than the non-fatigue group ($p < 0.05$). During retention and transfer, the fatigue group again displayed higher E compared to the non-fatigued group ($p < 0.05$).

Conclusion: The results of this study support that limb-specific fatigue may produce performance deficits during acquisition and interfere with motor skill retention.

Introduction

Both intrinsic and extrinsic information will shape how the motor system plans, coordinates, and executes purposeful movement (Wolpert, Pearson, & Ghez, 2013). Moreover, motor learning (i.e. the cognitive processes that occur as a result of practice) assumes that acquiring a motor skill relies on the synchronization of the CNS, PNS, and

neuromuscular system (Brooks, 1983). Therefore, deficits in motor ability may be attributed to acute or chronic dysfunction of one of these systems (Seidler et al., 2010).

One mechanism that can negatively impact motor ability is fatigue. Fatigue is thought to reduce proprioceptive acuity and interfere with fluid

movement (Huysmans, Hoozemans, Van der Beek, De Looze, & Van Dieën, 2008; Lee, Liau, Cheng, Tan, & Shih, 2003; Shields, Madhavan, & Cole, 2005; Wolpert et al., 2013). Additionally, task practice and ultimately performance under fatigued conditions could result in fewer correct responses, a weaker error detection mechanism, and less efficient learning relative to unfatigued practice (Godwin & Schmidt, 1971).

To date, the literature examining fatigue's influence on motor skills has produced inconsistent results (Mierau et al., 2009). Some researchers have suggested that fatigue produces decrements in performance but may not have any effects on the learning of motor skills (Alderman, 1965; Schmidt, 1969; Whitley, 1973, 1975). Whereas others have reported that both performance and learning are impaired (Carron, 1969; Cotten, Thomas, Spieth, & Biasiotto, 1972; Davey, Thorpe, & Williams, 2002; Forestier & Nougier, 1998; Godwin & Schmidt, 1971; Huysmans et al., 2008; Thomas, Cotten, Spieth, & Abraham, 1975). Therefore, the effects of fatigue on learning warrant further investigation.

Additionally, early research has primarily used aerobic exercise to induce fatigue (Paillard, 2012). These studies have primarily focused on the effects of generalized exercise instead of localized, limb-specific, exercise. Moreover, only a few studies have shown that limb-specific fatigue impacts performance (Forestier & Nougier, 1998; Huysmans et al., 2008).

However, the effects of limb-specific fatigue on motor skill acquisition and learning are not clear. Therefore, the purpose of this study was

twofold; 1- to investigate the effect of limb-specific- fatigue on motor skill acquisition; 2 – to measure this effect on motor skill retention. We hypothesized that limb-specific fatigue would inhibit motor skill acquisition and long-term retention of this specific motor task.

Method

Participants

College-aged (19-30) right-handed participants (n = 22) were randomly and equally assigned to either the fatigued or non-fatigued protocols. Participants had no prior experience with the protocol. The investigation was approved by the University's Institutional Review Board. Informed consent was obtained from all participants prior to the experiment.

Apparatus and task

Prior to completing the testing protocol, chair distance to the table was adjusted for each participant. Participants were seated upright with their posterior superior iliac spine in contact with chair's back and feet flat on the floor. The left arm was placed in a kinesthesiometer (Lafayette Instruments Co, Lafayette, IN) in neutral hand position. The opposite upper extremity was placed in a designated area on the table's surface. Chair distance from table remained individualized and constant throughout the subject's testing procedure.

Procedure

The experiment's design consisted of three phases: acquisition, retention, and transfer. Acquisition phase consisted of 5 blocks each with 12 trials. The kinesthesiometer was rotated counterclockwise by concentric activation of the elbow flexors and internal rotators of designated shoulder (i.e. positive movement). Each block consisted of the sequential 30, 50- and 70-degrees x 4 sets (n = 60 total trials). The blindfolded participants were directed to the degree – by “specified degree (i.e. 30) - go”. 100% verbal feedback was given to all participants after each acquisition trial. Each block was separated by 90 seconds.

The fatiguing protocol was introduced during acquisition phase only. The fatiguing protocol consisted of standing elbow flexion of ~75 to 85% of the participant's max (i.e. 6-10 repetitions). This occurred prior to each practice block and was continued to volitional exhaustion. Participants assigned to the fatiguing protocol chose an appropriate weight (U90 Stage 1 Powerblock, Owatonna, MN) based upon the predetermined goal of 6 to 10 repetitions prior to B1. Participants (n=11) were instructed to perform elbow flexion at a full range of motion and without the use of bodily momentum. Participants would also passively rest after the completion of the fatiguing set if time remained in the 90 second rest period. If the participant could not perform 6 consecutive repetitions, rest was encouraged between repetitions in the full elbow extension so loading volume would remain relatively consistent across

blocks and participants. Participants (n=11) assigned to non-fatiguing protocol passively rested in the chair between the acquisition blocks.

After 48 hours, all participants (n=22) performed a 1 block retention test (12 trials) with their left arm. This was immediately followed by 1 block transfer test (12 trials) with their right arm by changing location of the chair. No feedback was given during the retention or the transfer tests.

Measurement

All angular movements were measured to the nearest half degree and recorded on a data sheet. The primary dependent variable was the difference between the actual angle and the target angle. Total variability (E) was used as a measure of overall error (Schmidt & Lee, 2011). E was outlined by the equation, $E = \text{Sqrt}(\sum[X_i - T_i]/n)$; where, X_i = actual performance (range of motion on trial), T_i is the target degree (30°, 50° or 70°) and n is the number of trials the participant performed in a block. Variable error (VE) measured the inconsistency in movement outcome by computing the standard deviation of participant's performance across trials (Schmidt & Lee, 2011). VE was computed by the equation, $E = \text{Sqrt}(\sum[X_i - M]^2/n)$; where M is the subject's average movement and n is the number of trials the participant performed in a block.

Overall acquisition performance for each block was analyzed using a one-way analysis of variance (ANOVA). Performance differences between groups for acquisition was analyzed using a 2 x 5 (group x block) ANOVAs with repeated measures on the blocks. The performance on retention-

transfer was analyzed by separate ANOVAs. Statistical analysis was conducted with SAS 9.2 (SAS Institute Inc., Cary, NC) with statistical significance set at $p < 0.05$.

Results

Acquisition

One-way ANOVA demonstrated both groups decreased E as a result of practice across blocks, $F(4, 80) = 10.80, p < 0.01$. Post hoc Duncan Multiple Range Test revealed that block 1 ($M = 9.99, SE = 2.40$) had a significantly higher total error than blocks 2-5 in both groups, $p < 0.05$.

A mixed method ANOVA demonstrated there was no interaction between block and group, $F(4, 80) = 0.20, p > 0.05$. A main effect of group was detected, $F(1, 20) = 4.70, p < .05$, where fatigue condition ($M = 7.51, SE = 0.76$) produced more E than the non-fatigue ($M = 6.09, SE = 0.64$) across blocks (Figure I). Cohen's effect size value ($d = .67$) suggested a moderate to high practical significance.

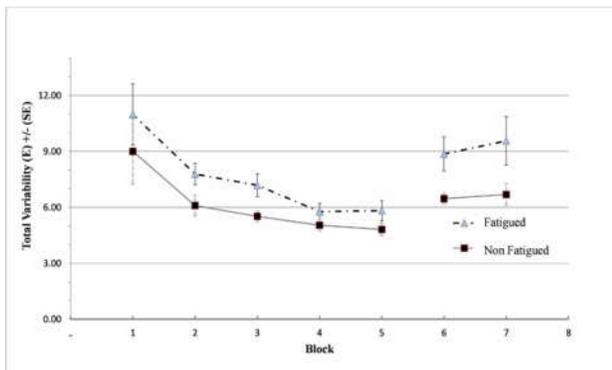


Figure 1. Fatigue vs. Non-Fatigue Total Variability (E). Block 1 to Block 5: Acquisition Phase. Block 6: Retention [48 hours post-Acquisition], Block 7: Transfer [right arm] The analysis also demonstrated both groups decreased VE as a result of practice, $F(4, 80) = 10.82, p < 0.01$. Post hoc Duncan Multiple Range Test revealed that block 1 had a

significantly higher VE than blocks 2-5 in both groups. The main effect of group was marginally detected for acquisition, $F(1, 20) = 4.35, p = 0.05$; where fatigue condition ($M = 6.81, SE = 0.64$) tended to be more inconsistent relative to the non-fatigue group ($M = 5.58, SE = 1.68$) (See Figure II; Blocks 1-5). The interaction between block and group was not significant, $p > 0.05$.

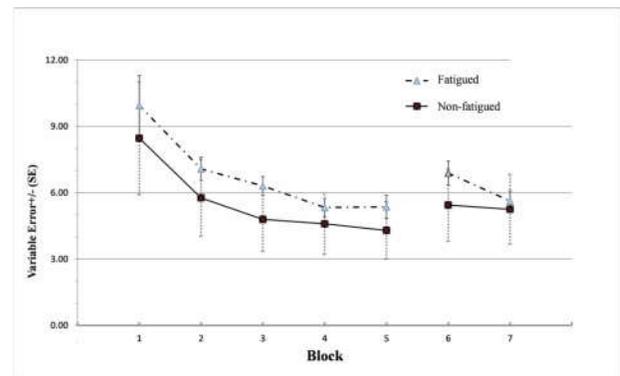


Figure 2. Fatigue vs. Non-Fatigue Variable Error (VE). Block 1 to Block 5: Acquisition Phase. Block 6: Retention [48 hours post-Acquisition], Block 7: Transfer [right arm].

Retention and Transfer

During retention and transfer, the fatigue group ($M = 9.22, SE = 1.57$) increased E; $F(1, 20) = 6.83, p < .05$, compared to non-fatigue ($M = 6.58, SE = 0.61$), Cohen's $d = 1.78$. Analysis did not detect difference between retention and transfer, $F(1, 20) = .47, p > 0.05$, or interaction.

The fatigue group ($M = 6.26, SE = 0.71$) did not differ from non-fatigue ($M = 5.35, SE = 0.42$) by VE; $F(1, 20) = 3.19, p = .09$. Analysis did detect difference between retention and transfer. Transfer test produced more VE than retention test, $F(1, 20) = 6.00, p < 0.05$. No interaction was found, $F(1, 20) = 3.29, p > .05$.

Discussion

The primary purpose of this study was to examine the effect of limb-specific upper extremity fatigue on motor skill acquisition and retention. Both the fatigued and non-fatigued groups learned the upper extremity proprioceptive task but the extent to which the task was learned was dependent upon fatigue status. In agreement with previous research, E was most affected by practice inconsistency as measured by VE (Paillard, 2012). Due to fatigue, the participant's ability to accurately judge position during acquisition was affected. Furthermore, fatigue interfered with optimizing task-specific memory which was demonstrated by reduced performance during retention and transfer blocks.

The findings from this study support previous research that found localized muscular fatigue is detrimental to performance (Davey et al., 2002; Evans, Scoville, Ito, & Mello, 2003; Lyons, Al-Nakeeb, & Nevill, 2006). This was evident by greater E exhibited by the fatigued group. Researchers have reported that a fatiguing task prior to the practice bout has been shown to reduce learning (Carron & Ferchuk, 1971). It has also been stated that local fatigue (i.e. limb-specific) introduced before and maintained throughout early practice may significantly depress motor learning (Whitley, 1975). However, the degree of impairment depends on why and where the fatigue was produced (Kanekar, Santos, & Aruin, 2008). This investigation found limb-specific fatigue interpolated throughout practice to be a variable that affects acquisition and retention (Carron,

1969; Carron & Ferchuk, 1971; Davey et al., 2002; Huysmans et al., 2008; Masters, Poolton, & Maxwell, 2008). Previous experiments have allowed participants to recover during practice by either providing a single fatigue bout (low disturbance to the system) or numerous practices after the participant has recovered (Alderman, 1965; Schmidt, 1969). By allowing a recovery period, it is difficult to know if fatigue is still present throughout the acquisition process. Additionally, allowing long and continuous practice trials may evoke active recovery rather than inducing fatigue (Benson, 1968; Carron & Ferchuk, 1971; Schmidt, 1969). The time required to perform this task was brief and therefore less susceptible to active recovery. Moreover, the interpolated nature of the fatiguing task increased the likelihood that the task was truly performed during a fatigued state.

The body inherently contains methods of ongoing compensation to counteract fatigue (Paillard, 2012). Compensatory mechanisms at various levels of the neuromuscular system may act to delay the effects of fatigue, thus prolonging the accuracy of the motor activity (Enoka et al., 2011). This study utilized a localized, guided task, eliminated visual compensation, controlled body position, and maintained the vestibular reference (i.e. head stayed in the same position) to limit such compensation. By controlling for compensatory motor strategies, we can better conclude that task-specific fatigue negatively affected motor skill acquisition and retention.

Conclusions

The findings from this study support that when learning a discrete upper extremity task, it is not recommended to do so in a fatigued state for optimal learning to occur. Our investigation indicated that (1) acute effects of fatigue are not limited to the lower body and (2) limb-specific fatigue affects task acquisition and retention. Future research should investigate relative workloads, duration of workloads, duration of rest intervals, and type of skill being learned before generalizing practical implications of such findings.

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