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Original Article

The Effect of Proprioceptive Neuromuscular Facilitation on Learning Fine Motor Skills: A Preliminary Study

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Abstract

Introduction: Preparation of neuromuscular system prior to performing motor skills affects the learning of motor skills. The present study was conducted to investigate the effects of Proprioceptive Neuromuscular Facilitation (PNF) on limb coordination and accuracy in dart throwing skill.

Methods: Thirty two male students were randomly selected as study sample. Based on the pretest scores, the participants were divided into three groups: experimental (proprioceptive neuromuscular facilitation), first control (without warm-up), and second control (specific warm-up). During the acquisition phase, the participants first performed the preparation training related to their own group, then all groups performed the exercise program of dart throwing consisting of 6 blocks of 9 trials in 4 training sessions. Finally, 20 days following the last exercise session, the subjects took the retention and transfer tests.

Results: The results of one-way ANOVA test for coordination variable in acquisition test showed no significant difference between the groups, while there was a statistically significant difference between groups regarding coordination variable in retention and transfer tests. Furthermore, the results of one-way ANOVA for the accuracy variable in acquisition and retention tests showed no statistically significant difference between the three groups, while there was a statistically significant difference between groups for accuracy variable in transfer test.

Conclusion: It seems that proprioceptive neuromuscular facilitation, as a preparation method before performance, can enhance the efficacy of training to better learn the coordination pattern of fine motor skills.

Introduction

Since useful learning saves the time and prevents the learner's loss of energy, it is necessary to apply all motor learning principles to educate motor skills (1). Preparation is an important principle and strategy in learning fine motor skills (2). According to this principle, every person should prepare his/her motor control system before learning and performing a motor skill (3). Hence, experts have proposed various strategies for preparation before learning the motor skills, including psychological readiness (motivation, attention, and concentration) and physical readiness (strength, endurance, and preparation of neuromuscular system) (4-6).

Neuromuscular system readiness before performing motor skills controls the body movements and affects motor learning (3, 6, 7). Proprioceptive Neuromuscular Facilitation (PNF), as a nerve facilitation approach, is based on ***reflex*/*hierarchical theory*** of ***motor control*** and is used for preparation of neuromuscular system before performing motor skills (8, 9). Through peripheral stimulations, PNF makes more use of motor pathways, recruits more motor units, and improves neuromuscular connections, and synaptic plasticity enhances the coordination and retraining of motor components (9-11). PNF has various techniques whose purpose is promotion of motor performance through neurophysiologic principles like facilitation, inhibition, and stretching and relaxing the muscle groups (9).

Contract-Relax-Antagonist-Contract (CRAC) is a PNF technique that causes the mastery of motor skills via active movement and isometric activity and use of stimulatory and inhibitory properties and muscle spindle afferents (12, 13). CRAC also stimulates different levels of spinal cord and distributes the nerve impulses at a larger area, which in turn causes the stimulation of motor neurons and application of many motor pathways (9, 12). In this regard, Sadys, Blank & Wortman (1982), Abraham & Etnyre (1991), and Hasen et al. (1992) showed that "CRAC increased the flexibility and range of motion and induced more ***electromyography*** (EMG) activity in the target muscle" (13). Further, Ryan & Lopez asserted that PNF using CRAC technique increased the connection of neuromuscular system, thereby improving the postural stability (14).

Most of the studies conducted in the domain of physiotherapy and physiology have analyzed the effect of CRAC on the motor performance of people. Few studies, however, have examined the impact of CRAC on learning fine motor skills. The only study in this regard was carried out by Alencar et al. (2011) in which they reported PNF affected the acquisition of motor skills of upper and lower limbs in the patients with spinal injury (15).

Based on the theoretical foundations, the long-term reinforcement and suppression of synapses constitute the important factors affecting the learning of motor skills (8) and CRAC, as a physical readiness technique, affects the long-term reinforcement and suppression of synapses (9). The question now posed is that whether CRAC, as a preparation technique of neuromuscular system, can promote the efficacy of deliberate practice and consequently the mastery of coordination and accuracy before dart throwing skill practice.

Materials and methods

The study population of this pretest-posttest quasi-experimental study comprised of all students of Hakim Sabzevari University, aged 19-25 years, except for the physical education students. Having registered and completed the demographic information form, 32 students were randomly selected as study sample from among 80 students qualified to be included in the study (being right-handed, no history of neuromuscular diseases, and no history of dart throwing training and practice). The exclusion criteria consisted of lack of doing dart throwing practice and CRAC exercises according to the principles presented.

The participants were trained by a dart trainer in a 45-minute session on correct handling of the dart, posture of feet behind the throwing line, and angles of arm and hand for an optimal throwing. The trainer also explained the scoring system and the nine-dart game according to the official rules of dart association. One day after the trainings, a pretest (9 darts) was administered to all the subjects. Based on the pretest scores, the subjects were randomly divided into three homogenous groups, including CRAC, first control (specific warm-up), and second control (without warm-up).

The subjects of experimental group were first trained by a physiotherapist on correct performance of CRAC exercises in two 45-minute sessions. After the physiotherapist confirmed the subjects mastered the CRAC exercises, the training sessions were initiated. In each training session, the experimental group performed RAC exercises (without help) for 13 minutes on the elbow and wrist extensor and flexor muscles for 35 seconds of their three replications. The break between each repetition 5 seconds and one minute rest between each muscle was considered. the first control group carried out specific warm-up exercises for 13 minutes include static stretching (3 reps, 30 seconds rest 5 seconds) and rotational movements and kinetic (2 reps, 30 seconds rest 5 seconds) extensor and flexor muscles of the elbow and the wrist, and second control group listened to the trainer's explanation about the history and various kinds of dart game. Then, all three groups attended four training sessions of dart throwing, each session with 6 blocks of 9 trials (three rounds). Each round lasted for 30 seconds, and the break time between rounds was 30 seconds and between blocks was 1 minute. It should be noted that the subjects focused on the number they had selected on the dart board while doing the practice and received only one feedback in each practice block on their will. All three groups were administered an acquisition test (nine-dart) at the end of the fourth session, a retention test (long-term) similar to the acquisition test after 20 days, and a transfer test similar to the real conditions of official nine-dart game.

During the administration of pretest, and acquisition, retention and transfer tests, two markers were installed on anatomic parts of the upper limb for all three groups. The camera was placed 1.5 meters away from the subjects with 90 º angle so that all the joints were seen during the movement and it was possible to record the absolute angular displacement of elbow and wrist in the sagittal plane. The angular displacement of elbow and wrist was calculated by MATLAB software from the start to the end of the movement for the best throwing, and elbow-wrist angle-angle plot was dawn for each subject during the throw. Then, the mean angle-angle plot was drawn for each subject, the plot of each subject was placed on the mean plot of his/her own group, and normalized mean square error (quantification of coordination pattern) was calculated for each subject in each group.

Mean, standard deviation and graphs were used to describe the data statistically. The normality of data distribution was evaluated by Kolmogorov-Smirnov test and homogeneity of variances of study groups was analyzed by Levene's test (16). The inferential statistics of the acquisition test was performed by mixed ANOVA (3×2) (group×day) followed by LSD test. To compare groups in the acquisition, retention and transfer tests, one-way ANOVA and follow-up Tukey tests were applied. The significance level was set at $\alpha=0.05$.

The subjects actively stretched the target muscle (e.g. triceps) until the pain threshold and held it for 10 seconds. Then, the subjects created a resistance with another hand for isometric contraction in agonist muscle (target muscle) and kept it for 10 seconds. The subjects stopped the contraction, took a deep breath, and held the organ at the starting point for 5 seconds. At the end, the subjects contracted the antagonist muscles (biceps) and stretched the target muscle toward a deeper stretching and kept it for 10 seconds.

Results

The results of mixed ANOVA (3×2) showed no significant difference between the pretest and acquisition test regarding coordination ($p=0.31$, $F=1.04$) and accuracy ($p=0.62$, $F=0.24$) in all three groups.

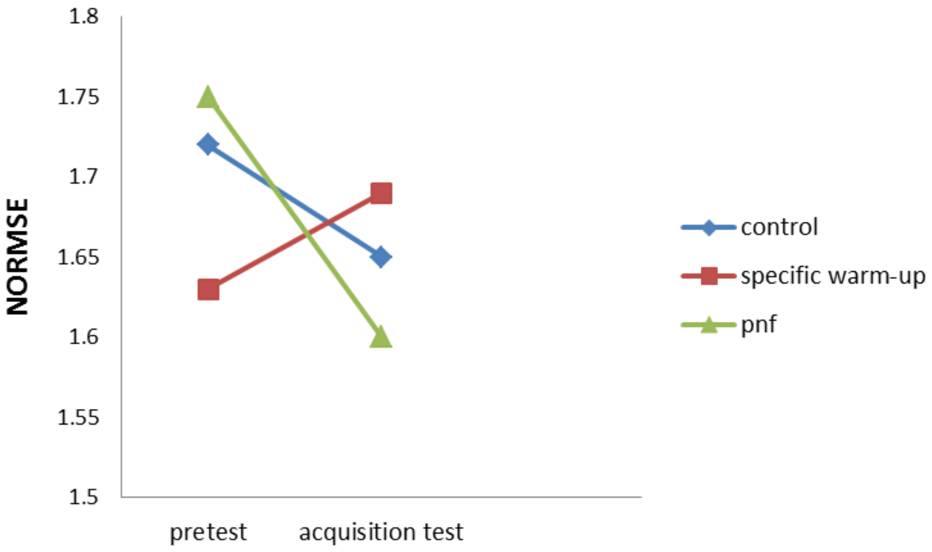

Figure 1. Mean coordination scores of study groups in pretest and acquisition test

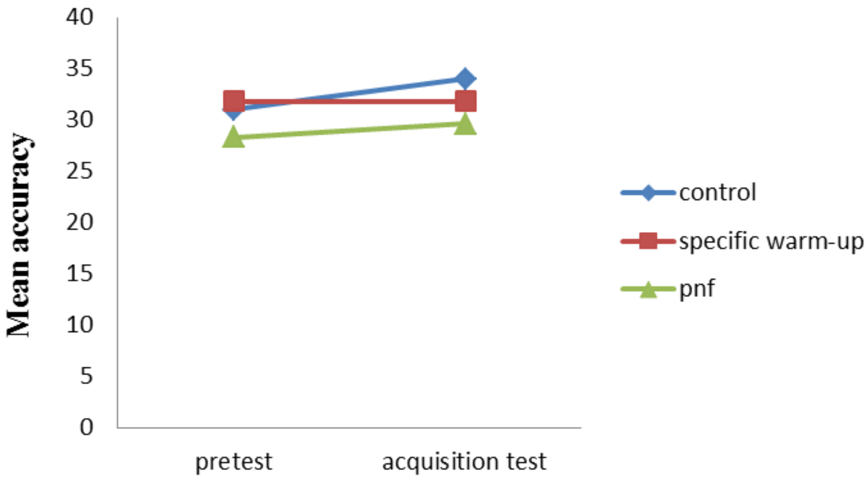

Figure 2. Mean accuracy scores of study groups in pretest and acquisition test

Further analysis of the research findings indicated a reduction in normalized mean square error in control and CRAC groups during the acquisition phase. However, this error was increased in the specific warm-up group (Figure 1).

Moreover, the analysis of mean accuracy of study groups showed that the accuracy of control and CRAC groups was slightly increased from pretest to acquisition test, while the accuracy of specific warm-up group in acquisition test was similar to that of pretest (Figure 2). The results of one-way ANOVA for acquisition test revealed that the null hypothesis (H_0) was confirmed at error probability of $p \leq 0.05$, indicating no statistically significant difference between the three groups in terms of coordination (p=0.81, F=0.21) and accuracy (p=0.71, F=0.33).

Furthermore, the results of mixed ANOVA (3×2) showed no significant difference between the three groups in acquisition and retention tests with regard to accuracy (p=0.29, F=1.12). However, a significant difference was found between acquisition and retention tests in coordination variable in all three groups (Table 1).

Table 1. Results of mixed ANOVA (3×2) for coordination variable of study groups in acquisition and retention tests

Variable	Source of changes	Sum of squares	df	Mean squares	F	P-value
Coordination	Exercise days	0.46	1	0.46	12.85	0.001*
	Group	0.1	2	0.5	1.05	0.36

*: significant level at p<0.05

In addition, the findings of one-way ANOVA for retention test indicated a significant difference in coordination variable between the three groups (Table 2). The results of follow-up Tukey test indicated the significant difference between specific warm-up and control groups (p=0.02). The results of one-way ANOVA for retention test, however, showed no statistically significant difference between study groups in accuracy variable at error probability of $p \leq 0.05$ (p=0.27, F=1.37).

The results of one-way ANOVA for transfer test showed a significant difference between study groups in coordination and accuracy variables. The findings of follow-up Tukey test also indicated the difference between CRAC and control groups (p=0.02), less error being reported for CRAC group. Also, the findings of Tukey test showed a significant difference between specific warm-up and CRAC groups (p=0.03), lower scores being found for CRAC group in accuracy of dart throwing (Table 3).

Table 2. Results of one-way ANOVA for coordination variable in retention test

Variable	Sum of squares	Mean squares	df	F	P-value
Coordination	0.4	0.2	2	4.58	0.01*

*: significant level at p<0.05

Table 3. Results of one-way ANOVA for coordination and accuracy variables in transfer test

Variable	Sum of squares	Mean squares	df	F	P-value
Coordination	0.6	0.3	2	4.49	0.02*
Accuracy	1046.37	523.18	2	3.99	0.02*

*: significant level at p<0.05

Discussion

This study was aimed to evaluate the effect of proprioceptive neuromuscular facilitation on the acquisition, retention and transfer of coordination and accuracy in dart throwing skill. The results of acquisition test showed that experimental group outperformed the other two groups in coordination. It seems that CRAC, as a preparation method before performance, has improved coordination in this group in acquisition test by relaxing the muscle, creating neuromuscular reflex patterns, postponing muscle fatigue, and changing the muscle stiffness (9-11, 17, 18). Thus, these findings are in line with those of Funk et al. (2003), Marek et al. (2005), Bradley et al. (2007), Mikolajec et al. (2012), and Miyahara et al. (2013), indicating that PNF and its techniques improve neuromuscular performance (19-23). Further, in agreement with the results of the present study, Ferber et al. (2002) showed that different PNF techniques affected the ***Electromyography*** (EMG) activity of knee flexors in the elderly, which is indicative of the effect of PNF techniques on the performance of neuromuscular system (24).

On the other hand, the findings of the current study regarding coordination in acquisition test are in contrast with the findings of Reis et al. (2013) which showed PNF had no impact on the EMG activity of knee extensors in futsal players. This discrepancy seems to be associated with the nature of task, involved muscles, and measurement tool (25). Moreover, the insignificant difference for accuracy in acquisition test may be due to high sensitivity of measurement of accuracy (scoring procedure based on international regulations) and selection of one throw with the highest score among the throws.

Therefore, these results are in agreement with those of Paiva Carvalho et al. (2009) demonstrating that PNF exercises had no effect on the performance of vertical jump during the practice time (26). However, these results are in contrast with the findings of Alencar et al. (2011) reporting that PNF affects the acquisition of motor skills in different parts of the body in patients with spinal injury (15). Furthermore, the findings of the present study are in disagreemnt with the results of Rayan & Lopez (2010) reporting that PNF along with CRAC technique enhance the neuromuscular connection and improve the postural stability during the exercise (14). This discrepancy seems to be related to the type of task and muscles involved in the performance, type of participants, and number of trials during the exercise.

The results of retention test regarding coordination revealed that experimental group had the minimum number of errors. Hence, it seems that CRAC has improved coordination in retention test owing to increased transmission speed of nerve signals, synaptic efficiency changes, noise reduction in sensorimotor system, reorganization of sensorimotor network, and improved performance of neuromuscular system (27-31). The findings also showed that although the study groups were not different in accuracy, the experimental group showed the minimum accuracy. Thus, the effect of CRAC on the retention of fine motor skills seems to be dependent upon the type of parameter measured (coordination, accuracy). However, further studies are needed to provide more accurate and transparent results in this regard.

The results of coordination in transfer test showed the experiment group outperformed the other groups. Since CRAC had more effect on the coordination of dart throwing skill in transfer test, it seems that proprioceptive neuromuscular facilitation has made more use of motor pathways, has increased motor unit recruitment, and has improved coordination through non-invasive cortical stimulation and environmental stimuli (9), which is in confirms Hebb's neurophysiological theory. This theory emphasizes the role of neurons in learning and suggests that as a result of experience, structural changes occur in areas of neurons with closer physical contact, and the number of cells in cellular colonies increase with repeated stimulation and add up to the former state in practice (32). Also, it seems that CRAC causes better coordination via synaptic plasticity and improvement of neuromuscular connections, which is in line with Kappers' neurobiotaxis theory. According to this theory, "the motor learning occurs as a result of the developed nerve connections and consequently reduced resistance in synapses" (3). Moreover, Leonard (2005) asserted that long-term reinforcement and suppression are neural mechanisms that can make long-term synaptic changes (33). Thus, CRAC seems to have caused the learning of coordination in dart throwing skill through long-term reinforcement and suppression.

In addition, the results of transfer test with regard to accuracy indicated that the experimental group had a poor performance against the other two groups. For a better performance in dart throwing skill, it is necessary for a person to move his/her wrist with appropriate speed and acceleration (temporal aspects), but during the motor skill learning, a person first learns the spatial characteristics of the skill and then the temporal aspects of performing the skill (34). Hence, it seems that the participants of this study did not learn the temporal aspects of the skill, so they did not show a good accuracy in transfer test.

Given the increased coordination and reduced accuracy of CRAC group in transfer test, the findings of the current research can be explained by the Newell's coordination and control model (1985). "This model suggest that for learning the motor skills, a person first acquires a proper model of limb coordination and then parameterizes the model based on the skill objective" (34). Therefore, the participants of CRAC group seem to have acquired an appropriate coordination model (angle displacement), but have not acquired sufficient ability to add kinematic values (linear and angular velocity and acceleration) to the basic pattern of movement to reach optimal accuracy.

Conclusion

In general, according to the results of the current study, it can be argued that CRAC, as a preparation method before performance, only improves some components of fine motor skills (coordination not performance accuracy). However, further studies are required to clarify whether CRAC is a learning variable or a performance variable.

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