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Acute Effect of Post-activation Potentiation on Semi-dynamic Balance in Girl Gymnasts Aged 9–12

Nazanin Afzali-Gorouh[1], **Mohammadtaghi Amiri-Khorasani**[1*], **Roohollah Nikooie**[2]

[1]Department of Sports Biomechanics, Faculty of Physical Education and Sports Sciences, Shahid Bahonar University of Kerman, Kerman, Iran
[2]Department of Sports Physiology, Faculty of Physical Education and Sports Sciences, Shahid Bahonar University of Kerman, Kerman, Iran

*__Corresponding Author:__ Mohammadtaghi Amiri-Khorasani, Email: amirikhorasani@uk.ac.ir

Abstract
Background: Post-activation potentiation (PAP) is a novel warm-up method shown to improve sports performance. This study aimed to investigate the acute impact of this method on semi-dynamic balance while walking on the balance beam among female gymnasts aged 9–12 in Kerman city.
Methods: Twenty healthy gymnasts volunteered to participate (height: 138.1 ± 5.04 cm; mass: 40.7 ± 3.12 kg) and were randomly divided into two equal sub-groups. The two groups attended the laboratory on two separate days, 48 hours apart. On the first day, the first sub-group performed a general warm-up (GWU), while the second sub-group performed a PAP warm-up. On the second day, the first sub-group switched to a PAP warm-up, and the second sub-group switched to a GWU. After the warm-up, the subjects took a two-minute rest, and then they walked on the balance beam while their movements were recorded using six motion analyzer cameras that captured the kinematic data of the shoulder, thigh, knee, and ankle joints. The data were processed using a low-pass Butterworth filter and analyzed using one-way ANOVA and paired *t* tests.
Results: The results showed significant differences in shoulder, hip, knee, and ankle joint positions in proximal-distal movements following GWU and PAP warm-ups ($P \leq 0.001$). In addition, PAP caused a significant decrease in shoulder, hip, knee, and ankle joint positions in medial-lateral movements compared to GWU ($P \leq 0.001$, $P \leq 0.001$, $P \leq 0.038$, $P \leq 0.001$, respectively).
Conclusion: PAP warm-up positively affects semi-dynamic balance factors in gymnasts. Given the importance of balance in gymnastics, PAP warm-up is recommended to improve sports performance.
Keywords: Gait, Warm-up, PAP, Balance, Girls, Gymnastic

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Introduction

Balance is the most important part of an athlete's ability and one of the key components of movement skills for maintaining posture and performing complex athletic skills (1). Balance is classified into three categories: static, dynamic, and semi-dynamic (2). As the ability to maintain a position for intentional activities and cope with perturbations (internal or external), it is an inseparable part of gymnastics, a competitive sport with a short championship period and successful athletes of low age (3,4).

The primary goal of gymnastics training is to cultivate fundamental skills, such as balance, for the future (3,4). Hence, optimal and proper exercise training plans for children are essential. Before gymnastics training or competition for children, coaches, trainers, or physical educators ask and encourage them to perform some type of warm-up program since warm-up is one of the activities that has been shown to enhance skill performance and prevent injury (4-7).

Numerous studies have been conducted on the effects of different warm-up methods on various types of athletic performance. Previous research has shown that using dynamic stretching during warming up, as opposed to static stretching and other stretching methods, leads to immediate improvements in physical performance, such as speed, agility, power, endurance, and flexibility (7-11). Papia et al (5) reported a 9.6% decrease in lower extremity strength and McNeal and Sands (12) reported a decrease in counter-movement jumps in female gymnasts as a result of static stretching. Although balance plays a crucial role both in sports performance and injury prevention, few studies have examined the effects of different stretching methods during warm-up on athletes' balance. Amiri-Khorasani and Mogharabi Manzari (1) demonstrated that dynamic stretching resulted in higher levels of static and dynamic balance compared to static stretching in female students. Additionally, Amiri-Khorasani and Gulick (13) reported that female soccer players who engaged in dynamic stretching experienced increased dynamic balance compared to those who engaged in static stretching. In this regard, among gymnasts, researchers have demonstrated that dynamic stretching increases dynamic balance and improves the execution of balance and vault movements, which require high levels of balance maintenance, compared to static stretching (14-16).

According to the ongoing research in this field, researchers have proposed using post-activation potentiation (PAP) during warm-up. PAP can be described as a temporary increase in muscle performance achieved through a brief contraction, which enhances subsequent muscle contractility. Therefore, PAP can be described as a muscle's enhanced contractile response resulting from activities such as maximum isometric contractions, near-maximal and maximum resistance training, ballistic training, and plyometric training. These activities can positively impact the muscular performance of individuals. The main mechanism of PAP involves the phosphorylation of light chain myosin, which enhances the interaction between actin and myosin. Another proposed mechanism is increased neurological excitability (17,18). Various studies have shown PAP to enhance performance (18-21). Dallas et al (22) demonstrated that PAP significantly increased drop jump height among female gymnasts aged 9 to 13. Furthermore, Dallas et al (23) reported significant PAP effects on increasing drop jump height and reducing duration among professional male and female gymnasts.

In addition to the various factors that contribute to success in gymnastics, such as physical fitness and sensory-motor skills, maintaining balance plays a crucial role in the performance of gymnasts and their overall achievements. Developing and enhancing balance enables gymnasts to execute movements with precision and grace and is a powerful tool in injury prevention. By improving their balance, gymnasts learn to control their bodies and stabilize themselves, reducing the risk of falls and other mishaps during routines. By researching the impact of PAP on gymnasts' balance, we can uncover valuable insights that can be utilized to develop targeted training programs and techniques that focus on balance improvement. This, in turn, can significantly increase the chances of gymnasts having successful and injury-free careers, ensuring a bright future in the sport. Based on previous studies, no research was found on the effect of PAP on the balance of gymnasts 9 to 12 years old. Hence, this study aimed to investigate the effect of PAP during warm-up on semi-dynamic balance while walking on the balance beam among female gymnasts aged 9 to 12.

Methods

The present study employed a semi-experimental design that utilized repeated measures. The statistical population of this research consisted of active female gymnasts in active clubs of Kerman city, totaling 987 individuals, as reported by the Sports Medicine Association of Kerman province. To ensure a representative sample, the sample size was determined using G*Power analysis, which indicated that the chosen sample size was sufficient to detect a medium effect size, given the following parameters: effect size of $f = 0.3$, significance level $\alpha = 0.05$, and power of $1 - \beta = 0.80$. Ultimately, a sample of 20 female gymnasts aged 9 to 12 from Kerman Province with a mean age of 10.4 ± 1.26 years was selected for the study. The gymnasts had an average height of 138.1 ± 5.04 cm and a mean body mass of 40.7 ± 3.12 kg. The selection of participants was based on specific entry criteria, including a maximum of 3 years of gymnastic experience, age range of 9–12 years, absence of any history of injuries, and being female. Deliberate sampling was employed, and access to participants was obtained through active clubs in Kerman city. Finally, from the pool of eligible participants, the final participants were randomly selected based on the result of the G*Power analysis. After presenting information on the goals and methodology of the study, written informed consent was obtained from the participant's parents.

The physical health assessments were carried out for a duration of two consecutive days. The examinations included measurement of some anthropometric and physiological variables, such as body mass (digital scale, SECA model, manufactured in Germany, with a precision of 0.1 kilogram) and height (wall-mounted height measuring device, 2MD model, manufactured in China, with a precision of 0.1 centimeter), one repetition maximum (1RM) test, and familiarization with the laboratory environment (24). The 1RM value was determined using the method previously described (25). Testing for 1RM was preceded by a warm-up set (ten repetitions using self-selected resistance). The testing procedure was initiated two minutes after the warm-up. Briefly, subjects tried to accomplish one repetition with the imposed load, which progressively increased after every successful attempt. The resting period was 2–3 minutes between attempts. 1 RM was defined as the highest weight that the subject could move once concentrically. The participants' dominant foot was determined following the methodology commonly used in gymnastics, where the dominant foot plays a significant role in movements like cartwheels and round-offs; marker placement was also conducted on the dominant foot (22,23).

The current study's design included repeated measures done with a counterbalancing method to eliminate the learning effect (26,27). With such a design, the subjects were their own controls because the model assesses how a subject responds to different warm-up procedures. Each subject participated in the study in two separate sessions. The participant conducted standard warm-up routines, encompassing both general warm-up (GWU) and warm-up with PAP, as depicted in Figure 1. Therefore, all subjects performed both kinds of warm-up programs. However, the participants were randomly divided in half to eliminate the learning effect. The first 10 participants completed the GWU trial in the first session followed by the GWU + PAP trial in the next session, and the remaining 10 participants completed the exercises in the opposite order (GWU + PAP in the first session and GWU in the second). This research was conducted on two non-consecutive days, as shown in Figure 1, in a biomechanics laboratory. During testing days, subjects in all sub-groups started 10 minutes of physical activity consisting of walking, jogging, and static stretching exercises targeting the lower extremity joints (14) under an observer's supervision. Warm-up with PAP consisted of one dynamic movement utilizing a leg extension machine, with an exertion level set at 80% of their one repetition maximum after the initial 10-minute warm-up phase (28).

After resting for two minutes, the participants proceeded to walk on a balance beam. During the activity, they positioned their non-dominant foot on the starting edge of the beam, placed their hands on their hips, and initiated forward movement with a gaze directed ahead. The motion system recorded the oscillations of the participants' hip, knee, ankle, and shoulder positions in both proximal-distal and medial-lateral movements throughout the entire path of the balance beam. While PAP in this study was induced in the lower extremities, previous research has demonstrated that shoulder position and function are associated with balance performance and fall risk in various patient populations. Therefore, measuring shoulder position while walking on a balance beam may provide valuable insights into an individual's balance abilities (29). Each participant's correct execution of this skill was recorded three times. The first and last steps on the balance beam were excluded, and the intermediate steps were used to record the maximum displacement of each variable to eliminate potential errors. Ultimately, the average of the variables from the three repetitions of walking on the balance beam was selected for statistical analysis.

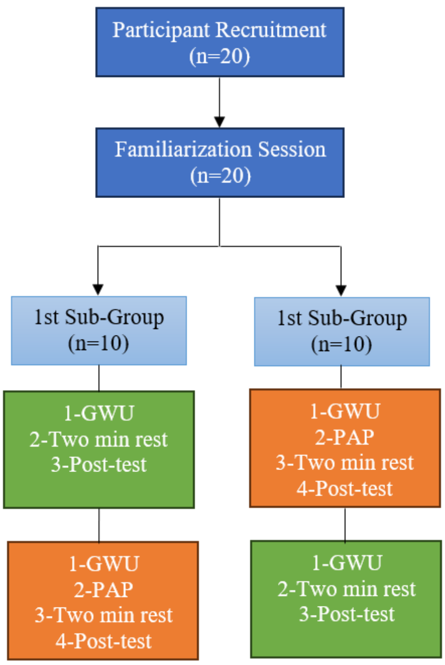

Figure 1. Study timeline overview of events. GWU: general warm-up; PAP: post-activation potentiation

As illustrated in Figure 2, the kinematics data was collected using a 6-camera, 3-dimensional motion analysis system (Eagle; Motion Analysis Corp., Santa Rosa, CA, USA) at a sampling frequency of 200 Hz. Once the cameras are positioned in the appropriate location (performance area), they are calibrated to set their volume origin. Coordinate data from the bony anatomical landmarks of the lateral malleolus, the lateral epicondyle of the knee, the lateral greater trochanter, and the acromion process were digitized in Cortex software (Motion Analysis Corp., SantaRosa, CA, USA). Kinematic data were filtered using a fourth-order zero-lag Butterworth 12-Hz low-pass filter (30).

The data were analyzed using IBM SPSS Statistics version 22. Descriptive statistics, including the mean and standard deviation, were calculated to summarize the data. The normality of data distribution was assessed using the Shapiro-Wilk test. A one-way repeated measure analysis of variance (ANOVA) was then conducted to compare the data. When justified, paired t tests were performed to confirm significant changes within each condition. The significance level was set at $\alpha = 0.05$.

Results

The repeated-measures ANOVA determined that the mean of the oscillations of the participants' hip, knee, ankle, and shoulder positions in proximal-distal movements differed significantly between the PAP and GWU ($P \leq 0.001$) groups. Paired t tests, as presented in Table 1, showed that PAP (1171.23 ± 6.95 mm) caused a significant decrease in shoulder position as compared to GWU (1196.49 ± 9.22 mm) ($P \leq 0.001$). In addition, there was a significant difference in hip position after PAP (713.77 ± 7.17 mm) as compared to GWU (731.01 ± 5.85 mm) ($P \leq 0.001$). Furthermore, PAP (384.24 ± 6.75 mm) caused a significant decrease in knee position as compared to GWU (409.87 ± 12.62 mm) ($P \leq 0.001$). There was also a significant difference in ankle position after PAP (94.67 ± 4.07 mm) compared to GWU (106.06 ± 4.02 mm) ($P \leq 0.001$), as shown in Table 1.

In addition, the repeated-measures ANOVA determined that the mean of the oscillations of the participants' hip, knee, ankle, and shoulder positions in medial-lateral movements differed significantly between PAP and GWU ($P \leq 0.001$). The paired *t*-test, as presented in Table 2, showed a significant decrease in shoulder position after PAP (-108.54 ± 5.95 mm) compared to GWU (-122.37 ± 7.56 mm) ($P \leq 0.001$). In addition, there was a significant difference in hip position after PAP (-121.94 ± 4.99 mm) as compared to GWU (-129.18 ± 4.29 mm) ($P \leq 0.001$). Furthermore, PAP (77.10 ± 5.15 mm) caused a significant decrease in knee position compared to GWU (82.24 ± 5.09 mm) ($P \leq 0.038$). There was also a significant difference in ankle position after PAP (-34.09 ± 2.54 mm) as compared to GWU (-41.01 ± 3.55 mm) ($P \leq 0.001$), as demonstrated in Table 2.

Discussion

This study investigated the effect of PAP during warm-up on the balance of young female gymnasts. The researchers measured how PAP affected the positions of the shoulder, hip, knee, and ankle while the gymnasts walked along a balance beam. The results showed that PAP significantly improved the gymnasts' balance compared to a GWU. All measured joint positions became more stable while walking on the balance beam after the gymnasts performed the PAP warm-up. No previous studies have looked specifically at PAP and gymnastics balance, but our results are consistent with other research showing that dynamic stretching before exercise improves balance (1,13). Other studies have also found that higher-intensity warm-ups can enhance athletic performance (18-23).

Although the biomechanical mechanisms responsible for the PAP protocol are unknown, two major physiological mechanisms have been proposed: neural-muscular changes and evidence related to H-reflex and myosin light chain phosphorylation (31). Generally, according to the H-reflex theory, PAP causes changes in neural-muscular performance, i.e., an electric reflex in the same path as the stretch reflex of the spinal cord, increasing neural efficiency and the speed of nerve impulses. As a result, optimal contraction, which is the regulatory sensitivity of regulatory light chain contractile protein phosphorylation, is increased, releasing more

Table 1. Paired *t* test of GWU and PAP on oscillations of selected landmark positions in proximal-distal movement

Landmarks (proximal-distal)	GWU	PAP	*t*	df	*P* value	ES
Shoulder	1196.49 ± 9.22	1171.23 ± 6.95	6.830	9	0.001*	0.623
Hip	731.01 ± 5.85	713.77 ± 7.17	5.888	9	0.001*	0.581
Knee	409.87 ± 12.62	384.24 ± 6.75	5.661	9	0.001*	0.549
Ankle	106.06 ± 4.02	94.67 ± 4.07	6.284	9	0.001*	0.601

*Significant ($P \leq 0.05$).

Table 2. Paired *t* test of GWU and PAP on oscillations of selected landmark positions in the medial-lateral movement

Landmarks (proximal-distal)	GWU	PAP	*t*	df	*P* value	ES
Shoulder	-122.37 ± 7.56	-108.54 ± 5.95	-4.543	9	0.001*	0.673
Hip	-129.18 ± 4.29	-121.94 ± 4.99	-4.642	9	0.001*	0.744
Knee	82.24 ± 5.09	77.10 ± 5.15	2.241	9	0.038*	0.501
Ankle	-41.01 ± 3.55	-34.09 ± 2.54	-5.011	9	0.001*	0.792

*Significant ($P \leq 0.05$).

Figure 2. Camera placement for subject walking on the gymnastic beam: biomechanics lab setup

calcium from the sarcoplasmic reticulum and resulting in stronger muscles and improved stretching ability (18,20).

Studies have shown that increased sensitivity and performance of mechanoreceptors in muscular chains and increased inputs from these structures inside the muscle are the main reasons for improvements in sports performance. Based on the findings above, it can be argued that dynamic warm-up and PAP directly affect both neural and muscular mechanisms by influencing the regulatory sensitivity of regulatory light chain contractile protein phosphorylation, releasing more calcium from the sarcoplasmic reticulum, and contributing to neural-muscular balance improvement. This effect is probably due to the improved performance of neural and muscular systems resulting from these warm-up methods (32). In the present study, a sub-maximal repetition was used to perform the PAP protocol, and given that the primary source of changes in neural excitability and increased motor unit recruitment, it can be assumed that performing a sub-maximal repetition may lead to temporary changes in motor unit recruitment and, generally, neural-muscular changes, resulting in an improvement in balance. One possible mechanism for improved deep sensation during exercise is increased attention. Attention is a neurocognitive process through which the central nervous system influences received information. According to some researchers, another possible mechanism for justifying the improvement of deep sensation and balance during exercise could be the activation of pathways, increasing the number of synapses, and increasing the associated sensory area seen in plasticity; all of these indicate neural-muscular facilitation and increased neural-muscular coordination, which is one of the most critical factors in improving balance. However, it is unclear whether these mechanisms can justify changes in proprioceptive accuracy during exercise or and other times. Additionally, studies have shown that the voluntary output of muscular chains can be increased, improving action accuracy through tone changes (17,18,33).

In summary, incorporating PAP protocols into warm-up can optimize neural efficiency and the speed of nerve impulses, leading to stronger muscles and improved stretching. Additionally, the activation of pathways and increased synapses seen in neural plasticity imply neural-muscular facilitation and coordination, both of which are crucial for maintaining balance during gymnastic routines. By implementing PAP that enhances these neural-muscular factors, gymnasts can improve their overall balance and proprioceptive accuracy. Furthermore, the potential role of increased attention in improving deep sensation during exercise raises exciting possibilities for training approaches. Coaches could explore techniques to enhance focus and attention during gymnastic routines, potentially leading to greater neural-muscular coordination and improved balance.

The limitations of the study include the small sample size and the focus on the short-term effects of PAP. The study was conducted with a limited number of female gymnasts aged 9–12 from the city of Kerman. Therefore, the findings may not be generalizable to other populations or age groups. Additionally, the study only examined the acute impact of PAP on semi-dynamic balance while walking on the balance beam without considering other potential factors that could influence gymnastics performance. Future research should address these limitations and explore the long-term effects of PAP warm-up on gymnastics performance and injury rates. A larger sample size from diverse gymnastic populations could provide more comprehensive results on the effectiveness of PAP warm-ups. Additionally, investigating the impact of PAP warm-ups over an extended period would allow for a better understanding of its potential benefits and risks. Further studies should also consider incorporating additional outcome measures, such as objective performance metrics and subjective assessments of athlete satisfaction, to gain a more holistic understanding of the effects of PAP warm-up on gymnastics performance.

Conclusion

In conclusion, the findings of this research suggest that PAP during warm-up is likely to increase power, neuromuscular coordination, and, as a result, improve semi-dynamic balance compared to GWU. It appears that after performing the PAP warm-up protocol, proprioception and the strength and performance of muscle groups improve, resulting in improved balance and athletic performance. Therefore, it is recommended that coaches, sports teachers, parents, etc., use the PAP during warm-up in girl gymnastics training and competitions to enhance balance levels.

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Authors' Contribution

Conceptualization: Nazanin Afzali-Gorouh, Mohammadtaghi Amiri-Khorasani, Roohollah Nikooie.

Data curation: Nazanin Afzali-Gorouh, Mohammadtaghi Amiri-Khorasani, Roohollah Nikooie.

Formal analysis: Nazanin Afzali-Gorouh, Mohammadtaghi Amiri-Khorasani, Roohollah Nikooie.

Funding acquisition: Nazanin Afzali-Gorouh, Mohammadtaghi Amiri-Khorasani, Roohollah Nikooie.

Investigation: Nazanin Afzali-Gorouh, Mohammadtaghi Amiri-Khorasani, Roohollah Nikooie.

Methodology: Nazanin Afzali-Gorouh, Mohammadtaghi Amiri-Khorasani, Roohollah Nikooie.

Project administration: Mohammadtaghi Amiri-Khorasani.

Resources: Nazanin Afzali-Gorouh, Mohammadtaghi Amiri-Khorasani, Roohollah Nikooie.

Software: Nazanin Afzali-Gorouh.

Supervision: Mohammadtaghi Amiri-Khorasani, Roohollah

Nikooie.
Validation: Mohammadtaghi Amiri-Khorasani, Roohollah Nikooie.
Visualization: Mohammadtaghi Amiri-Khorasani, Roohollah Nikooie.
Writing–original draft: Nazanin Afzali-Gorouh.
Writing–review & editing: Mohammadtaghi Amiri-Khorasani, Roohollah Nikooie.

Competing Interests
The authors declare no conflict of interest concerning this research study.

Ethical Approval
This study has been approved by the Ethics Committee of Shahid Bahonar University of Kerman, Kerman, Iran (IR.UK.VETMED.REC.1398.027).

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