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EFFECTS OF STATIC AND DYNAMIC STRETCHING ON JOINT POSITION SENSE IN ARTISTIC GYMNASTS

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Abstract This study aimed to examine the effects of static and dynamic stretching as part of warm up routines on shoulder and knee joint position sense in artistic gymnasts. A randomized crossover design was employed, involving twenty-six artistic gymnastics athletes (age = 8.94 ±1.11 yr.), who performed on three separate days the following protocols: (a) 3 min of jogging followed by dynamic stretching, (b) 3 min of jogging followed by static stretching, and (c) 3 min of jogging without stretching. After the 3 protocols the athletes performed the active angle reproduction test for shoulder and knee joint position sense. The repeated measures ANOVA revealed no significant differences between static and dynamic stretching concerning shoulder and knee joint position sense. Gymnasts devote much of their training to stretching routines, resulting in exceptional flexibility compared to other athletes. Thus, warm-up stretching may not significantly alter young gymnasts' musculotendinous units, leaving their joint position sense unaffected. Moreover, the study sample consisted of young athletes, who have lower musculotendinous stiffness than adults, possibly making their joint position sense less affected by stretching due to their inherent lower stiffness. This study's findings indicate that 30-second warm-up static stretching does not adversely affect shoulder and knee joint position sense in gymnasts.

Key words: joint position sense, proprioception, gymnastics, stretching, children

Introduction

Traditionally, stretching exercises are performed during warm-up in gymnastics because they are considered to protect against injuries and enhance performance (Behm & Chaouachi, 2011; D'Anna & Gomez Paloma, 2015). However, recent literature provided evidence that pre-exercise static stretching (SS) might impair athletic performance, especially in sport activities related to maximal strength, jumping, and speed (Trajano et al., 2017).

The static stretch-induced decreases in strength and power parameters have been attributed to two mechanisms: (a) alterations in the musculotendinous unit (decreased muscle–tendon unit stiffness), and (b) disruptions in neural output, including decreased activation of motor units and changes in reflex sensitivity (Jelmini et al., 2018; Zaggelidou et al., 2023). Considering that stretching affects both extrafusal fibers and muscle spindle fibers (Guissard & Duchateau, 2004), it is reasonable to hypothesize that SS may also impair the function of muscle spindles (i.e. proprioceptive acuity) (Shah et al., 2023). Muscle spindles are intramuscular sensors that provide information about muscle length and velocity at which a muscle is stretched or contracted (Kröger & Watkins, 2021). They lie parallel to the main muscle and undergo stretching as the muscle lengthens, while they contract when the muscle shortens (Abbott et al., 2024). Therefore, alterations in the structure of muscle spindles, due to stretching, may also lead to impairments in sensory information related to the joint proprioceptive acuity (joint position sense).

Sensory information regarding joint positions plays a crucial role in enabling individuals to coordinate the movement of their body parts with respect to each other and their overall spatial orientation. A decrease in the acuity of joint position sense (afferent information from muscle spindles) could potentially lead to decreased performance (uncoordinated movements) and an increased risk of injury (Vasconcelos et al., 2018). It is widely recognized that acute SS has a short-term negative effect on extrafusal muscle fibers properties, such as muscle tendon stiffness and tendon tap reflex (T-reflex) (Behm et al., 2021; Murakami et al., 2024). However, the effects of acute SS on intrafusal muscle fibers (muscle spindles) remain relatively understudied.

A few studies investigated the impact of acute SS on joint position sense and their results have been inconclusive. Oskouei et al. (2021) reported that SS of the hamstrings affected negatively the knee joint position sense in football players. Whereas Ghaffarinejad et al. (2007) reported enhanced knee joint position sense in university students (25.6 ±1.2 years) after SS. On the contrary, Larsen et al. (2005) with a sample of university students (median age 25 years) and Torres et al. (2012) with a sample of healthy men (age: 22.1 ±2.7 years*)* reported that SS exercises have no effect on knee joint position sense. All those studies were conducted on the lower limbs; thus, their findings are limited to that specific body region. However, the performance in gymnastics depends not only on the precision of movement in the lower limbs but also in the upper limbs (Williams, 2023). To our knowledge, no study examined the effects of SS on shoulder position sense in gymnastics. Furthermore, the participants in studies examining the influence of SS on joint position sense (JPS) were adults. As far as we know, no study has compared the effects of SS and dynamic stretching (DS) on JPS in children. Children's musculotendinous units have greater compliance compared to adults, and they exhibit smaller stretch reflexes. Consequently, children may respond differently to stretching protocols compared to adults.

The purpose of the present study was to compare the effects of static and dynamic stretching on knee and shoulder position sense in young gymnasts. Since intrafusal fibers of muscle spindles exhibit thixotropic properties (Proske & Gandevia, 2012), it was hypothesized that SS might potentially modify the sensitivity of muscle spindle feedback, resulting in reduced accuracy of JPS. On the contrary, DS has been shown to increase muscle temperature and stimulate the nervous system (Herda et al., 2013), factors that are assumed to enhance the sensitivity of mechanoreceptors and potentially improve joint position sense (Sayyadi et al., 2024).

Methods

Participants

The sample size of the study was determined using G*Power (version 3.1) (Faul et al., 2007). The calculation parameters included an effect size (f) of 0.25, an alpha (α) of 0.05, and a power of 0.8. Based on G*Power's calculations, the optimal sample size is 28 children. Thirty-one guardians and children expressed interest in participating in the research (8.94 ±1.11 years old). However, the final sample consisted of 26 children because 5 children did not take part in all the procedures. The inclusion criteria for participation in the study were: (a) regular participation in artistic gymnastics training, at least 3 times per week, for a minimum duration of one year and (b) absence of acute musculoskeletal injuries, as reported by guardians.

The research adhered to the ethical guidelines of the local university. Informed consent was obtained from the children's guardians, and the children provided their oral assent. All procedures were conducted in accordance with the declaration of Helsinki.

Procedures

The participants attended an orientation session one week before the experimental protocols were performed. During this session, they were familiarized with both the stretching routines and the measures.

The study employed a randomized crossover design, comprising three experimental protocols. The three protocols were performed at the same time of the day (17:00–19:00 hr), with a period of 3–4 days between them. The order of the protocols and the tests was counterbalanced for each participant and each day to avoid carry-over effects.

Each protocol started with a 3-minute jogging at a self-selected moderate intensity (approximately 400m). After the 3-minute jogging, participants engaged in one of the three protocols: (a) 7 min SS, (b) 7 min DS or (c) sitting quietly for 7 min.

Stretching protocols

The stretching exercises targeted the main muscle groups relevant to the study's measurements. (shoulder and knee flexion): quadriceps, hamstrings, anterior deltoid, and pectoralis major (Figure 1). The typical duration of static stretching in gymnastics warm-up routines ranges between 15–30´´ per muscle group, and several studies reported that this duration is sufficient to achieve an increased range of motion (Chatzopoulos et al., 2019; Katsanis et al., 2021; Melocchi et al., 2021). Static stretching of the muscles was held for 30 s at a point of mild discomfort.

After a 10–15 s interval, the contralateral muscle group was stretched. The total duration of SS was approximately 7 min (±1 min).

The DS protocol comprised exercises that stretch the same muscle groups as in the SS protocol (Figure 1). The DS exercises lasted 30 s with a rate of approximately one stretch cycle every 2 s. The duration varied depending on the diverse range of movements performed by each participant. Each exercise consisted of 5 slow repetitions, followed by 10 repetitions performed as quickly as possible, all executed in a controlled manner without bouncing (Antonopoulos et al., 2014; Chatzopoulos et al., 2015). A similar 10–15 s rest period was provided between exercises, in accordance with the rest period in the SS protocol. The total duration of the DS was equivalent to that of the SS (7 ±1 min).

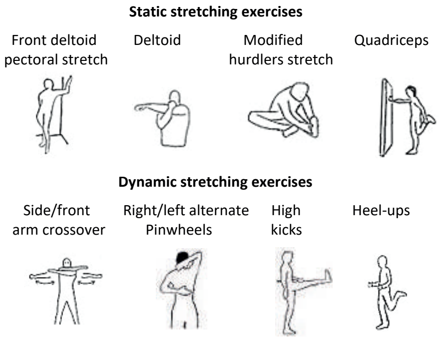

Fig. 1. Static and dynamic stretching exercises

Measurements

Shoulder and knee flexion was measured with KFORCE Sens® electrogoniometer, which offers real-time feedback of the angle on the tablet screen (measurement accuracy 1°, sampling rate 75Hz, Kinvent, France) (Tekin et al., 2022). Only the dominant arm and leg was measured. Arm dominance was determined with the question "Which hand do you use for eating?". Leg dominance was determined through the test of kicking a ball. The participants wore comfortable gymnastic clothes and shoes during the measurements to standardize proprioceptive input.

Standing shoulder flexion test

The KFORCE Sens® device was attached with Velcro fasteners perpendicular to the humeral shaft, positioned below the deltoid tuberosity (Figure 2). The participants were instructed to execute a forward flexion arm movement in the frontal plane with full elbow extension and maintaining neutral wrist flexion/extension.

Fig. 2. Standing shoulder flexion test

From a standing position with the arms relaxed at their sides, the participants were instructed to gradually flex their tested shoulder until reaching an angle of 30°, which was displayed on the tablet screen (the device provides real time feedback). After reaching the 30° angle, participants were instructed to maintain this position for 5 s and remember it. Subsequently, participants returned to the initial position with their arms relaxed at their sides. After a 5-second interval, they were asked to reproduce the memorized angle with closed eyes (blindfolded). Upon reaching what they perceived as the memorized reference position, they indicated to the examiner by saying “here,” and their angle was recorded. After one practice trial, participants performed 3 trials with a resting period of 3 s. The mean of the 3 absolute differences between the 30° angle and the reproduced angle (blindfolded) was used for data analysis.

Standing knee flexion test

The KFORCE Sens® device was attached by Velcro fasteners above the lateral malleolus. The participants stood on a wooden platform (15 cm high) on their non-dominant leg, while their dominant leg hung freely beside the platform (Figure 3). The opposite hand of their dominant leg was attached to the wall to maintain their balance (Chatzopoulos, 2019).

Fig. 3. Standing knee flexion test

The participants were instructed to flex their dominant knee until reaching the angle of 30°. The angle was displayed on the tablet screen (the application provides real time feedback). Once the leg had reached the 30° angle, the participants were instructed to stop there and remember this knee angle (position) for about 5 s. Then, the participants returned to the starting position, and after 5 s they were asked to reproduce the memorized knee angle without screen feedback (the screen was removed from their field of vision). When the participants felt they had reached the memorized angle position, they notified the examiner by saying “here,” and the angle was recorded. After one practice trial participants underwent three trials with a restin°g period of 3 s. For data analysis, the mean of the three absolute differences between the 30° angle and the reproduced angle (without feedback) was calculated.

Statistical analysis

The differences among the three protocols were analyzed using one-way Analysis of Variance (ANOVA) repeated measures. In case the assumption of sphericity was violated, the Greenhouse-Geisser correction was applied. Effect sizes of ANOVA are presented as partial eta square values (η_p^2 small effect: 0.02; medium effect: 0.13; and large effect: 0.26). Post hoc analyses were conducted using the Holm-Sidak method for multiple comparisons.

Reliability was assessed using a two-way, random-effects, single measure Intraclass Correlation Coefficient (ICC 2,1). The ICC values were interpreted according to the guidelines of Hallgren (2012), that is, ICCs < 0.40 were labelled “poor”, 0.40–0.74 “fair to good”, >0.75 “excellent”. All statistical analyses were carried out employing SPSS (version 28). Statistical significance was set at $p \leq 0.05$.

Results

The descriptive statistics for the dependent variables are presented in Table 1.

Table 1. Descriptive data of shoulder and knee JPS tests

Joint position sense test	No stretching	Static stretching	Dynamic stretching
Shoulder (°)	2.79 ±1.60	3.76 ±2.03	3.09 ±1.70
Knee (°)	3.85 ±2.17	4.17 ±2.04	4.03 ±2.24

Shoulder joint position sense

There was no significant difference between the three protocols ($F = 2.08$, $p = 0.135$, partial eta squared $\eta_p^2 = 0.077$). Specifically, there was no significant difference between NS and SS ($p = 0.100$), NS and DS ($p = 0.926$) and between SS and DS ($p = 0.451$).

Knee joint position sense

Mauchly’s Test of Sphericity indicated a violation of the assumption of sphericity ($\chi^2 = 6.756$, $p = 0.034$), and a Greenhouse-Geisser correction was applied. There was no significant difference between the three protocols ($F = 2.07$, $p = 0.766$, $\eta_p^2 = 0.008$). Specifically, there was no significant difference between NS and SS ($p = 0.772$), NS and DS ($p = 0.986$) and between SS and DS ($p = 0.991$).

Reliability of the measurements

The reliability of the shoulder and knee flexion tests was assessed using the test–retest method in a pilot study involving 10 children (aged 9–10 years), conducted one week prior to the main study. The children underwent a retest 48 hours following the initial assessment, and the intraclass reliability coefficients were satisfactory (knee ICC2,1 = 0.615, shoulder ICC2,1 = 0.64). The children involved in the reliability measurements were not included in the main study.

Discussion

The aim of this study was to investigate the acute effects of static and dynamic stretching on joint position sense (JPS) in the upper and lower limbs of young gymnasts. Contrary to the hypothesis, the results did not indicate that static stretching (SS) would result in a reduction in knee and shoulder JPS of young gymnasts. Moreover, the findings did not support the hypothesis of an increase in JPS following dynamic stretching (DS).

The finding of the present study that SS does not affect JPS agree with the results of Torres et al. (2012) and Larsen et al. (2005). Indeed, Torres et al. (2012) reported no effects on knee JPS after 10 passive stretches lasting 30 s each (sample age: 22.1 ±2.7 years), and Larsen et al. (2005) no effects on knee JPS after 3 × 30 s SS (sample median age 25 years, range 21–31). Thus, it could be concluded that the results of this studies do not support the hypothesis that SS affects the viscoelastic properties of the muscle spindles and alters their proprioceptive sensitivity. However, another possible explanation for the no significant findings could be that sensory inputs are not restricted to muscle spindles (Riemann & Lephart, 2002). Proprioceptive input originates from various receptor submodalities situated in distinct tissues (e.g. muscle, tendon, skin ligamentous) (Cordo et al., 2011). It is quite probable that the relative importance of each receptor varies depending on the task. For instance, studies have demonstrated that skin receptors fire reliably in relation to the position and movement of adjacent joints (Cordo et al., 2011). In addition, articular afferents also convey information regarding position and movement in an additive manner with muscle and skin afferents. The cumulative nature of these signals, whether proportional or not, suggests that the sum of these afferent responds dictates the magnitude of sensation (Collins et al., 2005). Consequently, it seems that the descending commands from the central nervous system depend on the comprehensive processing of information originating from various receptors, and not exclusively from muscle spindles (Proske & Gandevia, 2012).

In contrast to our neutral findings, Walsh (2017) documented enhancements in knee JPS among 10 athletes competing in various sports (rugby, soccer and tennis) following SS (90 s duration). On the contrary, Oskouei et al. (2021) demonstrated that the SS of the hamstrings had an adverse impact on knee joint position sense in a sample of 12 adult football players (3 × 30 s). Apart from the variations in stretching procedures (e.g. pre-stretching aerobic activity, stretching duration, intensity), one significant difference between the previous studies and ours lies in the composition of the sample. The samples in the previous studies comprised athletes participating in sports with low flexibility demands (e.g. soccer, basketball), while ours consisted of gymnastics athletes. In gymnastics the level of technical and artistic perfection is determined by the range of motion (RoM) an athlete can achieve during the execution of these movements (Batista et al., 2019). For this reason, stretching exercises play a substantial role in daily gymnastics training, resulting in exceptionally high levels of flexibility compared to athletes in other sports (e.g., soccer, basketball, track and field) (Vernetta et al., 2022). Thus, it is possible that the stretching exercises of our study may not induce significant alterations in the musculotendinous unit of the gymnastics athletes, and consequently their JPS was not affected. Future research comparing samples with different levels of flexibility may help clarify this issue.

Regarding DS, the results of the present study showed no significant difference with NS (only jogging, without stretching), neither a difference compared to SS. The results of the current study agree with Younis et al. (2018) who reported no significant improvements in knee JPS after DS and proprioceptive neuromuscular facilitation (PNF) stretching (6 × 10 s contraction followed by 20 s of stretching). In addition, Romero-Franco et al. (2020) reported no differences between the SS group (5 min of running followed by 20 s SS) and the DS group (20 repetitions each muscle, gastrocnemius, hamstrings and quadriceps) in knee JPS. On the contrary Pamboris et al. (2019) reported that slow DS resulted in a better performance compared to pretesting (adult participants). Whereas Chen et al. (2018) reported decreased accuracy of knee JPS after DS (6 × 8 repetitions per set, total 48 repetitions). The divergent findings could be attributed to various factors, including muscle groups, stretching velocity, level of physical conditioning, and the testing protocol employed (e.g., passive repositioning test versus active).

Previous studies have suggested that active repositioning tests may provide a more precise evaluation of joint performance compared to passive tests (Benjaminse et al., 2009; Sayyadi et al., 2024). During active repositioning tests, participants can adjust the angle, while in passive repositioning, participants can only stop the movement at a point without adjustment (Ghanbari et al, 2014). In our study the active repositioning test was applied, and the participants showed high repositioning performance (the absolute difference was only a few degrees). Therefore, perhaps it was difficult to enhance this already high level of repositioning performance any further.

To our knowledge this is the first study that examined the effects of stretching on young children’s JPS. Hence, comparisons between the results of previous studies and the present one should be approached with caution, considering the different viscoelastic properties of the muscle-tendon units between children and adults (Kubo et al., 2001). Children display lower musculotendinous stiffness compared to adults and their JPS may therefore be less affected by stretching. Future studies could explore whether children's JPS responds differently to stretching compared to adults.

The limitation of the study pertains to the characteristics of the sample (young gymnasts with high level of flexibility). Thus, the findings might not be applicable to other athletic populations. Another limitation refers to the subjective stretching in SS and DS. Despite instructing participants during SS to stretch "at a point of mild discomfort" and during DS to stretch "as high as possible," it was not possible to ascertain whether they exerted their maximum effort.

Conclusions

The successful execution of the technical elements in artistic gymnastics demands extreme flexibility levels (Di Cagno et al., 2014). For this reason, SS are an integral part of the warm-up routines in gymnastics. The findings of the present study suggest that a practical duration of warm-up SS of 30 s has no detrimental effects on shoulder and knee JPS.

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