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The Acute Effects of Whole-Body Vibration Training on Passive and Dynamic Flexibility in Gymnasts

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ABSTRACT

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Gymnasts must attain extreme ranges of flexibility to execute performance requirements, thus effective stretching proves vital to advancement in the sport. This study examined the acute effects of whole-body vibration (WBV) on passive and dynamic flexibility in young, female gymnasts. Participants ($n = 27$, Junior Olympic levels 5-10) served as their own control. Measurements of passive and dynamic flexibility were obtained using the TOPS forward split testing method to examine passive flexibility and dynamic flexibility was measured via split jumps that were analyzed with video and Dartfish software. According to randomized order, all participants completed a stretching protocol either with the WBV platform turned on (VIB) or off (C) separated by 48 h. Participants performed 4 sets of three stretches on the WBV platform. An ANCOVA was performed (using height, weight, age, years of experience, and gymnastics level as covariates). Significant improvements were found in passive flexibility for both VIB and C conditions, but there was no significant difference between the two stretching conditions ($p = 0.17$). The maximum split jump decreased significantly from pre to post measurement in both the VIB ($p < 0.0001$) and C ($p = 0.04$) conditions. VIB decreased the split jump significantly more than C. Based on the results of our study, an acute session of static stretching or stretching with WBV immediately before performance decreases split jump performance. Therefore, this WBV protocol is not recommended immediately prior to gymnastics competition.

Keywords: whole-body vibration, flexibility, gymnastics

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Introduction

Flexibility, both passive and dynamic, proves a crucial aspect of multiple sports (Decoster, Scanlon, Horn, & Cleland, 2004; Law et al., 2009). Whether extreme ranges of motion are necessary for skill execution or evidence of technique, such as track hurdles or split jumps in gymnastics, certain athletes must strive to improve flexibility for advancement within their sport (Folpp, Deall, Harvey, & Gwinn, 2006; Johnson, Mitchell, Meek, & Feland, 2013). Additionally, flexibility is important for talent identification and screening measures for gymnasts, divers, and dancers (Sands, McNeal, Stone, Russell, & Jemni, 2006). Flexibility is crucial in gymnastics since performance assessments result in deductions when precise positions cannot be attained (USA Gymnastics Code of Points). Therefore, determining the best approach for developing essential ranges of motion, both passively and dynamically, are important for improving a gymnast's performance.

Whole-body vibration (WBV) may be a modality that can be used to increase passive and dynamic flexibility (Feland et al., 2010b; Sands, McNeal, Stone, Haff, & Kinser, 2008). WBV training has been studied as it relates to tonic vibration reflex (Issurin, Liebermann, & Tenenbaum, 1994), motor control (Haas, Turbanski, Kessler, & Schmidtbleicher, 2006), muscle tension (Abercromby et al., 2007) and strength development (Delecluse, Roelants, & Verschueren, 2003; Johnson et al., 2010; Sands et al., 2006). Additionally, performance enhancement via WBV training has been demonstrated to increase vertical jump (Cardinale & Lim, 2003), strength (Marin & Rhea, 2010), and flexibility (Feland et al., 2010b; Issurin et al., 1994). Sands et. al hypothesized the mechanisms for increased ranges of motion resulting from WBV and stretching include increased temperature, increased relaxation, decreased myotatic reflex activity, reduction of phasic and static stretch reflexes via intrafusal muscle fatigue, and reduced pain (Sands, McNeal, Stone, Haff, et al., 2008). Additionally, improved neural efficiency through enhancement of the stretch-reflex loop (Cardinale & Lim, 2003), and increased motor unit recruitment have been hypothesized (De Gail, Lance, & Neilson, 1966).

Research on the effects of WBV training on flexibility has primarily documented increases in passive flexibility (Feland et al., 2010b; Kinser et al., 2008; Sands, McNeal, Stone, Haff, et al., 2008; Sands, McNeal, Stone, Kimmel, et al., 2008; Sands et al., 2006). Such studies have reported an increase in passive flexibility of forward splits (Kinser et al., 2008; Sands, McNeal, Stone, Haff, et al., 2008; Sands, McNeal, Stone, Kimmel, et al., 2008; Sands et al., 2006); sit and reach assessments (Atha & Wheatley, 1976; Cardinale & Lim, 2003; Cochrane & Stannard, 2005; Fagnani, Giombini, Di Cesare, Pigozzi, & Di Salvo, 2006; Issurin et al., 1994; van den Tillaar, 2006); and passive knee extension measurements (Feland et al., 2010b). Only a couple studies have focused on dynamic range of motion (ROM) (Cronin, Nash, & Whatman, 2008) or active flexibility (Sands, McNeal, Stone, Kimmel, et al., 2008). Cronin et al. investigated dynamic ROM in male athletes and found significant improvement in passive hamstring stretching, but no statistical difference in dynamic ROM resulting from vibration or simultaneous vibration and stretching protocols. Moreover, Sands et al. (2008) examined dynamic ROM in elite synchronized swimmers and reported increases in passive, but not dynamic, flexibility. This was an acute response following WBV training intervention involving one set of 2 stretches, each held for 40 s. Furthermore, their results were limited to adult elite athletes who have possibly reached their maximal range of motion without intense interventions. WBV might be more effective in improving flexibility in novice athletes due to training plateaus in more flexible athletes. Thus, the influence of WBV on passive flexibility and the presumed corresponding dynamic flexibility is not clear.

The purpose of this study was to examine the effectiveness of acute WBV training on both passive and dynamic flexibility in novice and advanced competitive gymnasts. We hypothesized that an acute session of WBV training would produce significant improvements in both passive and dynamic flexibility as seen in the static forward split and compulsory split jump performed by female gymnasts.

Methods

Experimental Approach to the Problem

We conducted this study to determine if one session of lower extremity stretching on a whole-body vibration platform would increase passive and dynamic flexibility in young female gymnasts. The gymnasts who participated in the study were levels 5 to 10 according to the USA Gymnastics Junior Olympic Program and between the ages of 9 to 15 y. We used the Talent Opportunity Program (TOPS) method (Sands, et al., 2006) of testing to measure passive flexibility and video analysis to assess the degree of dynamic flexibility during the compulsory split jump maneuver. Young female gymnasts reported to the gym and after a typical 20 min warm-up for participation in gymnastics, including cardio warm up, and stretching muscles and gymnastics positions, each participant was assessed for flexibility first by the TOPS method and then each participant completed three standing split jumps. Instruction and supervision of the stretches was provided by the same trained researcher. These measurements were recorded by video for later analysis by another researcher blinded to condition. After the initial measurement participants completed either the experimental stretching condition consisting of 4 sets of three stretches simultaneously with the WBV platform set at a fixed frequency of 30 Hz and 2 mm amplitude or a control condition where participants completed the same 4 sets of three stretches with the WBV platform turned off. The experimental or control condition order was randomly assigned to each participant by a random draw and stretching days were separated by at least 48 h. Gymnasts' flexibility was reassessed using the same procedure as the pretest. All gymnasts were seen at the same time of day, completed the same warm-up each day, and were encouraged to follow the same pre-participation routine.

Subjects

Twenty-seven competitive female gymnasts, levels 5-10 ranging in age from 9-15 y, participated in the study as volunteers (age: 12 ± 2 y; height: 1.46 ± 0.1 m; weight: 40 ± 8.4 kg; years in gymnastics: 7.2 ± 2.8 y; gymnastic level: 7.3 ± 1.7). Exclusion criteria included recent lower extremity or back injury, current menstruation, or related surgery within the past year. The Institutional Review Board at Brigham Young University approved this study. All subjects gave individual written assent and signed parental consent after thorough explanation of procedures and study expectations. A priori power assessment of sample size (power set at 0.8, alpha set at 0.05) indicated that we needed 20 individuals to detect a difference of 2.0 cm with a standard deviation of 2.2 cm (reported by (Sands, McNeal, Stone, Kimmel, et al., 2008) and 19 individuals to detect a dynamic flexibility difference of 4° with a standard deviation of 4.3°.

Procedures

All gymnasts qualifying to participate in this study reported to their typical training center, where the researchers met with them and explained the procedures of the study. After completing normal warm up procedures, 5 min of cardio warm-up followed by 15 min of stretching muscles and gymnastics positions, each subject was initially tested for passive forward split flexibility on her preferred dominant leg using the TOPS method of testing as previously described (Kinser et al., 2008; Sands, McNeal, Stone, Haff, et al., 2008; Sands, McNeal, Stone, Kimmel, et al., 2008; Sands et al., 2006). The gymnast then performed three split jumps, which were videotaped to assess dynamic flexibility. After obtaining baseline measurements, each subject was counter-balanced assigned to order of treatment for both conditions: either the stretch with vibration (VIB) or stretch without vibration control condition (C) by a random draw.

Each subject performed 4 sets of three stretches with vibration at a fixed frequency of 30 Hz and 2 mm amplitude, or with the vibration platform turned off according to condition assignment for that particular day. The first stretch had the gymnast place her rear thigh on top of the WBV platform in a lunge position, while leaning her shoulders back to focus the stretch on the thigh and hip flexors (Figure 1). For the second stretch, the gymnast knelt on her rear leg with her knee flexed at 90° while the front leg was extended 180° at the knee and supported by the WBV platform under the hamstrings (Figure 2). Finally, the third stretch had the gymnast assume a forward split with her forward heel supported on the WBV platform (Figure 3). Each stretch was held for 30 s with 5 s rest in between each position taking a total of 7 min to complete the whole cycle. Flexibility measurements were reassessed using the same protocol as during the pre-test. The second experimental condition was performed at least 48 h later with subsequent flexibility measurements.

Measurements

For the passive flexibility evaluation, the researcher implemented the TOPS method by measuring the distance from the anterior superior iliac spine to the floor with a meter stick while the subject assumed her dominant forward split keeping her hips squared, back knee flexed with shin vertically supported by a standard sized gymnastics spotting block. The forward split leg was placed on a gymnastics mat to prevent the gymnast from achieving a "flat" split where the ischial tuberosity touches the floor (Sands, McNeal, Stone, Haff, et al., 2008; Sands, McNeal, Stone, Kimmel, et al., 2008). A photograph was taken of the measurement for assessment at a later time by a researcher blinded to the condition. A vertical meter stick was included in the photograph positioned next to the gymnast to set a reference distance for the later measurement. Only one measurement was taken and recorded for use in data analysis. The intra-rater reliability of the TOPS measure of passive flexibility was assessed by having the same person record two separate measurements in 20 individuals yielding an Intraclass Correlation Coefficient ($ICC_{3,1}$) of 0.99.

In order to assess dynamic flexibility, each subject completed two warm-up split jumps before being videotaped for her best of three. Dartfish software (Alpharetta, GA, USA) was used to evaluate the angle (defined for this study as a line from the toe at the head of the first metatarsal of the leading foot to the pubic bone and then to the toes of the trailing foot) achieved at the maximum height of the split jump. The video camera (Casio Ex-FH25, Casio Computer Co., Tokyo, Japan) was set to high-speed video at a frame rate of 100 frames per second in order to capture the fullest extent of split during the jump. The video camera was positioned 5 m from the location of the split jump in order to minimize image distortion. Subjects were asked to perform three split jumps with a rest of 15 s between each attempt. Subjects were encouraged to perform a maximal or "best" split jump by verbal encouragement. The average and maximum of the three jumps was used for data analysis. A meter stick was used to set a reference distance for use in the later analysis by another blinded researcher. The intra-rater reliability of the dynamic flexibility was assessed by having the same researcher assess the split jump angle of three separate trials of 27 individuals yielding an $ICC_{3,1}$ of 0.97.

Statistical Analysis

This study employed a 2×2 within subject repeated measures experimental cross-over design. The independent variable for this study included condition (VIB and C), while the dependent variables were passive (TOPS method forward split) and dynamic (split jump) flexibility. Reliability in obtaining the passive flexibility measurements was assessed for the researcher taking these measurements and the reliability of the dynamic flexibility was assessed for the individual analyzing the videos of the split jumps.

An ANCOVA was used to analyze differences in passive and dynamic flexibility among the control and experimental conditions for this study. Post-Hoc testing was done as needed to determine where differences in passive and dynamic flexibility existed between the conditions. We used height, weight, age, years of experience, and gymnast level as covariates in this study. The means and standard deviations are reported in results.

Results

Stretching, under both conditions, significantly improved passive flexibility in gymnasts. Both VIB and C conditions improved the TOPS forward split test score showing a significant within difference pre to post measurement. There was no significant difference in passive flexibility between the 2 stretching conditions ($p = 0.17$). The VIB condition improved the TOPS score by -1.75 ± 1.2 cm ($p < 0.0001$), while C improved the TOPS score by -1.35 ± 1.2 cm ($p < 0.0001$), see Table 1. However, both treatment conditions negatively affected the maximum split jump results. The maximum split jump decreased significantly from pre to post measurement in both the VIB ($p < 0.0001$) and C ($p = 0.04$) conditions. VIB decreased the split jump by $5.83° \pm 5.9°$, which was significantly more than C ($2.56° \pm 6.1°$) ($p = 0.02$).

Discussion

The purpose of this study was to examine the effectiveness of an acute bout of WBV training on passive and dynamic flexibility in competitive gymnasts. Both stretching with (VIB) and without (C) significantly improved passive flexibility. However, both conditions also negatively impacted dynamic flexibility, and VIB had a greater negative impact on the split jump. Even though our results are only representative of acute change, it would be interesting to study the effects of stretching with vibration over a training period of weeks or months on changes in passive flexibility in gymnast. Prior multi-week studies have shown faster progressive increases in hamstring flexibility when stretching with vibration (Feland et al., 2010b) and this may help gymnasts struggling to reach split flexibility requirements, such as younger gymnasts. Additional research needs to explore the best ways for gymnasts to translate passive flexibility to dynamic flexibility. Gymnasts spend hours working on their passive flexibility in order to apply that flexibility in a dynamic skill.

Our results show that stretching under both conditions decreased dynamic flexibility as measured performing the compulsory split jump. Since our split jump was performed within 1-2 min following each stretching session, our results may be reflective of static stretch induced performance impairment. Due to the nature of the split jump (a vertical jump with a split at the height of the jump) the potential deleterious effects of stretching on power (Bacurau et al., 2009; Cornwell, Nelson, & Sidaway, 2002) may have overridden the effects of WBV on vertical jump in our study. A recent research finding indicates that extended static stretching can decrease dynamic flexibility (Page, 2012). Another study in adolescent boys and girls reported that static stretching significantly negated sprinting performance and explosive power (Paradisis et al., 2013). The mechanism behind performance impairment following static stretching is not clear, nor is it in agreement. But, it is possible that aggressive stretching reduces the excitatory drive from Ia afferents to the motor neuron (Avela, Kyrolainen, & Komi, 1999), and this in turn could affect the number of muscle fibers that could be activated (Beedle, Rytter, Healy, & Ward, 2008).

The finding that our stretching protocol with WBV magnified decreased dynamic flexibility was unexpected and adds to the inconclusive research on the subject. Previous research using WBV combined with stretching did not significantly increase the particular measure of dynamic flexibility used in other studies (Cronin et al., 2008; Jacobs & Burns, 2009; Sands, McNeal, Stone, Kimmel, et al., 2008). However, measures of dynamic flexibility in these studies lacked a power aspect that is needed in the compulsory split jump. Prior studies suggest that WBV training can improve power output and vertical jump (Annino et al., 2007; Cochrane & Stannard, 2005; Wyon, Guinan, & Hawkey, 2010). The suggested increase in vertical height would perhaps lead to a greater predicted ability to perform the split jump. This possible effect seems to be enhanced by vibration. The muscles contracting during the vertical jump are used to produce a powerful upward movement. These muscles would include the gluteus maximus, hamstrings, quadriceps and gastrocnemius. The facilitation of these muscles to increase power output may inhibit their ability to stretch due to an increased tone in the muscles (Osawa, Oguma, & Ishii, 2013).

The long-term use of WBV on overall flexibility in gymnasts and its effect on their performance is not known. Since WBV application has been found to enhance muscle activation, and hence, muscle work (Perchthaler, Horstmann, & Grau, 2013), perhaps stretching with WBV may improve ROM and not hinder dynamic performance if there is a sufficient rest time between the application of stretch with WBV. The particular protocol used in this study significantly decreased the dynamic flexibility as measured by a split jump. Our protocol, similar to other protocols of vibration used with gymnasts, placed only a portion of the lower limb on the vibration platform, so it may have functioned more as locally applied form of vibration. Perhaps a more full body vibration protocol similar to the one used by Feland et al (Feland et al., 2010b), where the athlete stands with full body weight on the platform and then assumes a stretching position would have produced different results. Furthermore, a recent meta-analysis suggests that longer exposure to vibration may be necessary to elicit strength effects in a younger population (Osawa et al., 2013). However, it appears more research is needed to determine the best vibration protocols to produce strength benefits for improving vertical jump in younger subjects. Additional research has shown that WBV training can be combined with stretching to increase flexibility without impeding jumping ability or explosive strength (Gerodimos et al., 2010; Kinser et al., 2008). WBV protocols involving half-squat (demi-plié) holds for 30-40 s with similar frequencies and amplitudes found significant improvements in jump height for trained dancers (Annino et al., 2007; Wyon et al., 2010). Further research is needed to determine the best method or delivery of vibration during stretching to improve passive flexibility that translates into dynamic flexibility improvement of younger gymnasts. Perhaps protocols involving stretching with WBV along with non-stretching WBV training would be beneficial for improving both passive and dynamic flexibility.

There are limitations to this study. One limitation was using the TOPS method to assess passive flexibility, despite it being used in other studies investigating the effect of vibration on flexibility in gymnasts. The issue is that flexible athletes can potentially reach a point where no further flexibility can be accurately assessed due to the athlete contacting the floor with maximal compression of the pelvis. This would then become a measurement of the height of the pelvis rather than a measure of flexibility. The use of an elevated surface to bolster the forward leg and increase the potential downward movement of the pelvis and stretching of muscles and other tissues would be required to accurately measure the full change in ROM. In our study, some of the athletes may have reached this point and we did not use a bolster in order to keep the TOPS method consistent in all participants. This may explain why we were not able to detect a difference in passive flexibility between our two conditions. Other research has indicated that stretching with WBV is superior to stretching alone (Cochrane & Stannard, 2005; Fagnani et al., 2006; Feland et al., 2010b; Issurin et al., 1994; Kinser et al., 2008; Sands et al., 2006; van den Tillaar, 2006). We may have had similar results but were not able to detect it due to the limitation of not using a block or bolster during the passive flexibility testing.

Practical Applications

Flexibility is a crucial aspect of gymnastics, since gymnasts must attain extreme dynamic ROM to execute performance requirements. Based on the results of our study, both static stretching and stretching with WBV improved passive flexibility. However, we were not able to detect a significant difference between stretching with WBV and normal static stretching in passive flexibility. Both VIB and C decreased split jump performance with VIB producing a greater decrement to the dynamic split jump. Perhaps the effect of aggressive stretching decreased the power output needed to optimally perform the split jump. Additionally, the possible fatigue created by the increased work of the muscles during WBV further hindered the performance in the split jump. Thus, the vibration could have induced more fatigue necessitating a longer rest period between application and performance. Therefore, this WBV protocol is not recommended immediately prior to gymnastics competition.

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Table 1. Pre and Post Passive and Dynamic Flexibility Measurements

Passive Flexibility			**Dynamic Flexibility**		
TOPS forward split	Pre (cm)	Post (cm)	**Split Jump**	Pre (°)	Post (°)
WBV	14.9 ± 6.2	13.3 ± 3.9*	**WBV**	166.6 ± 13.5	160.8 ± 18.6*†
Control	15.0 ± 8.8	13.5 ± 4.7*	**Control**	167.6 ± 14.7	165.3 ± 16.4*

*Significant difference between pre and post ($p < 0.05$).

†Significantly different than control ($p = 0.02$).

Figure 1. Stretching position 1

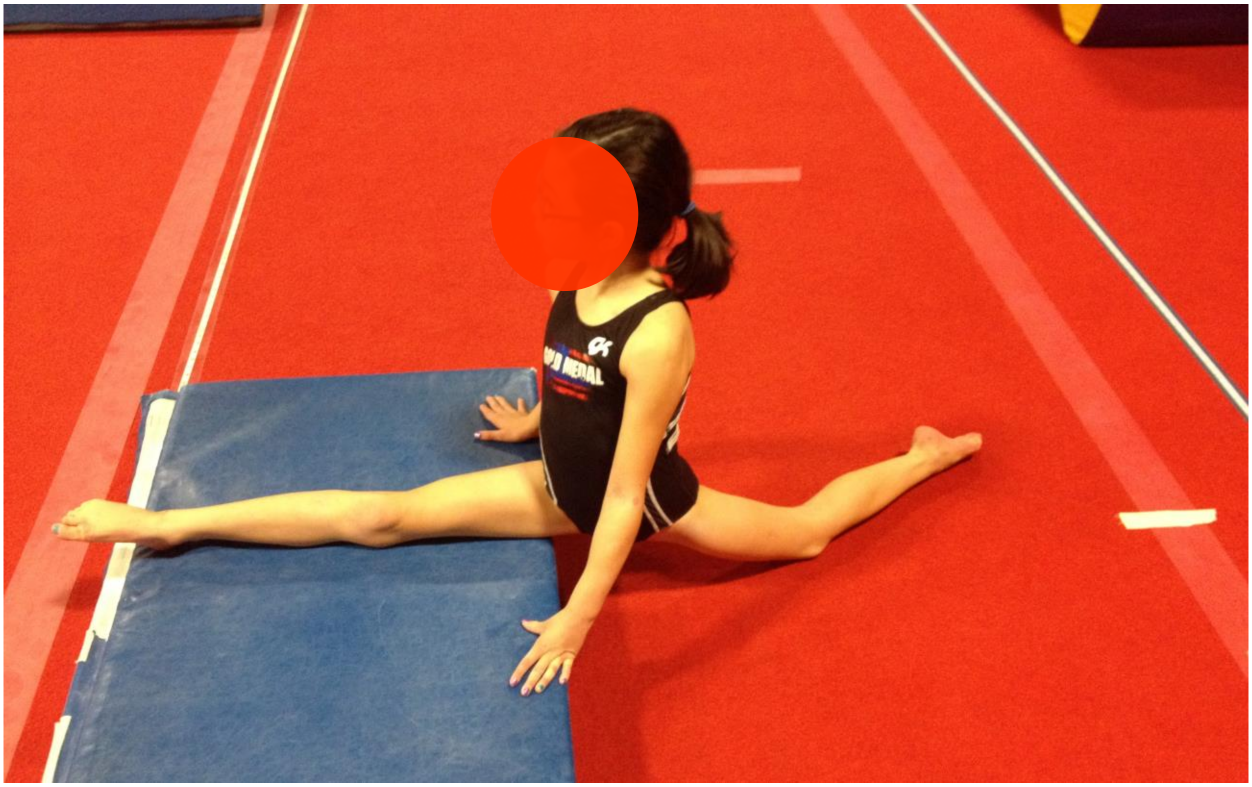

Figure 2. Stretching position 2

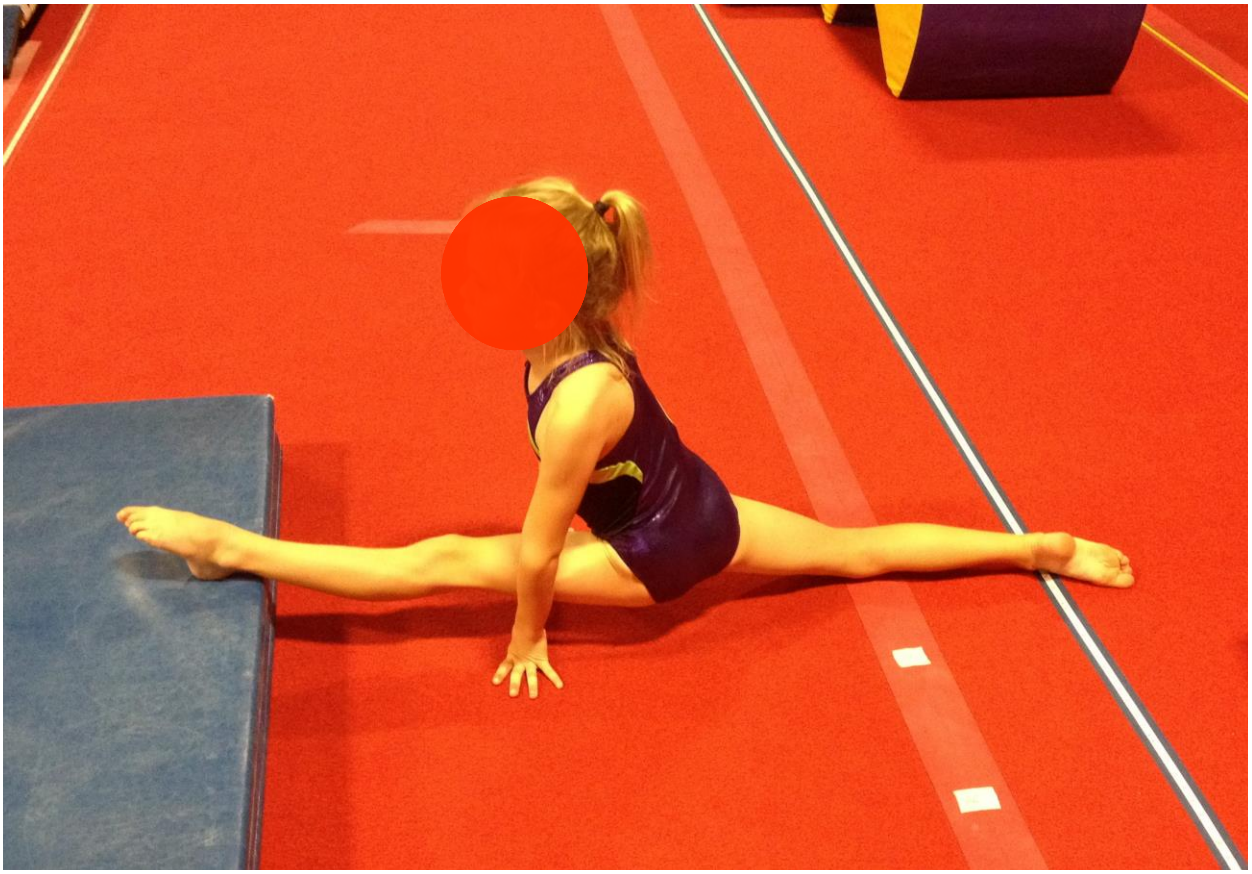

Figure 3. Stretching position 3