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A COMBINED SENSORIMOTOR SKILL AND STRENGTH TRAINING PROGRAM IMPROVES POSTURAL STEADINESS IN RHYTHMIC SPORTS ATHLETES

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ABSTRACT

Purpose. The aim of this controlled trial was to evaluate the effects of a combined sensorimotor skill and strength training program on postural steadiness in junior females performing rhythmic sports gymnastics. **Basic procedures.** Twenty-six rhythmic sports athletes, aged 9 to 12 years, were randomized into one of two groups; a 6-week experimental group or to a control group, (during the 2004–2005 training period). In the experimental group, a sensorimotor and back-muscle-strengthening regime was added to the everyday training, while the control group continued with their ordinary training. Before and after the intervention, and at a 12-month follow, bipedal-stance center of foot pressure (CoP) sway area was examined with a statokinesigram indicating amplitude of vertical pressure fluctuations after stimulation of the vestibular system, and the distribution of body weight between legs. **Main findings.** At the 6-week follow-up, the experimental group had a larger decrement in CoP sway area (–59%, $p = 0.004$) and in asymmetrical body weight distribution (–58%, $p < 0.001$) compared to the control group (–0.1% and 2.3%, respectively), but not at the 12-month follow-up. **Conclusions.** The present sensorimotor skill and strength training program indicated short-term improved postural steadiness in rhythmic sports athletes. Exercises that specifically emphasize somatosensory and back strength aspects of training for postural steadiness may advantageously be integrated into their training routines.

Key words: Body weight distribution, CoP sway, motor control, sensorimotor skills, training regime

Introduction

In rhythmic sports gymnastics accurate and well-trained balance and control of postural steadiness are important for the gymnast's ability to accomplish good performance [1] as well as for injury prevention [2]. Studies indicate that gymnasts have particularly developed the ability to integrate relevant information from sensory systems for regulating posture [3, 4]. Results also indicate that postural skills are affected by threats to posture [5] and that different training strategies may improve postural stability [6–10]. However, repeated asymmetric training of the spine seems typical, and a high incidence of scoliotic spine has been found in female rhythmic sports athletes [11]. Experience from our group is also that rhythmic sports gymnastics training – especially in young females – often leads to asymmetric development of the back musculature. One sees a "weak diagonal", with weaker low-back muscles above the unpreferred stance leg and weak contra-lateral shoulder musculature. Here, our preliminary stance-postural observations indicate that young rhythmic sports athletes distribute their body weight unevenly between their feet in quiet bipedal stance, seeming to load the preferred-stance leg more than the other. Moreover, a Bulgarian study [11] indicated that rhythmic sports gymnastic training involves asymmetric loading for the upper limbs as athletes mainly use their "strong" hand during rhythmic sports gymnastics to ensure better control and performance. This asymmetric loading of the spine and extremities may hypothetically alter the sense of positioning and perhaps increase the risk for injuries. It seems reasonable, however, that sensorimotor skill program may enhance or normalize postural steadiness and sense of stance positioning. Hitherto, little is known about the effects of such exercise skill programs in rhythmic sports athletes. We therefore evaluated the efficacy of a specific sensorimotor and muscle-strengthening regime on postural steadiness and body weight dis-

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tribution. Our hypothesis was that the present intervention might improve postural steadiness, expressed as decreased postural sway area and normalization of body weight distribution between legs in bipedal stance.

Material and methods

Study design

This study was a prospective controlled trial with unblinded treatment and blinded outcome assessments. An initial power calculation at 80%, to detect a potential 30% ($\alpha < 0.05$) reduction in center of pressure (CoP) sway area, (based on our preliminary measurements), revealed that a sample of 13 subjects in each group was needed. Posturographic evaluation measurements of CoP and body weight distribution were done before and directly after the intervention, and 12 months later. Intention-to-treat analyses were performed, that is, the analysis procedure and the conclusion were based on all participants originally assigned to each of the groups. The Research Ethics Committee at the Technological Educational Institute of Thessaloniki approved the study protocol. Together with their parents, the subjects were informed about the study and prior written consent was obtained.

Subjects

Twenty-six healthy, junior rhythmic sports athletes from three rhythmic sports gymnastic clubs in Thessaloniki, Greece, volunteered and were enrolled. Subjects were included if they had had at least three years of intensive training (> 6 hrs $\cdot$ wk^{1}) and no record of previous severe injuries or other relevant pathology. Mean (SD) for age, weight, height and number of years of participating in rhythmic sports gymnastics were: 10.9 (1.52) years, 33.2 (7.5) kg, 1.42 (0.10) m, and 5.1 (1.29) years participating in rhythmic sports gymnastics, respectively. After baseline measurements, an independent observer first matched the subjects pair-wise by age and years of participating in rhythmic sports gymnastics. In each matched pair, the subjects were then assigned to either the experimental group or the control group by chance (the observer tossed a coin). The experimental group underwent a multimodal training regime, including sensorimotor-skill and back-muscle-strengthening exercises, while the control group had no additional intervention.

Intervention

During a study period of 6 weeks a senior physiotherapist, not involved in the pre- and post evaluations, supervised all intervention training in the experimental group. The program was run four times a week after daily rhythmic sports gymnastics training and consisted of five exercises lasting 30 min in total. Three of the exercises were designed to “manipulate” the vestibular system, possible changing (reweighing) the central processing of the somatosensory signals. These exercises are part of a vestibular training program described by Gans [12]. The exercises, to the best of our knowledge, have not yet been evaluated in other studies. However, clinical experience has shown that the exercises were very useful for increasing the vestibular capacity of both patients and healthy individuals. A high vestibular capacity is thought to be crucial for good performance of rhythmic sports athletes. The other two exercises were designed to strengthen the back and shoulder musculature of the “weak diagonal”. These exercises are common excercises in other sports, but have not yet been used regularly in rhythmic sports gymnastic training. The exercises were as follows:

Sensorimotor skill exercises

Horizontal head movements. Starting in quiet bipedal stance, with arms relaxed along the body, head facing straightforward. While keeping the trunk still, the gymnast quickly turned her head to the right, then to the left and then returned to forward-looking position, which was maintained for 2 seconds. In all movement directions, the gymnasts were told to maintain eye focus on a point on the wall directly ahead. This procedure was repeated 16 times, for three sets.

Head circles. In the same starting position as the first exercise, the gymnast started to move her head in a fluid circular motion: chin on chest, then left ear on left shoulder. She then moved her head to a backward (looking up) position, right ear on right shoulder, finally returning chin to chest. This circular movement was repeated 10 times, two sets clockwise, two sets anti-clockwise (10 repetitions). After the four sets of head circles with eyes open, the same procedure was repeated with eyes closed.

Gait with head movements. After three steps at normal speed the gymnast was instructed to turn her head rapidly and look to the right and then back to the forward position while continuing to walk straight ahead. After three more steps she turned her head and looked to the left, still walking straight ahead. The gymnast walked with turning head 15 m, 10 times.

Strengthening exercises

Prone contra-lateral arm and leg lifting. From prone position on the floor, with her arms extended above her head, the gymnast lifted the "unpreferred-side-arm", and the contra-lateral leg a few centimeters from the floor, in a cross-lifting movement ("weak side diagonal"). She held for 10 s, and then returned to the starting position. This movement was repeated 10 times, four sets.

Quadruped contra-lateral arm and leg lifting. From quadruped position on the floor, with body weight distributed to both knees and hands, the gymnast extended the unpreferred-side arm and the contra-lateral leg in a cross-lifting movement, held for 10 s and returned to starting position. This movement was repeated 10 times, four sets.

Instrument and test procedure

Foot pressure was recorded and analyzed on a vertical posturographic digital platform (Foot Checker 3.0 Comex S.A. / LorAn Engineering Srl; Castel Maggiore, Bologna, Italy), on the floor. The 700 × 500 mm platform contained 2304 resistive sensors. Measuring accuracy was 0.001 kPa. The vertical force was sampled at a frequency of 60 Hz and the sway density curve analyzed in an integrated software module (Foot Checker, 3.2). In a quiet stance, postural steadiness can be quantified in healthy subjects in which decreased (CoP) oscillations have been associated with improved postural skill [4, 9, 13, 14]. The advantage of CoP posturographic recordings using a mobile platform is that it is easy to use for empirical measurement in environments familiar to the subjects.

The subjects stood upright, barefoot on the platform (bipedal stance). They were told to stand with their feet as they wished. Their foot positions were then symmetrically corrected for anteroposterior direction, and the distance between their feet was recorded for accurate reproduction in the follow-up measurements. They held their arms at their sides, the central resting position. Before the body weight distribution was recorded, the subjects were told to distribute their body weight as evenly as possible between their feet, to be relaxed and to breathe normally; and then to signal when they were ready for the test leader to record the distribution. The body weight distribution was sampled over 20 s and percentage of body weight distribution (% BW distribution) was defined as the average deviation from 50% over the 20 seconds' interval. Still standing on the platform, the subjects were then familiarized with the subsequent CoP sway recording procedure. They were instructed to perform ten circular head movements with their eyes closed. Each circle took 1 s, governed with a metronome (tuned by electronic chronometer). Immediately after the tenth circle, the subjects were told to open their eyes and focus on a point on the wall directly ahead, at eye level, and to stand as still as possible for 20 seconds' sway sampling. The sway area gives an indication of the amplitude of postural sway [4] and here represents the ability of postural steadiness. The CoP sway area (statiokinesiogram (cm^2) was defined as an ellipse containing 90% of all displacement points. All measurements were performed with a blinded examiner.

Data management and statistics

Two dependent variables were included in the analysis: (1) CoP sway area and (2) % BW distribution. As these outcomes were mainly non-symmetrically distributed around the mean, the data were log-transformed to approximate a normal distribution before being statistically analyzed. To test our hypothesis, a repeated-measures mixed-model analysis of covariance was chosen, to examine whether follow-up recordings of CoP sway and % BW distribution differed significantly between the two subject groups. The between group factor was group (experimental, control) and the within group factor was follow up (6 weeks and 12 months). Baseline values were set as continuous covariate [15], thus eliminating potential effects of initial differences in the follow-up examinations. Wherever significant main or interaction effects were detected, a group difference was further estimated with post hoc tests for each follow-up occasion. A significance level was set at $p \leq 0.05$. Statistical analyses were performed using procedure Mixed in SAS®.

Results

All 13 subjects in the experimental group completed every session during the intervention period, and all 26 subjects completed the six-week follow-up. Twenty-three subjects (88.5%) completed the 12-month follow-up measurement. Two subjects had quit rhythmic sports gymnastic training (one withdrawal from each group) and one had moved abroad (dropout from control group). There were no injury or pain experiences, or other complications reported from the present intervention. The athletes reported no difficulties in performing the exercises correctly.

CoP sway area

Fig. 1 shows how the CoP sway area for the two subject groups developed. Compared to baseline, the CoP sway area in the experimental group decreased with –59% (md) compared to –0.1% in the control group at the six-week follow-up, and –39% in the experimental group compared to 0.0 % in the control group at the 12-month follow-up. A repeated-measures mixed model analysis revealed a statistical interaction effect for follow-up and group (follow-up · group): $F_{1,21} = 8.87$, $p = 0.007$. Results for each follow-up showed that the experimental group had significant CoP sway decrement at the six-week follow-up, $p = 0.004$. There were no such remaining effects at the 12-month follow-up ($p = 0.699$).

Percentage of body weight distribution

Fig. 2 shows the course of the % BW distribution. The variances were not homogeneous within and/or between the groups. The covariance structure heterogeneous compound symmetry together with between subject heterogeneity was considered most desirable and gave the smallest value of the Akaike's Information Criterion (AIC). Compared to baseline, % BW distribution in the experimental group decreased with –58% (md) compared to 2.3% in the control group at the six-week follow-up, and –14% in the experimental group compared to –19% in the control group at the 12-month follow-up. The mixed model procedure revealed a statistical interaction effect for follow-up × group; $F_{1,21} = 24.08$, $p < 0.001$. Results for each follow-up showed significant improvement in the experimental group (reduction of deviated % BW distribution) at the six-week follow-up, $p < 0.001$. Again, the effect was no longer significant at the 12-month follow-up ($p = 0.957$).

Discussion

The results of this study support our initial hypothesis that the rhythmic sports athletes who practiced the present multimodal training program would improve their postural steadiness in quiet standing, measured as decreased CoP sway area and asymmetric body weight distribution. However, the 12-month follow-up indicated that the effect was not maintained in the long term.

The present sample of gymnasts represented three Rhythmic Sports Gymnastic Clubs of Thessaloniki,

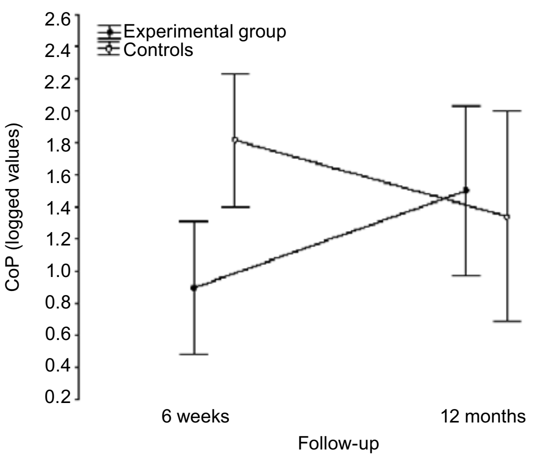

Figure 1. Changes in center of foot pressure (CoP) sway area (cm^2) during quiet standing for experimental group (filled circle) $n = 13$ and for controls $n = 13$, respectively. Values are presented as longitudinal follow-up at a 6-week and a 12-month assessment after baseline measurement. Baseline values were set as continuous covariate. Error bars show mean and 95% confidence intervals using procedure Mixed in SAS® (analysis based on logged values)

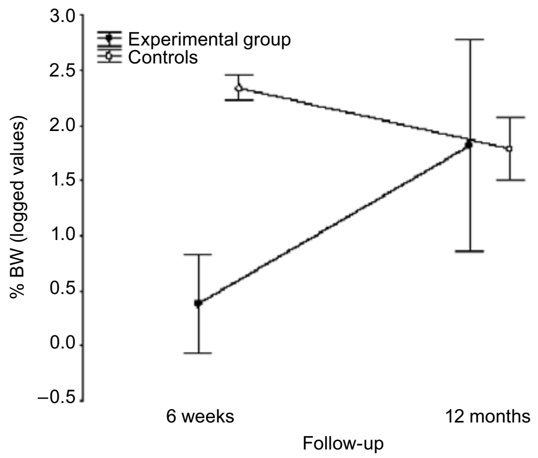

Figure 2. Changes in percentage of body weight distribution (% BW) for experimental group (filled circle) $n = 13$ and controls $n = 13$, respectively. Values are presented as longitudinal follow-up at 6-week and 12-month assessments after baseline measurement. Error bars show mean and 95% confidence intervals using procedure Mixed in SAS® (analysis based on logged values)

Greece, and was considered representative for junior rhythmic sports athletes. The reason for selecting junior rhythmic sports athletes only is that the group is more homogeneous concerning adoption and learning of the postural control system, compared to a group of senior rhythmic sports athletes. The 26 subjects were age- and years-of-practice matched before random assignment to an experimental group or a control group. This procedure was followed to facilitate uniformity between the groups in our relatively small sample.

Postural control or postural steadiness has been well debated in recent years [e.g. 16–20] and there has been progress in understanding its complexity in relation to task and environment. In the literature, however, postural control (and balance) is defined in various ways [17, 18, 21, 22]. The use of different methodology and different aspects of postural control may explain this inconsistency. For the gymnasts studied, it is necessary to manage CoP adjustment within a small base of support. This involves controlling kinematic, or center-of-mass (CoM), displacement by motor command for CoP adjustment for upright stance equilibrium during high skill performance, for example turns, pivots, and other near-acrobatic movements. Although postural stability, defined as keeping CoM within a given surface, can be reflected by CoP sway [17], less sway area does not necessarily mean good postural control in every population. For example, a smaller safety margin between peak CoM and peak CoP in patients with Parkinson's disease tends to increase the risk of falling [23]. Nevertheless, the ability to maintain the body as still as possible can be defined as postural steadiness in *healthy* subjects and quantified by recording the variation in ground reaction forces [24, 25]. However, crucial for the present study, our mobile posturographic platform and the relative simplicity of the set-up allowed us to conduct empirical measurements on the rhythmic sports gymnastic club's premises. Studies show high reliability for body weight distribution, while for CoP sway reliability seems more limited, though acceptable [21]. While a mean of multiple sway measurements seems to increase reliability [21], repeated measures may also introduce learning effects [26]. However, in our control group, there seemed to be a small, longitudinal, within-subject variation. This was perhaps partly because all the tests were conducted by the same test leader so as to eliminate possible intertester variability. Important to consider, however, participating in the intervention group and being encouraged by a physiotherapist might have increased the subjects′ motivation concerning rhythmic sports gymnastic training, perhaps causing overestimation of the effect of the training regime tested.

Our results, showing improvement in postural steadiness after sensorimotor skill and muscle strength training, tally with those of other authors [6, 8] who used training regimes that involved fairly comparable exercises. Moreover, it has been discussed [17] that adoption and learning of the postural control system could have a significant effect on successful training and performance in elite athletics. The mechanism of such improvement may be increased sensitivity of feedback pathways from proprioceptive sensory input, which regulate the *expected* relationship between motor output and the environment for postural equilibrium [see for further reading 27]. By training sensorimotor skills, these gymnasts may not only improve their postural steadiness but perhaps also their gymnastic techniques. The test procedure was developed to reflect the techniques used in rhythmic sports gymnastics, that is, a better performance in the tests should also logically increase the performance in sports, e.g. one leg standing. The present study was limited in the ability to study the effects on the improvement of performance or the occurrence of injuries. The use of good technique has been proposed as one factor for reduced incidence of spinal pain in rhythmic sports athletes [2]. Thus, further studies should examine the effect of sensorimotor skill programs on other kinematic features of postural steadiness and aspects of injury prevention. Moreover, future studies should endeavour to separate the effect of each domain concerning the training, i.e. vestibular or strength training exercises.

As expected, the baseline measurement showed that the gymnasts had asymmetric body weight distribution (Fig. 2). One study found that body weight distribution was close to 50–50% in young persons [21]. Moreover, Engardt found that healthy subjects rose and sat down with good symmetric weight distribution [28]. However, the present multimodal regime seemed to temporally normalize the rhythmic sports athletes' % BW distribution. Such time-limited postural effects have also been found after a muscular training regime in patients with central diseases [28]. Although the present multimodal design did not allow separate analysis of the specific effects of the strength training, we believe that strength exercises for the "weak diagonal" of the back may with benefit be integrated in rhythmic sports gymnastic training. Also, hypothetically, such integrated training may prevent musculoskeletal pain syndromes caused by repeated asymmetric loading. Previous results show, nevertheless, that different multimodal training protocols have been found effective concerning postural control and stability in healthy subjects [9], as well in patients with ankle instability [7]. The temporary differences between the exercise group and the control group found in the present study may be explained by the increased exercise-dosage. However, it seems that the ½ hour additional training should not have had such an impact, taken into account the total amount of training and the years of participating in rhythmic sports gymnastics.

At the 12-month follow-up there were no significant differences in maintained effect between the two groups. This indicates that in order to retain the effect in postural steadiness, as defined in this study, this type of training should be regular; for example by integrating the exercises in rhythmic sports gymnastic training routines.

Conclusions

Our results showed that the present sensorimotor skill training regime improved the rhythmic sports athletes' postural steadiness, measured as decreased CoP sway area and normalized body weight distribution between their feet. Nevertheless, the effects were limited over time. This indicates that sensorimotor/strengthening exercises may beneficially be integrated into continuous rhythmic sports training routines. Further research that includes CoP and kinematic variables is however required to provide more understanding regarding effects of postural regulation.

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