https://doi.org/10.5817/StS2025-1-11

Effects of Jump Training Program on Static Balance Parameters in Healthy Children

Sanja Ljubičić[1], Ljubomir Antekolović[2], Vedran Dukarić[2]

[1] *Department for Teaching methods in the field of natural and social science, Faculty of Teacher Education, Rijeka, Croatia*

[2] *Department of Kinesiology of Sports, University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia*

ABSTRACT

Balance in childhood has a significant impact on proper growth, the development of postural control and the learning of new motor tasks. Since activities such as running and jumping require a stable body position, the aim of this study is to determine the effects of specific plyometric exercises on unilateral balance performance of the take-off leg in children. This research involved 41 children (17 boys and 24 girls) aged from 7 to 11 years old (Mean ± SD, 9.08 ± 1.32). The children had an average height of 137.51 ± 10.28 cm and weight of 32.72 ± 7.76 kg. The study observed variables related to balance ability. During testing, antero-posterior length (AP), medio-lateral length (ML), and overall mean distance (D) of body movement were observed. Repeated measures univariate analysis of variance (ANOVA) was used to determine differences between measurements. Tukey post hoc test was used to further analyse differences of each variable across different time periods. ANOVA results showed significant differences in observed variables ($F=5.95$; $p=0.00$; $\eta^2=0.51$). Significant differences were found for AP between the initial and final measurements ($p=0.04$). Additionally, there was a difference in AP between the final testing and delayed training effects ($p=0.02$). Presented results had positive effect, respectively, children maintain better static balance after training program. No differences were found for D and ML variables. These findings suggest that plyometric training could be integrated into regular physical education programs to enhance balance and motor skills in children.

Keywords: unilateral training; balance development; postural control in children

INTRODUCTION

Balance is a fundamental ability in motor development during childhood, as it enables postural control, stability, and the execution of various movements. It serves as the foundation for all other motor skills, ranging from basic movements to the most complex motor abilities (Frick & Möhring, 2016; Ramachandran et al., 2021). It refers to a type of motor coordination in which the visual and kinesthetic components of the body's muscles work together with the balance sensors located in the inner ear to maintain body stability without unnecessary movements or falls (Goddard Blyth, 2017). Activities that require maintaining proper posture and balance are present in various aspects of children's daily lives, including play, sports, and physical activities (Oliveira Junior et al., 2021).

Balance is particularly important for children in everyday activities such as walking, running, and jumping, as well as for more complex motor skills required in sports and play. Maintaining balance depends on the integration of sensory information from the visual, vestibular, and proprioceptive systems within the central nervous system, resulting in coordinated neuromuscular responses (Brachman et al., 2017).Balance is also influenced by external factors such as the base of support, centre of gravity, and body structure and mass (Davlin, 2004). It is divided into static and dynamic balance. Static balance is defined as the ability to maintain the centre of mass above the base of support with minimal movement (Hrysomallis, 2011), while dynamic balance involves maintaining body stability during movement execution (Bressel et al., 2007).

The ability to maintain balance changes throughout a person's life due to factors such as body structure changes, experience in specific activities, and task complexity (Yanovich & Bar-Shalom, 2022). In addition to its key role in daily tasks and fall prevention, balance is crucial for successfully performing sport-specific skills in athletic populations (Boccolini et al., 2013).

Plyometric exercises in children require a high level of proprioception, and as these stimuli develop the ability for rapid muscle contractions, children become more capable of maintaining a stable position, even when exposed to external destabilizing factors (Granacher et al., 2016). PT stimulates the stretch-shortening cycle (SSC) of muscles, leading to adaptations in both the muscular and nervous systems (Moran et al., 2021; Ramírez-Campillo et al., 2022), thereby improving movement control and body stability. Meta-analyses have shown that PT can enhance both static and dynamic balance (Ramachandran et al., 2021), with the inclusion of unilateral and bilateral jumps in various directions and on different surfaces further recommended to stimulate the somatosensory system (Peterka, 2018). In addition to improving strength and explosiveness, PT is thus recognized as a valuable tool for balance development in childhood (Surakhamhaeng et al., 2020).Most research has focused on the impact of balance training interventions on postural control with varying results (Distefano et al., 2010; Granacher et al., 2011; Muehlbauer, 2021). Regarding plyometric training as a standalone intervention, the literature shows mixed effects on balance measures across different groups. While studies like those by Ramírez-Campillo et al. (2015) and Makhlouf et al. (2018) reported small to moderate effects of PT on dynamic and static balance in young soccer players, others, such as Meszler and Váczi (2019) and Asadi and Arazi (2012), found no significant effects of the same training type on young basketball players. These discrepancies may be due to methodological differences (e.g., balance test types, training protocols), sport-specific characteristics, fitness levels, and other factors.

Research on the effects of PT on balance improvements in children is scarce. Ramachandran et al. (2021) provided a systematic review and synthesis of evidence from randomized and non-randomized controlled studies on balance measures in participants aged 9 to 63. Positive changes were achieved, comparable to those observed with balance training. Ljubičić et al. (2019) examined gender differences in static balance among children aged 7 to 10 without training intervention. In later research (Ljubičić et al., 2022), they identified a positive impact of specific jumping exercises (SSC) on the development of specific motor skills in children. Unilateral balance is a key component of motor skills developed during childhood (Haywood & Getchell, 2009).

Understanding how PT contributes to balance development in children can help enhance their overall motor abilities, prevent injuries, and address the limited research specifically focusing on the effects of PT on unilateral balance in children. Authors hypothesized that improvement in observed parameters will occur after training process. Furthermore, in delayed training effect it is expected that results remain same as after jump training intervention. Thus,the aim of this study is to determine the effects of specific plyometric exercises on the performance of unilateral balance on the take-off leg in children.

METHODS

Participants

This research involved 41 children (17 boys and 24 girls) with age ratio from 7– to 11-year-old (Mean ± SD, 9.08 ± 1.32). Children in average had height of 137.51 ± 10.28 cm and weight of 32.72 ± 7.76 kg. Participants were members of Track & field club Kvarner, Rijeka. Before research protocol, parents were introduced to research goals, workflow of program and trainings and potential risks. Parents gave written consent for their children to participate in research. This research was approved by Ethics committee of the Faculty of Kinesiology, University of Zagreb in accordance with the Declaration of Helsinki (Opinion No. 11/2017). The exclusion criterion of children was participation in trainings, at least 80 % of trainings was necessary for the results to be taken for statistical analysis.

Furthermore, if any type of locomotor disabilities (strain, sprain) or sickness occur during procedure, these results were not taken for further observation.

Instruments and variables

This research observed variables related to balance ability. During testing, antero-posterior length (AP); medio – lateral length (ML) and overall mean distance (D) of the body movement was observed. Gyko inertial sensor (Microgate, Bolzano, Italy) was used to assess postural stability of children. Device was placed at the participants upper back with a special strap (Jaworski et al, 2023). Device height was measured and was written in the software for the calibration of instrument on each participant.

Measurement was conducted in indoor track and field gym with hard floor surface. Prior to testing, participants were introduced to measurement protocol that consisted of balance test. Test was performed with the gyko inertial device. Participants were asked to stand still on dominant leg. Dominant leg was previously determined on training when children was asked to perform long jump with run-up and take-off leg was recorded as dominant. Three time points were used for testing: initial testing, final testing (after 3 months) and testing of delayed training effects (3 weeks after final testing).

Measurement protocol

Before the start of the testing protocol, the task was verbally explained and demonstrated to the participants. Static balance test was used to evaluate children balance. During the measurement, the participant stood on one leg (the take-off leg) with their hands placed on their hips and head in the Frankfurt plane. The knee of the standing leg was in an actively extended position (without "locking" the joint), while the knee of the other leg was bent at a 90° angle. Each participant had one practice attempt lasting 10 seconds, followed by official testing. Three attempts of 20 seconds each were measured on the take-off leg, and the arithmetic mean was used for further data processing.

The group trained twice a week for twelve weeks, with at least 48 hours between sessions. Before performing the specific jump exercises, a standardized warm-up was conducted for 15 minutes. The volume of load for the specific high jump exercises was determined based on the number of foot contacts with the ground (number of sets x number of repetitions), which ranged from 78 contacts in the initial phase to 102 contacts in the final phase of the training protocol. The specific vertical jump exercises (SVS) included nine types of jumps. The load volume was consistent with previous research (Meylan & Malatesta, 2009). The distribution of the load volume followed the principles of continuity, progression, and undulation. During the training protocol, attendance records of the children were kept.

Data analysis

Statistical analysis was performed with the use of Statistica 14.0.1.25 (TIBCO software, Inc., Palo Alto, CA, USA). Descriptive parameters were used to determine average, minimum and maximum values of observed variables. Repeated measures univariate analysis of variance (ANOVA) was used to determine differences between measurements. Tukey post hoc test was used to further analyse difference of each variable in different time periods. Also, effect size (η^2) calculations (partial eta squared; small ($\eta^2 \geq 0.01$), medium ($\eta^2 \geq 0.06$), and large ($\eta^2 \geq 0.14$)) were used to estimate the magnitude of the result. The significance level was set at $p < 0.05$.

RESULTS

Results presented in this study observe balance variability after jump training intervention. In Table 1. decriptive parameters of variables were shown in three time points, initial measurement, final measurement and delayed training effects.

Table 1. Descriptive parameters of observed variables through 3 time points

Variable	N	M	Min	Max	SD
D_1	41	170.37	61.31	602.93	102.09
D_2	41	148.01	64.97	502.44	84.05
D_3	41	166.12	79.05	461.85	76.92
ML_1	41	109.16	38.92	423.54	73.52
ML_2	41	94.72	35.98	400.82	66.77
ML_3	41	101.12	37.79	358.83	60.68
AP_1	41	107.13	38.96	353.87	58.18
AP_2	41	92.60	45.75	211.64	40.03
AP_3	41	108.94	54.61	223.56	39.22

*D – distance values; ML – medio-lateral values; AP – antero-posterior values; N=number of participants; Mean – average values; Min – minimum values; Max – maksimum values; St.Dev.- variation of the mean value

In table 1. it can be observed that mean results through different time points have smallest values in final testing after finishing the intervention (D_2; ML_2; AP_2). Variation of the results had smallest results in AP variable rather than ML. The best result was measured in ML_2 (35.98 cm). Furthermore, maximum results were determined in D across all testings. AP_3 variable showed greatest mean decrease after intervention and presents lower results than at AP_1. Initial measurements of D_1 and ML_1 presented a higher imbalance during the performance.

Repeated measures ANOVA was used to determine differences of training programme in 3 different time periods. ANOVA results presented significant differences in observed variables ($F=5.95$; $p=0.00$; $\eta^2=0.51$). Tukey post hoc test was further used to determine differences in observed variables (Table 2.).

Table 2. Tukey post hoc test with interactions of variables in 3 time points

			D	
		{1}	**{2}**	**{3}**
1	**1**		0.09	0.92
2	**2**	0.09		0.21
3	**3**	0.92	0.21	
			ML	
		{1}	**{2}**	**{3}**
1	**1**		0.18	0.58
2	**2**	0.18		0.71
3	**3**	0.58	0.71	
			AP	
		{1}	**{2}**	**{3}**
1	**1**		0.04*	0.95
2	**2**	0.04*		0.02*
3	**3**	0.95	0.02*	

*marked values were significant when p<0.05

Significant differences were obtained for AP between initial and final measurement (p=0.04). Furthermore, there was difference obtained in AP between final and delayed training effects (p=0.02). In D and ML variables there was no difference.

DISCUSSION

It was hypothesized that training intervention will improve single leg balance of the children. This hypothesis is partially accepted since not all variables showed improvement. Also, delayed training effects did not achieve expected results and it can be concluded that the performance at final measurement results were similar to initial testing.

The results of this study indicate that the participants achieved a statistically significant improvement in the antero-posterior (AP) variable after the intervention program (p=0.04). Since the intervention included jumps with a horizontal orientation, it can be concluded that this is why the AP variable showed the most significant changes. The participants are also members of an athletics club, and generally engage in horizontal activities through the training process, thus showing better balance values in the AP plane. Repeated exposure to balance challenges during plyometric training promotes adaptations related to postural control (Ramírez-Campillo et al., 2021), intermuscular coordination, and changes in the size and mechanics of muscle fibers (Marković and Mikulić, 2010). Three weeks after the program, significant differences were again observed in the AP variable, with a negative impact (p=0.02), indicating that static balance ability decreased. Fuchs et al. (2020) found opposing effects of jump training on performance in a static balance test. The authors measured significantly better results in the ML plane, while AP and D results showed no significant changes after the intervention. Single leg stance for some participants proves to be difficult task since high variability was measured. It can be concluded that variability could be even higher if task was performed with non-dominant leg. Moreover, values of D and ML length showed tendency of improving after intervention. These variables presented much less improvement than AP since training program was oriented to perform exercises in horizontal plane. Overall mean distance (D) values observed in this research are improving with maturation but is also under high influence of activity. Martinez-Corcoles et.al (2022) proved that inactivity caused significant reduction in balance performance at children aged 8 and 12 years old. These findings suggest that regular physical activity benefits postural control. Measuring effects after a certain period post-training provides insights into the retention of skills and motor performance. It was noted that the intervention effect was not maintained long-term. AP results that showed significant changes after training intervention proved to have lower results in final measurement than at initial state (108.94 vs. 107.13) After only three weeks without further intervention activities, there was a tendency for results to regress, suggesting a return of balance in the antero-posterior variable to its initial state. The results highlight the importance of continuous training for long-term maintenance of program effects. Plyometric exercises stimulate adaptive processes in the muscular and neural systems (Ramírez-Campillo et al., 2022), but according to this study's results, they also lose their effectiveness once activities cease, which is especially evident in static balance that requires regular maintenance and stimulation.

Analysing the distribution of results, even though some results are not statistically significant, the intervention was found to impact all three variables, with participants demonstrating greater stability at the final measurement. A meta-analysis by Ramachandran et al. (2021) also highlighted that plyometric training is effective in improving balance in both sports and recreational contexts.

Based on the results of this study, which indicate that the most significant changes were observed in the anteroposterior plane, while the effects of plyometric training were short-term, it is recommended that plyometric exercises be systematically and continuously implemented across different planes to enhance stability and prolong the positive effects on balance. Plyometric exercises should be adapted to the age and motor abilities of children and performed under professional supervision to ensure proper execution and minimize the risk of injury.

The limitations of this study include the wide age range of the sample, and the participants were children with prior sports experience, which may hinder the generalization of the results to specific age groups, such as children without sports experience. Additionally, the effects were studied exclusively on the dominant leg, which limits insight into the impact of the training intervention on both legs. Future research should focus on the role of neuromuscular adaptations in maintaining balance and investigate the effects of training on children with varying sports backgrounds and age groups. Furthermore, it is important to explore the effects of plyometric training on balance in both legs, as this may provide a better understanding of the transformational processes involved.

CONCLUSION

As mentioned before, balance in children represents important factor in maintaining correct body position during different sport activities. Thus, it is very important to include daily routine exercises that are in function of improving overall balance. The primary contribution of this research lies in demonstrating the positive effects of plyometric training on balance in children, particularly in the sagittal plane. The results indicate that the training effects are short-term, emphasizing the importance of continuous exercise to maintain balance. Furthermore, the study provides a deeper understanding of how various aspects of balance respond to plyometric training, thereby filling gaps in the literature on motor development in children and offering practical guidance for sports practice.

ACKNOWLEDGEMENTS

Research was approved by Ethics committee of the Faculty of Kinesiology, University of Zagreb in accordance with the Declaration of Helsinki (Opinion No. 11/2017). Informed consent was obtained from all subjects involved in the study.

REFERENCES

Asadi, A., & Arazi, H. (2012). Effects of high-intensity plyometric training on dynamic balance, agility, vertical jump and sprint performance in young male basketball players. *J. Sport Heal. Res. 4*, 35–44.

Boccolini, G., Brazzit, A., Bonfanti, L., & Alberti, G. (2013). Using balance training to improve the performance of youth basketball players. *Sport Sci. Health 9*, 37–42. doi: 10.1007/s11332-013-0143-z

Brachman, A., Kamieniarz, A., Michalska, J., Pawłowski, M., Słomka, K. J., & Juras, G. (2017). Balance training programs in athletes-A systematic review. *J. Hum. Kinet. 58*, 45–64. doi: 10.1515/hukin-2017-0088

Bressel E., Yonker, J.C., Kras, J., & Heath, E.M. (2007). Comparison of static and dynamic balance in female collegiate soccer,basketball, and gymnastics athletes. *J Athl Train, 42(1)*:42-6.

Davlin, C.D. (2004). Dynamic balance in high level athletes. *Percept Mot Skills, 98* (3 Pt 2):1171-6. doi: 10.2466/pms.98.3c.1171-1176. PMID: 15291203.

DiStefano, L.J., Padua, D.A., Blackburn, J.T., Garrett, W.E., Guskiewicz K.M., & Marshall, S.W. (2010). Integrated injury prevention program improves balance and vertical jump height in children. *Journal of Strength and Conditioning Research, 24(2)*, 332-342. doi: 10.1519/JSC.0b013e3181cc2225

Frick, A., & Möhring, W. (2016). A Matter of Balance: Motor Control is Related to Children's Spatial and Proportional Reasoning Skills. *Front Psychol, 12(6)*, 2049. doi: 10.3389/fpsyg.2015.02049. PMID: 26793157; PMCID: PMC4709580.

Fuchs, P.X., Fusco, A., Cortis, C., & Wagner, H. (2020). Effects of Differential Jump Training on Balance Performance in Female Volleyball Players. *Appl. Sci. 10*, 5921. https://doi.org/10.3390/app10175921

Goddard Blyth, S. (2017). Attention, Balance and Coordination: The A.B.C. of Learning Success, 2nd ed.; Wiley-Blackwell: Hoboken, NJ, USA.

Granacher, U., Lesinski, M., Büsch, D., Muehlbauer, T., Prieske, O., Puta, C., & Behm, D. G. (2016). "Effects of resistance training in youth athletes on muscular fitness and athletic performance: a conceptual model for long-term athlete development." *Frontiers in Physiology, 7*, 164.

Granacher, U., Muehlbauer, T., Maestrini, L., Zahner, L., & Gollhofer, A. (2011). Can balance training promote balance and strength in prepubertal children? *Journal of Strength and Conditioning Research, 25(6)*, 1759–1766. doi: 10.1519/JSC.0b013e3181da7886

Haddad, J.M., Rietdyk, S., Claxton, L.J., & Huber, J. (2013). Task-dependent postural control throughout the lifespan. *Exerc. Sport Sci. Rev., 41*, 123–132.

Haywood, K. M., & Getchell, N. (2009). Life Span Motor Development. Human Kinetics

Hrysomallis, C. (2011). Balance ability and athletic performance. *Sports Med. 41*, 221–232. doi: 10.2165/11538560-000000000-00000

Jaworski, J., Lech, G., Witkowski, K., Kubacki, R., & Piepiora, P. (2024). Evaluation of measurement reliability for selected indices of postural stability based on data from the GYKO Inertial Sensor System. *Biology of Sport, 41(2)*, 155-161. https://doi.org/10.5114/biolsport.2024.132986

Ljubičić, S., Antekolović, Lj., & Petrić, V. (2022). Integration of Bilateral Coordination in Children's Motor Learning Process. *Journal of elementary education, 15(3)*, 285-299. doi: 10.18690/rei.15.3.285-299.2022.

Ljubičić, S., Trajkovski, B., & Antekolović, Lj. (2019). Application of Modern Technology for the Evaluation of Balance in Children of Lower Forms of Primary School. *Odgojno-obrazovne teme*, 2, 3-4, 113-128.

Makhlouf, I., Chaouachi, A., Chaouachi, M., Othman, A., Ben Granacher, U., & Behm, D. G. (2018). Combination of agility and plyometric training provides similar training benefits as combined balance and plyometric training in young soccer players. Front. *Physiol. 9*:1611. doi: 10.3389/fphys.2018.01611

Markovic G., & Mikulic P. (2010). Neuro-musculoskeletal and performance adaptations to lower-extremity plyometric training. *Sport. Med. 40*, 859–895. 10.2165/11318370-000000000-00000

Martinez-Corcoles, V., Nieto-Gil, P., Ramos-Petersen, L., Ferrer-Torregrosa, J. (2022). Balance performance analysis after the COVID-19 quarantine in children aged between 8 and 12 years old: Longitudinal study. Gait & posture, 94, 203–209. https://doi.org/10.1016/j.gaitpost.2022.03.019

Meszler, B., & Váczi, M. (2019). Effects of short-term in-season plyometric training in adolescent female basketball players. *Physiol. Int. 106*, 168–179. doi: 10.1556/2060.106.2019.14

Meylan, C. & Malatesta, D. (2009). Effects of in-season plyometric training within soccer practice on explosive actions of young players. *Journal of Strength and Conditioning Research, 23(9)*, 2605–2613. doi: 10.1519/JSC.0b013e3181b1f330

Moran, J., Liew, B., Ramirez-Campillo, R., Granacher, U., Negra, Y., & Chaabene, H. (2021). The effects of plyometric jump training on lower limb stiffness in healthy individuals: a meta-analytical comparison. *J. Sport Heal. Sci*. doi: 10.1016/j.jshs.2021.05.005.

Muehlbauer T. (2021). Effects of balance training on static and dynamic balance performance in healthy children: role of training duration and volume. *BMC research notes, 14(1)*, 465. https://doi.org/10.1186/s13104-021-05873-5

Oliveira Junior, E., Mendes da Silva, A.F., Dias Antunes, F., Jacinto, J.L. & Aguiar, A.F. (2021). Analysis of postural balance in children who practice and those who do not practice sports activities. *Rev Bras Med Esporte, 27(6)*. https://doi.org/10.1590/1517-8692202127062021_0032

Peterka, R. J. (2018). Sensory Integration for Human Balance Control. 1st Edn. Amsterdam: Elsevier B.V.

Ramachandran, A.K, Singh, U., Ramirez-Campillo, R., Clemente, F.M., Afonso, J., & Granacher, U. (2021). Effects of Plyometric Jump Training on Balance Performance in Healthy Participants: A Systematic Review with Meta-Analysis. *Front Physiol*, 20;12:730945. doi: 10.3389/fphys.2021.730945.

Ramírez-Campillo, R., García-Pinillos, F.T., Nikolaidis, P., Clemente, F., Gentil, P., et al. (2022). Body composition adaptations to lower-body plyometric training: a systematic review and meta-analysis. *Biol. Sport 39*, 273–287. 10.5114/biolsport.2022.104916

Ramírez-Campillo, R., Garcia-Pinillos, F., Chaabene, H., Moran, J., Behm, D., & Granacher U. (2021). Effects of plyometric jump training on electromyographic activity and its relationship to strength and jump performance in healthy trained and untrained populations: a systematic review of randomized controlled trials. *J. Strength Cond. Res.* 35, 2053–2065. 10.1519/JSC.0000000000004056

Ramírez-Campillo, R., Gallardo, F., Henriquez-Olguín, C., Meylan, C. M., Martínez, C., Álvarez, C., Caniuqueo, A., Cadore, E. L., & Izquierdo, M. (2015). Effect of Vertical, Horizontal, and Combined Plyometric Training on Explosive, Balance, and Endurance Performance of Young Soccer Players. *Journal of strength and conditioning research, 29(7)*, 1784–1795. https://doi.org/10.1519/JSC.0000000000000827

Surakhamhaeng, A., Bovonsunthonchai, S., & Vachalathiti, R. (2020). Effects of balance and plyometric training on balance control among individuals with functional ankle instability. *Physiother. Q. 28*, 38–45. doi: 10.5114/pq.2020.92474

Yanovich, E., & Bar-Shalom, S. (2022). Static and Dynamic Balance Indices among Kindergarten Children: A Short-Term Intervention Program during COVID-19 Lockdowns. *Children, 9*, 939. https:// doi.org/10.3390/children9070939.

Contact Information:

Sanja Ljubičić
Sanja.ljubicic@yahoo.com

Ljubomir Antekolović
Ljubomir.antekolovic@kif.unizg.hr

Vedran Dukarić
Vedran.dukaric@kif.unizg.hr
+385917607137