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Is young age a limiting factor when training balance? Effects of child-oriented balance training in children and adolescents

Effects of child-oriented balance training

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ABSTRACT

Purpose: Balance training studies in children reported conflicting results without evidence for improvements in children under the age of eight. The aim of this study therefore was to compare balance training adaptations in children of different age groups to clarify whether young age prevents positive training outcomes. **Method:** The effects of five weeks of child-oriented balance training were tested in 77 (38 girls; 39 boys) participants of different age groups (6-7, 11-12, and 14-15 years) and compared to age-matched controls. Static and dynamic postural control, explosive strength, and jump height were assessed. **Results:** Across age groups, dynamic postural sway decreased (-18.7%; $p = .012$; $\eta^2_p = .09$) and explosive force increased (8.6%; $p = .040$; $\eta^2_p = .06$) in the intervention groups. Age-specific improvements were observed in dynamic postural sway, with greatest effects in the youngest group (-28.8%; $p = .026$; $r = .61$). **Conclusion:** In contrast to previous research using adult-oriented balance exercises, this study demonstrated for the first time that postural control can be trained from as early as the age of six years in children when using child-oriented balance training. Therefore, the conception of the training seems to be essential in improving balance skills in young children.

Keywords: balance training; postural control; children; adolescents; child-oriented

1 INTRODUCTION

Balance training (BT) can improve postural control. This has recently been confirmed in systematic reviews for older adults (21) and healthy young adults (20). In addition, there are several studies demonstrating that BT interventions lead to improved postural control in children/adolescents older than 12 years (4, 17, 25, 38). However, evidence that postural control can be improved by means of BT in younger children is much weaker.

It is well established that the postural control system is developing during childhood and adolescence, with a strong reorganization at the age of about six years (28). Young children rely predominantly on the visual-vestibular system to maintain balance (19), while they start to change towards a more somatosensory-vestibular control at around the age of six (31). However, this transition to an adult-like balance control is not yet completed at the age of 12 (2, 26). In addition, hierarchical lower level systems of postural control (i.e. reflexes) are already present at birth, whereas supraspinal systems mature later and do not show adult-like behavior until about 10 years old (3). It may therefore be speculated that young children rely on a premature postural control system and therefore respond differently to BT than older children or adolescents. As there is increasingly more evidence that supraspinal centers are largely responsible for BT-induced improvements (35), the immaturity of the supraspinal system may prevent an improvement in postural control in young children. It might therefore be assumed that the age (or the developmental stage) plays an important role for the acquisition and the transfer of balance skills in childhood and adolescence.

To our knowledge, only three studies have investigated the impact of BT on stance stability in children younger than 12 years. When considering the youngest participants aged six to seven years, several weeks of BT using unstable support surfaces with a predefined number of sets and durations (i.e. classical BT) did not provoke any improvements in postural stability (13), although this kind of training is known to be beneficial in elite athletes (36), young adults (34), and older adults (11). When applying slackline training in older children (age 10.1±0.4 years), Donath and colleagues (8) did indeed observe task-specific improvements on the slackline. However, no improvements in transfer (i.e. untrained) balance tests have been detected. Improved postural control in transfer balance tests has been demonstrated after inline skating (22) with children at the age of around 11 years. Furthermore, there are several studies demonstrating improved postural control in trained and untrained postural tasks after BT interventions in children/adolescents older than 12 years (4, 17, 25, 38). Thus, it seems that with advancing age, the beneficial effect of BT is increasing.

Apart from the children's age, the BT intervention content may greatly influence the outcome on postural control. It was previously assumed that classical BT as intervention form is rather inappropriate for young children (13). The authors assumed that classical BT did not sufficiently motivate young children to participate with any great effort as active participation of the children was observed only when they were directly supervised by the teacher. It is therefore not clear whether the content of the BT or the age of the children was responsible for the divergent results in previous BT studies with young children. To clarify this issue, the present study applied child-oriented BT (for a detailed description see methods section) in three different age groups (6–7, 11–12, and 14–15 years). The applied child-oriented BT was in particular developed with the aim to increase children's motivation during the intervention by providing favorable challenges for every participant. This means that different levels of difficulty were provided for each exercise and that exercises and activities were frequently modified and adapted to avoid monotonous repetitions. Furthermore, participants were allowed in some activities to make their own choices how to manage a given task (1, 18).

The aim of the study was therefore to test whether postural control can be improved by means of child-oriented BT in young children as early as the age of six and compare their training-induced adaptations with those of older children and adolescents. In addition, jump performance and explosive strength were analyzed as it has been shown previously that BT can improve jump height and explosive force in adults (35). We hypothesized that older children/adolescents would benefit more from the child-oriented BT as they use a more mature postural control strategy.

2 METHODS

The realization of the present study was approved by the local ethics committee (87/14). All parents and children were thoroughly informed and written consent was obtained from the children over 10 years old and from the parents. The experimental protocol respected the latest ethical principles for medical research involving human subjects of the Helsinki Declaration.

2.1 Participants

Seventy-seven children of three different age groups (Y: young, 6–7; M: middle, 11–12; O: old, 14–15 years) participated in the study (see Table 1). Each age group consisted of an intervention group (INT; regular school classes) and a control group (CON). The regular school class for O-INT consisted of 15 pupils, who all participated and completed the experiment. In the M-INT, 19 pupils started the procedure, but due to an injury suffered in the leisure time of one child, only 18 finished the intervention. In the youngest school class, 15 out of 20 pupils volunteered to participate in the study. The children for the CON groups originated from different schools in the same region. None of the participants or parents reported neurological/orthopedic diseases or motor difficulties. In a few cases, due to the difficulty of some tests or errors in data recording, not all of the 77 participants were included.

2.2 Training intervention

The BT was held during physical education lessons and lasted for five weeks with two sessions per week (45 minutes/session). Each session started with a warm-up (10 minutes) containing small games related to postural control. For the main part of the lesson (35 minutes) a special topic was selected for each week (see Table 2). All intervention lessons were guided by a supervisor and the regular school teacher to keep the pupil–teacher ratio low.

Importantly, the child-oriented BT differed from classical BT (for a definition of classical BT, see 14), as previous research suggested that classical BT may not be adequate for children (13). Children's participation in physical education was assumed to be enhanced by promoting intrinsic motivation (1). For this purpose, the intervention consisted of three different topics, starting with a balance circuit, followed by two Parkour lessons and finally ended with competitive balance games (child-oriented BT; see Table 2). The aim of the balance circuit was to provide a high variety of different balance exercises with adjustable levels of difficulty to provide appropriate challenges for all children/adolescents. The following Parkour lessons were designed to foster the freedom of choice by engaging the participants to explore their own way and techniques to balance over the (unstable) obstacles. And finally, the competitive balance games challenged participants to perform balance exercises as long/good as possible. For this purpose, performances were regularly compared with other participants or with own previous results (18). The balance exercises and the specific instructions were tested in a pre-study in three other school classes with children and adolescents of similar age (6–7, 11–12, and 14–15 years). Participation was captured by analyzing the activity time during physical education sessions. Participants mean activity time in the pre-study was above the recommended 50% of total lesson time (37) for all of the 10 developed sessions. In addition, in all age groups the activity time during exercises at the end of the sessions was not decreased compared to exercises at the beginning of the sessions, indicating that the willingness of participation was high until the end of the BT.

All participants of the CON groups followed regular physical education lessons during the five weeks between pre- and post-tests. The amount of physical education was therefore identical for INT and CON groups. While the INT groups were exclusively working on postural control, the CON groups were exercising on common physical education topics (no specific BT exercises).

2.3 Measurements

Pre-measurements took place in the week before the training (INT) started. Similarly, post-measurements were assessed in the week after the training was completed. The same procedure was considered for participants of the CON groups.

2.3.1 *Balance tests on the force plate*

Center of pressure (COP) measurements on the force plate (508*464 mm; OR6–7 force platform; Advanced Mechanical Technology Inc., Watertown, MA, USA), which have previously been shown to be reliable to analyze balance abilities (24), were used to evaluate balance tests with different test difficulties (i.e. static and dynamic, double- and single-leg stance) to cover a wide range of postural control levels. Before recording, participants performed two repetitions in double- and single-leg (right leg) stance for 15 s to become familiar with the spinning top (Pedalo® Kreisel "Pro-Pedes"; ø 27 cm, height: 4.9 cm). After the familiarization phase, data acquisition started with three static balance tests: tandem stance (feet on one line, right foot in front), Romberg stance (feet parallel and in touch), and Romberg stance with eyes closed. Subsequently, two dynamic balance tests were executed: double- and single-leg (right leg) stance on the spinning top.

For each test, participants were instructed to stand as quiet as possible for 15 s on the force plate with their arms akimbo and with visual fixation on a cross marked on the wall. Each test was repeated twice with a pause of 1 min between trials and 2 min between different tests. The short recording time and the few repetitions were chosen due to the fact that concentration of children/adolescents is limited in time. To stand as quiet as possible demands high levels of concentration and prohibits any voluntary movements, which was particularly hard for the youngest group to accomplish for over 15 s. If a participant moved the foot or stumbled during data acquisition, a third trial was recorded (maximal three trials per test). Data was recorded at 1 kHz with custom-built software (LabView based, National Instruments Corporation, Austin, TX, USA) and analyzed offline in MatLab (R2015a, The MathWorks, Inc., Natick, MA, USA). After applying a low-pass filter (10 Hz), the x- and y-coordinates of the COP were calculated with the equations $x = \frac{-hF_x - M_y}{F_z}$ and $y = \frac{-hF_y + M_x}{F_z}$, respectively, where h corresponded to the distance between the feet and the force plate. For the first three tests, h was defined as 0 cm because subjects stood directly on the force plate. For the tests with the spinning top, h was defined as the height of the spinning top (4.9 cm). The coordinates x and y were used to generate a stabilogram and the COP sway was calculated by summing the distance between the points of the stabilogram (i.e. COP sway per 15 s). For each test, only the best trial was used for further analysis because of the high variability between trials. Three participants of Y-INT and two participants of Y-CON had to be excluded in the single-leg stance on the spinning top as they were not able to maintain the correct position for 15 s.

2.3.2 Balance test on the free-swinging platform

A two-dimensional free-swinging platform (Posturomed, Haider, Bioswing, Pullenreuth, Germany) was used to assess balance in a dynamic stabilization task (23). After two familiarization trials on the platform in double- and single-leg (right leg) stance for 15 s, all participants started with three consecutive double-leg stance trials followed by three single-leg trials. Test instructions and pauses between trials and series were similar to the tests on the force plate. If one trial was not executed correctly, one additional trial was recorded. Two reflecting markers were fixed on the platform to capture the sway of the platform with a Vicon 512 System (Vicon Motion Systems Ltd., Oxford, UK). Data were sampled at 120 Hz with

Vicon Software and analyzed offline with MatLab. For both tests, the best trial was used for further analysis. Two participants of the O-INT had to be excluded in the single-leg stance on the free-swinging platform due to incomplete data acquisition.

2.3.3 Countermovement jump

After a short warm-up (jogging and hopping), participants performed countermovement jumps (CMJ) on the force plate. Participants were instructed to jump, with their arms akimbo, as high as possible with maximum effort in each jump. After two jumps for familiarization, six CMJs were recorded with a break of 10 s between jumps. Vertical ground reaction forces from the force plate were sampled at 1 kHz and analyzed offline with MatLab. Values below 5 N were considered to represent the flight phase. Jump height was calculated by the formula: jump height = $1/8 * g * t^2$, where g is the acceleration of gravity and t represents the duration of the flight phase. The best out of the six CMJ was used for further analysis. One participant of O-CON had to be excluded from this test.

2.3.4 Explosive strength

Explosive strength of the plantar flexor muscles was assessed by determining the maximal rate of torque development (RTD). For this purpose, participants were in a supine position with straight legs and the right foot tightly fixed to an isokinetic dynamometer (Humac Norm, Computer Sports Medicine Inc., Stoughton, MA, USA). The axis of the ankle joint was exactly aligned with the axis of the dynamometer. The lower leg was fixed to the seat by a large strap to avoid contribution from knee or hip extensors. Data was recorded during isometric contractions in a neutral ankle joint position. Participants were instructed to execute the plantar flexion as fast as possible. The measurement contained three trials for familiarization followed by 2*10 trials. A pause of 6 s between two consecutive trials and of 3 min between the two sets was given. Sampling frequency for RTD data was set at 1 kHz. The maximal RTD was determined offline in MatLab selecting the 10 ms window with the largest increase in torque. The value of the best trial was used for further analysis. Due to incomplete data acquisition, three participants of O-INT could not be included in the analysis.

2.4 Statistics

Changes in balance performance were analyzed using a three-way mixed design repeated measures ANOVA with the within-subject factor TIME (pre vs. post) and the between-subject factors GROUP (INT vs. CON) and AGE (Y vs. M vs. O). In the case of significant *F*-values ($p < .05$), a post hoc analysis with Bonferroni-corrected Student's *t*-tests was applied to determine significant differences between factors levels. Furthermore, effect sizes of ANOVAs are presented as partial eta square values (η^2_p; small effect: .02; medium effect: .13; large effect: .26) and for Student's *t*-tests as Pearson correlation coefficient (r; small effect: .10; medium effect: .30; large effect: .50). SPSS software (Version 23, IBM Corp. IBM SPSS Statistics for Windows, Armonk, NY) was used for all statistical analyses.

3 RESULTS

3.1 Age

The three-way mixed design ANOVA with repeated measures revealed a significant effect for the factor AGE in all measured postural control parameters, in RTD and in CMJ. Post hoc analyses showed significant differences between Y and the two older groups (M and O) for each parameter, indicating that performances of the youngest group were significantly lower compared to the older groups. No differences were found between M and O except for RTD ($p < .001$; $r = .57$), where the oldest group generated higher values than M.

3.2 Training adaptations

Significant TIME*GROUP interactions were found for tandem stance ($F_{1,71} = 4.085$; $p = .047$; $\eta^2_p = .05$), single-leg stance on the spinning top ($F_{1,66} = 6.652$; $p = .012$; $\eta^2_p = .09$; see

Figure 1) and RTD ($F_{1,68} = 4.375$; $p = .040$; $\eta^2_p = .06$; see Figure 2). Post hoc analyses of tandem stance revealed no significant changes for either INT or CON over time. In contrast, children of the INT group improved significantly from pre- to post-test in the single-leg stance on the spinning top (18.7%; $p = .002$; $r = .45$), whereas performance of the CON group did not change (-0.1%; $p = .985$; $r < .01$; see Figure 1). Figure 1 displays better initial balance performances (pre-test) for CON groups compared to INT groups. However, this difference is statistically not significant ($p = 0.167$; $r = .16$). Positive adaptations in response to BT can also be reported for RTD, where the explosive strength of INT increased significantly (8.6%; $p = .024$; $r = .33$) while there was no significant change in the CON group (-3.5%; $p = .409$; $r = .16$; see Figure 2). In all other measured parameters, no significant TIME*GROUP interactions could be determined. In this context, it has to be noted that the TIME*GROUP interaction for single-leg stance on the free-swinging platform failed to reach significance due to improved performance in both the INT and the CON group (see Figure 3B).

3.3 Age-specific adaptations

Statistical analyses revealed significant TIME*GROUP*AGE interactions for single-leg stance on the spinning top ($F_{2,66} = 3.217$; $p = .046$; $\eta^2_p = .09$; see Figure 3A) and for single-leg stance on the free-swinging platform ($F_{2,69} = 4.069$; $p = .021$; $\eta^2_p = .11$; See Figure 3B). Post hoc testing of single-leg stance on the spinning top indicated significant improvements for Y-INT ($p = .026$; $r = .61$) and for M-INT ($p = .006$; $r = .60$), whereas for O-INT ($p = .274$; $r = .29$) and for all CON groups no significant changes from pre to post were observed. Interestingly, the largest improvement in this postural control task could be detected in Y-INT (28.8%). The older groups followed with 13.5% (M-INT) and 8.4% (O-INT), demonstrating positive adaptations in response to child-oriented BT particularly in the youngest children. Post hoc analyses for single-leg stance on the free-swinging platform showed substantial improvements in Y-INT (*p* = .001; *r* = .73) and O-INT (*p* = .017; *r* = .63) but no performance gains for M-INT (*p* = .096; *r* = .39). Platform sway reductions in single-leg stance were not exclusively observed for the intervention groups but were also seen in the control groups M-CON (*p* = .048; *r* = .64) and O-CON (*p* = .034; *r* = .64) on the free-swinging platform. The reductions of 34.7% for M-CON and 31.2% for O-CON in the platform sway path in single-leg stance were smaller than in Y-INT (54.7%), but larger than in O-INT (27.8%) and M-INT (21.8%). Post hoc analyses of pre-test performances between INT and CON for each age group revealed no significant differences in single-leg stance on the spinning top (Y: *p* = .088; *r* = .39; M: *p* = .444; *r* = .15; O: *p* = .703; *r* = .08; see Figure 3A) and single-leg stance on the free-swinging platform (Y: *p* = .163; *r* = .29; M: *p* = .493; *r* = .14; O: *p* = .144; *r* = .31; see Figure 3B). No age-specific adaptations were detected for RTD ($F_{2,68}$ = 0.534; *p* = .589; η^2_p = .01), indicating that RTD was similarly increased in the three different age groups that underwent child-oriented BT.

4 DISCUSSION

The current results are important to highlight that balance skills can be successfully trained in children from (at least) the age of six. Previous studies implementing balance interventions in children and adolescents were heterogeneous in terms of age and training content and revealed ambiguous results without clear evidence for a positive effect of BT on postural control. Notably, this is the first study showing positive effects of BT in young children. This may be surprising, as it is well known that BT promotes postural control in young (20) and older adults (21).

4.1 Postural control and explosive strength across ages

Postural control (10, 28) as well as force abilities (27) develop with increasing age and do not achieve peak values before early adulthood (5, 16). While the youngest group in the present study clearly showed the worst performance in all tests, the difference between the two older groups was small or even nonexistent. In postural control and jump tasks, no statistical differences between M and O were detected. However, RTD differed significantly among all age groups, indicating that explosive strength and postural control do not develop in parallel in children/adolescents. Our results therefore support the assumption that force is continuously and considerably increasing during childhood (7), whereas postural control seems to mature predominantly between the age of six and 11 (6, 29), and only marginally from 11 to 14 years (2). In line with this, an adult-like balance control can usually be seen around the age of 12–14 years (2, 26). As mentioned above, the postural control system undergoes a profound reorganization process starting at around the age of six (28). The youngest group of the present study was at the beginning of this reorganization process and was probably using other mechanisms to control balance than the older participants. As the two older groups showed comparable balance performances, we assume that these groups relied on similar and more mature postural control strategies.

4.2 Training adaptations

Previous BT studies in children younger than 12 years reported either no effects on postural control (13), task-specific adaptations only (8) or even improved postural control in transfer tasks (22). However, comparisons between those studies are hardly possible as not only the age of the participants greatly differed but also the training content. Therefore, the first step in evaluating the current training adaptations is to assess the impact of the child-oriented BT in general, i.e. across all three age groups. When analyzing all three INT groups together, dynamic balance was improved. In addition, explosive strength was significantly increased from pre- to post-test in the intervention groups. Although in young adults increases in explosive strength after BT have repeatedly been reported (for review, see 35), this is the first study demonstrating that BT can improve explosive strength in children and adolescents.

Apart from these general effects across all age groups, we also observed age-related training adaptations in postural control. Based on previous studies showing no or only limited adaptations in young children after BT (8, 13), it was hypothesized that older children/adolescents would benefit more from the intervention; probably due to their more matured postural control system. However, the youngest group improved to a larger extent than the two older groups that showed similar performance adjustments. The reason for this greater improvement in the youngest group of children might be due to their lower level of postural control at baseline. Thus, young children had a larger range of improvement available whereas ceiling effects might have limited improvements in the two older groups. Alternatively, it could be argued that the immaturity of the balance control system in children has a greater adaptive reserve and might therefore adapt more quickly. However, in order to answer this question balance tests need to be developed that allow a continuous (linear) progression of difficulty that can be quantified. Nevertheless, although we cannot answer why the youngest group displayed the largest training effects, the present results point out that the age – or the immature postural control system – is not a limiting factor for BT-induced improvements in young children.

4.3 Training content

Previous BT interventions with healthy children differed quite clearly from one another. The first training intervention applied in young children was classical BT. According to the authors, this kind of training did not sufficiently motivate the children to active participation (13). Subsequent studies applied other training contents, such as inline skating (22) or slacklining (8). While the former provoked improvements in postural transfer tasks, the latter reported only task-specific improvements on the slackline, even though the training schedule incorporated daily training sessions of 10 minutes with only a small number of children (two to three). However, it has to be noted that when considering slackline training in general, behavioral adaptations seem to be specific to the slackline, with little or no transfer to other balance tasks (9, 12). In contrast, the present results demonstrate that child-oriented BT leads to improvements in postural (transfer) tasks in children from the age of six onwards. The child-oriented BT was designed to highly motivate the children for the balance intervention. In order to test the compliance in the child-oriented BT, activity time was measured in a pre-study and was shown to be higher than the recommended value of 50% of total lesson time (37). In addition, the supervisors of the training reported the persistent interest and willingness of the children and adolescents to participate in the training sessions with great dedication and effort. All teachers and supervisors considered the training intervention to be adequate for children and adolescents. It may therefore be assumed that the child-oriented tailoring of the BT was essential to get the participants highly involved in the training process; probably the most important prerequisite for positive training adaptations. Consequently, great emphasis should be placed on the training content in order to improve postural control in (young) children and adolescents.

4.4 Limitations

No improvements from pre to post were found when assessing balance in static conditions. We assume that the static tests were not difficult enough to detect any improvements. Similarly, two dynamic tests in which children were standing on both legs were probably not difficult enough to identify performance gains. This finding has previously been reported for healthy seniors after an inline skating intervention (33), where the magnitude of training adaptation correlated with balance test difficulty. It was further observed that

Parkinson patients may perform static balance tests even more steadily than healthy persons but as soon as the difficulty level of the balance test was increased, Parkinson patients clearly displayed more sway (15, 30, 32). This illustrates that less demanding balance tests are often unsuitable to detect improvements or differences in postural control. For the present study, the level of difficulty for the postural control tests was chosen to be rather low so that the six-year-old children could also successfully accomplish them (i.e. avoiding floor effects). As the range of task difficulty for training gain detection is probably small – due to ceiling effects for facile tests and floor effects for difficult tests – the postural challenge might have been too low for the older age groups in the current study. Thus, the ceiling effects might have prevented greater adaptations in the two older groups. To counteract this limitation, future studies should apply tests with adjustable difficulty levels.

Significantly reduced sway paths for two CON groups (M and O) were found in the single-leg stance on the free-swinging platform. Although several familiarization trials were performed before the first measurement, it might be assumed that pre-testing on the free-swinging platform – which was a novel device for all participants – still elicited learning effects that led to improved performance in the post-test.

5 CONCLUSION

The present study provides evidence that postural control in transfer tasks and explosive strength can be improved in children and adolescents by applying child-oriented BT. Age-specific training adaptations were found, with greatest gains in the youngest group. We assume that the lower performance level of the young children led to this greater improvement. More importantly, we have shown that the young age, and thus the immaturity of the postural control system, did not prevent positive adaptations. To the best of our knowledge, this is the first study demonstrating that postural control can be trained by means of BT from as early as six years old. The fundamental prerequisite for this seems to be the content of the BT, which should be tailored to the needs of children and adolescents.

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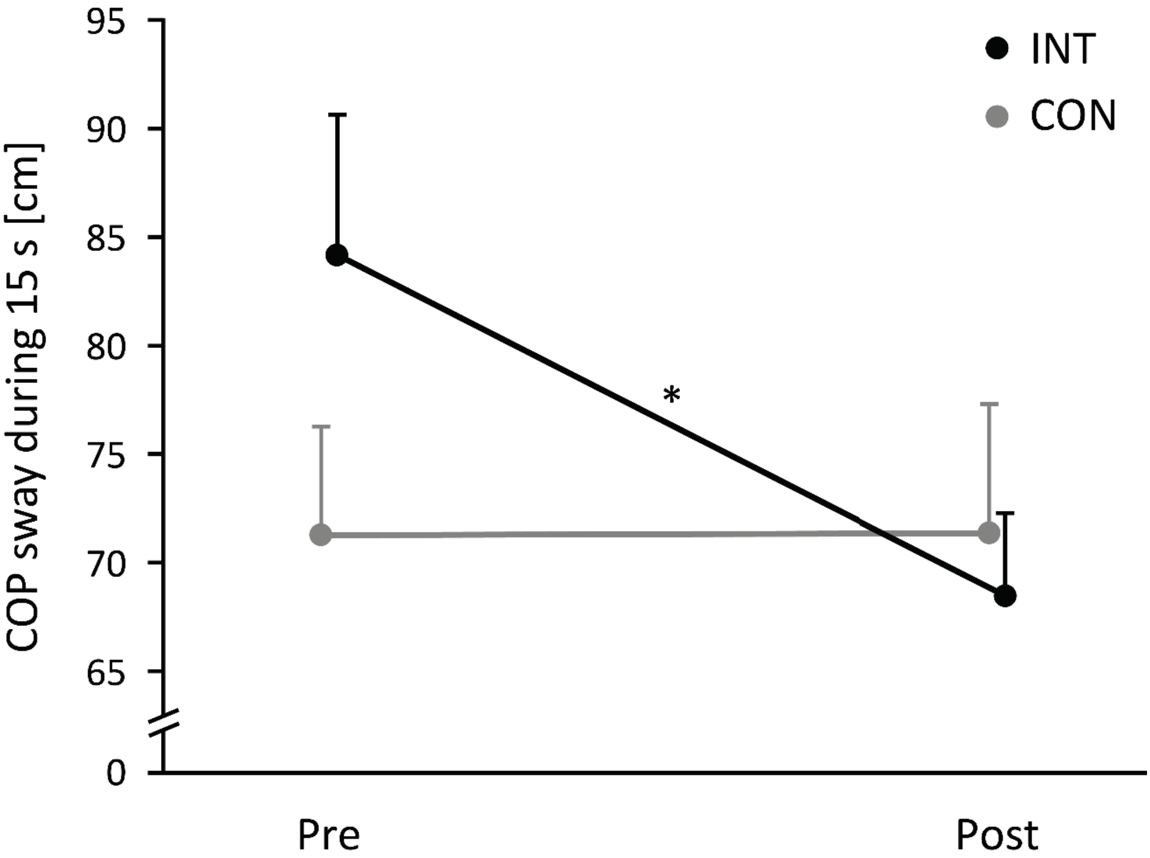

Figure 1. Center of pressure (COP) sway for single-leg stance on the spinning top (Interaction: p = .012; η^2_p = .09; INT: r = .45). Black dots and lines represent all intervention groups (INT) and grey dots and lines all control groups (CON). Values displayed as mean and standard error. * p = .012.

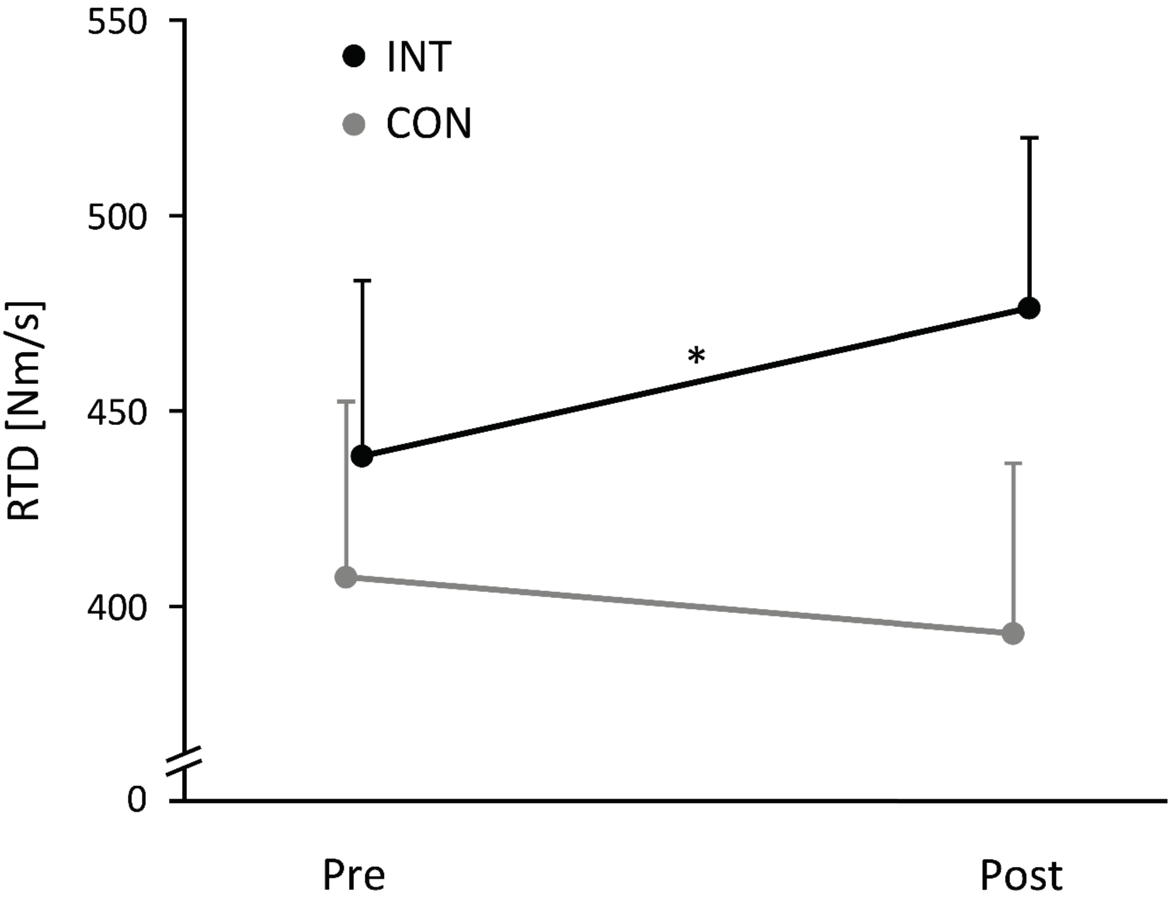

Figure 2. Rate of torque development (RTD) for explosive strength test in an isometric right-leg plantar flection (Interaction: $p = .040$; $\eta^2_p = .06$; INT: $r = .33$). Black dots and lines represent all intervention groups (INT) and grey dots and lines all control groups (CON). Values displayed as mean and standard error. * $p = .040$.

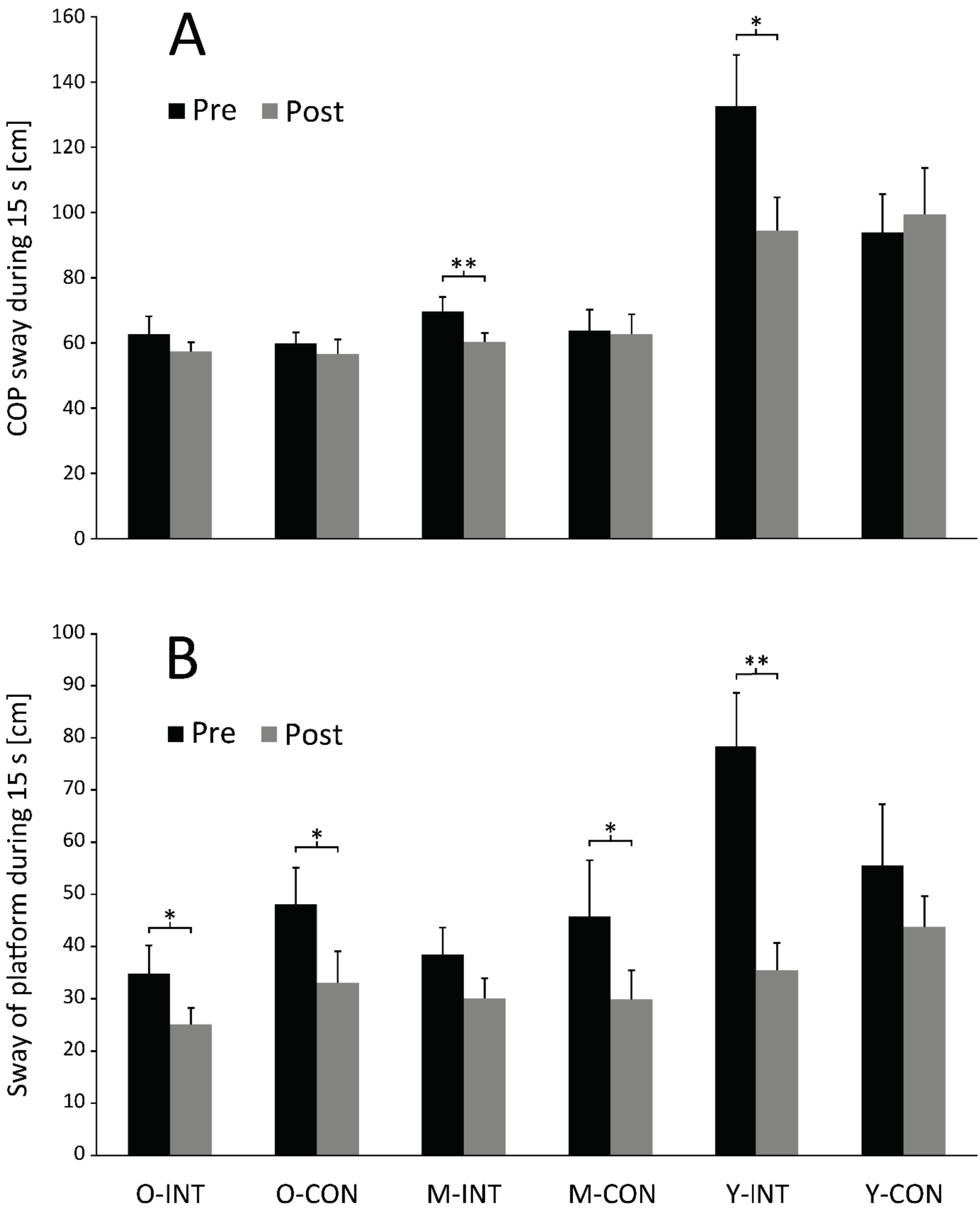

Figure 3. A: Center of pressure (COP) sway for single-leg stance on the spinning top (Interaction: $p = .046$; $\eta^2_p = .09$; Y-INT: $r = .61$; M-INT: $r = .60$). B: Sway of platform for single-leg stance on the free-swinging platform (Interaction: $p = .021$; $\eta^2_p = .11$; Y-INT: $r = .73$; O-INT: $r = .63$; M-CON: $r = .64$; O-CON: $r = .64$). Black bars represent pre-test and grey bars post-test values. Values displayed as mean and standard error. * $p < .05$; ** $p < .01$.

Table 1. Anthropometric data of intervention (INT) and control (CON) groups for the different age groups (young, middle, old).

	YOUNG		**MIDDLE**		**OLD**	
	INT	*CON*	*INT*	*CON*	*INT*	*CON*
n	15	10	18	9	15	10
Gender [f/m]	8/7	4/6	7/11	4/5	9/6	6/4
Age [years]	6.2 ± 0.4	6.2 ± 0.8	11.4 ± 0.5	11.4 ± 0.7	14.1 ± 0.5	14.9 ± 0.8
Weight [kg]	23.0 ± 4.3	22.5 ± 3.4	47.9 ± 11.2	39.5 ± 5.7	56.3 ± 9.1	65.8 ± 12.3
Height [cm]	119.5 ± 6.5	122.5 ± 11.9	154.3 ± 5.7	150.1 ± 4.9	163.4 ± 9.0	168.7 ± 10.4

Note: Values for age, weight and size are indicated as group mean ± standard deviation. In some cases, not all of the 77 participants could be included. f = female. m = male.

Table 2. Content of the training intervention program developed for children and adolescents (i.e. child-oriented BT). Each topic was treated in two sessions of 45 min each.

Training	*Topic*	*Content*
1 & 2	Balance circuit	Children executed different balance exercises such as walking over bars, moving forward with a Pedalo, walking on a ball that is between two mats or standing on a mat on free-moving balls. The aim was to explore and modify the exercises by themselves and at the end to execute the exercises for as long/far as possible.
3 & 4	Parkour 1	Children had to explore a way to cross over different (unstable) obstacles and to accomplish predefined routes without touching the ground.
5 & 6	Parkour 2	Children had to explore a way to cross over newly defined (unstable) obstacles and to accomplish predefined routes without touching the ground.
7 & 8	Competitive balance games 1	Children were asked to make their opponent lose balance in different situations, such as hopping on one leg, standing on a small surface, standing on wobbling surfaces, etc.
9 & 10	Competitive balance games 2	Children competed against each other or tried to outperform their previous scores in different balance exercises. The organization form was varied (one against one, two against two, groups against each other, echelons, etc.).

Note: The listed content represents only a short summary of the main parts of the lessons. In each lesson, multiple exercises on different balance devices were executed in variable forms to provide a constant challenge for the pupils.