Maturation-related effect of low-dose plyometric training on performance in youth hockey players

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Abstract

Purpose: The purpose of this intervention study was to investigate if a low-dose of plyometric training (PT) could improve sprint and jump performance in groups of different maturity status. **Method**: **Male** youth **field** hockey **players** were divided into Pre-PHV (from -1 to -1.9 from PHV; Experimental: n = 9; Control = 12) and Mid-PHV (0 to +0.9 from PHV; Experimental: n = 8; Control = 9) groups. **Participants** in the experimental groups completed 60 foot contacts, twice-weekly, for 6 weeks. **Results**: PT exerted a positive effect (effect size: 0.4 [-0.4 to 1.2]) on 10 m sprint time in the experimental Mid-PHV group **but this was less pronounced in the Pre-PHV group (0.1 [-0.6 to 0.9])**. **Sprint time over 30 m (Mid-PHV: 0.1 [-0.8 to 0.9]; Pre-PHV: 0.1 [-0.7 to 0.9]) and CMJ (Mid-PHV: 0.1 [-0.8 to 0.9]; Pre-PHV: 0.0 [-0.7 to 0.8]) was maintained across both experimental groups.** Conversely, the control groups showed decreased performance in most tests at follow up. **Between-group analysis showed positive effect sizes across all performance tests in the Mid-PHV group, contrasting with all negative effect sizes in the Pre-PHV group**. **Conclusion**: These results indicate that more mature **hockey players** may benefit to a greater extent than **less mature hockey players** from a low-dose PT stimulus. Sixty foot contacts, twice per week, seems effective in improving short sprint performance in Mid-PHV **hockey players**.

Keywords: Trainability, maturation, strength, young, athletes, load.

Introduction

Field hockey is a high-intensity team sport that requires players to engage in multiple short-distance sprints intermittently over the course of a competitive game (8, 26). With similar physiological demands to soccer (26), the performance of skills such as tackling and ball striking require players to express high force output with jumping, accelerating and decelerating also dependent on this ability (9, 29). In movement terms, the sport is characterised by multiple changes of direction, often in a semi-crouched posture which increases energy demand (8). Directly related to this, sprinting and jumping are important determinants of athletic performance in youth sport and should thus be targeted through physical training (2). An individual's ability to efficiently utilise the stretch-shortening cycle in such movements is an indicator of good athleticism and plyometric training (PT) has been shown to be an effective way in which to enhance this ability (36).

Because adaptations to PT may differ between youths of different maturity status (36), appropriate planning is likely to be a crucial element in the long-term periodisation of training. Previously, a trigger hypothesis has been proposed (22), suggesting that a maturational threshold may moderate responses to training around the time of peak height velocity (PHV). A longitudinal investigation (39) of physical parameters in **youths** supports this position, suggesting that an interaction between training and maturation may enhance sprint and jump performance at the time of PHV. This is supported by an earlier review (51) which stated that the greatest increase in physical performance was concomitant with progressing maturation in boys. However, the results of a recent meta-analysis (36) suggest a lowered response to PT around the time of PHV, contrasting with a higher level of trainability in the Pre-PHV phase (<13 years of age).

The results of that meta-analysis are in line with PT studies (42-44) that have measured biological maturity status with the maturity offset (34). **However, because very few researchers have compared groups of heterogeneous maturity status within the same study, it has thus far been difficult to accurately gauge the effect of biological maturation on adaptations to PT. Furthermore, comparisons between studies which use the maturity offset and those which account for participants' Tanner stage (30, 31) can be difficult to make as the latter measure refers to stages of pubic hair and genital development** (27) **whilst the former is related to anthropometric variables (34)**.

In addition, the minimum effective dose of PT has not been rigorously described in the literature. In their recent meta-analysis on the dose response between resistance training and physical performance in youth athletes, Lesinski et al. (24) included several studies of PT. However the authors' method of grouping PT studies with those that examined other training modalities makes it difficult to draw definitive conclusions with regard to exercise dosing. Previously, in their systematic review, Bedoya et al. (1) had recommended a minimum starting dose of 50 to 60 foot contacts per session though this was based on a very narrow range of studies and the authors did not elaborate on the dose which could be minimally effective. This is also true of the wider body of literature which has not investigated the effectiveness of this suggested dose. This has implications for athletic programing as the application of the minimum effective dose could be an integral element of athletic development given the recent debate on overuse injury and burnout in youth sport (7). **The importance of this is further emphasised by recent guidelines on strength and conditioning training in youths which broadly suggest 2, 3 or more sessions per week whilst acknowledging the confounding variables of volume, intensity,**

exercise type and degree of difficulty on the stimulated response (11). To date, the guidelines on PT in youth remain vague, particularly for the sport of field hockey with most PT research on male youths carried out in soccer (36).

Because of these limitations and conflicting results, it is unclear if there is an optimal time for the prescription of the minimum effective dose of PT in youth hockey players and this warrants further investigation. In light of these observations, the current investigation sought to examine the effects of a low-volume, low-intensity plyometric warm-up protocol on sprint and jump performance in youth **hockey players**, comparing responses in prepubertal (Pre-PHV) and midpubertal (Mid-PHV) male participants. A second objective was to **examine the effectiveness** of a minimum effective dose of PT that could be conveniently applied within a short timeframe around primary sports training.

Methods

Participants

Thirty-eight male youth field hockey players completed this study. They were recruited through a local school **which competes against other schools in the area** and were allocated into experimental (n = 17) and control (n = 21) conditions. **This was based on the school team that they played for and the number of participants that could be recruited from each. We did not use playing position either as an inclusion or exclusion criteria**. **The participants carried out two hockey training sessions per week in addition to one competitive game against other school opposition**. None of the participants in either group were carrying out a systematic fitness program. However, aside from their primary sport, they were involved in an intensive physical education program and military-style exercises on a daily basis. The characteristics of the participants are shown in Table 1. The study was approved by the institutional review board and participants provided informed parental consent to take part.

Pre-PHV Group	Experimental (n = 9)	Control (n = 12)
Age (years)	12.6 ± 0.7	12.8 ± 0.8
Maturity offset (years)	-1.5 ± 0.3	-1.4 ± 0.3
Maturity offset range (years)	-1 to -1.9	-1 to -1.9
Height (cm)	155.4 ± 5.1	160.4 ± 5.5
Sitting height (cm)	76.6 ± 2.9	76.7 ± 2.4
Mass (kg)	50.9 ± 8.7	52.9 ± 9.0
Mid-PHV Group	**Experimental (n = 8)**	**Control (n = 9)**
Age (years)	14.3 ± 0.6	14.4 ± 0.5
Maturity offset (years)	0.3 ± 0.2	0.4 ± 0.3
Maturity offset range (years)	0.1 to 0.5	0 to 0.9
Height (cm)	173.1 ± 5.4	171.2 ± 6.0
Sitting height (cm)	85.1 ± 3.0	84.6 ± 2.0
Mass (kg)	58.8 ± 3.4	64.0 ± 8.1

Table 1 Descriptive data for participants

Procedures

Participants attended performance testing sessions in the week before and the week after the training intervention. Anthropometric measurements were taken prior to tests of physical performance. **To estimate participant maturity status, anthropometric measurements were taken and entered into an equation to predict maturity offset** (34). **This equation is: Maturity Offset = -9.236 + (0.0002708 x leg length and sitting height interaction) + (-0.001663 x age and leg length interaction) + (0.007216 x age and sitting height interaction) + (0.02292 x weight by height ratio). The equation can measure maturity offset within an error of ± 1 year, 95% of the time (34). Sitting and standing height were measured with a stadiometer (Seca, Leicester, United Kingdom) and body mass with a portable scales (HoMedics Group Limited, Kent, United Kingdom).** The participants ranged from -1.9 to +0.9 years either side of PHV and were divided into Pre-PHV (Experimental: n = 9; Control = 12) and Mid-PHV (Experimental: n = 8; Control = 9) groups for analysis (34). The Pre-PHV group had an offset range from -1 to -1.9 years relative to PHV. The Mid-PHV group had an offset range of 0 to +0.9 years relative to PHV.

Countermovement jump (CMJ) was measured with a Newtest Powertimer jump mat (Newtest OY, Oulu, Finland). For the test, the arms were positioned akimbo and participants executed a downward movement to a self-selected depth before performing a vigorous extension of the lower-body limbs to jump as high as possible. **There was at least one minute's rest between efforts and the highest of three trials was used in the analysis (41).**

The 10 metre sprint (10 m) and 30 metre sprint (30 m) running times of the participants were measured using TC System timing gates (Brower Timing Systems, Draper, Utah, United States). **These distances were chosen based on their identification by Cronin et al. (4) as appropriate for measuring acceleration (10 m) and maximal speed (30 m).** Participants positioned the big toe of their lead foot behind the start line and initiated performance when desired, triggering the timer when passing through the system gates. There was at least one minute of rest between efforts and the best of three trials was used for analysis.

Similar to Zech et al. (54), we incorporated the PT program into the warm up prior to the in-season hockey **practice** of the experimental groups. It was delivered by the school fitness coach and the coaches of the respective groups. The control groups concurrently executed low intensity hockey skills work. Displayed in Table 2, the program was formulated based on the recommendations of previous systematic reviews of PT in children (21), youth athletes (1) and general population (5). **These studies have suggested a minimum dose of PT in youths but to date, the effectiveness of this dose has not been examined. Accordingly, the current program comprised 60 foot contacts per session on two days per week, for 6**

weeks with exercises chosen based on the recommendations of de Villarreal et al. (5) who advocate a varied PT stimulus that includes CMJs along with bilateral and unilateral hops. By programming in this way we ensured that participants were exposed to vertical, horizontal, bilateral and unilateral movements thus ensuring a well-rounded training stimulus. We assigned no more than 10 repetitions for each exercise based on the recommendations of Faigenbaum et al. (11) who highlight the importance of minimising fatigue to perform PT safely and effectively. The total **duration** of the program was 7 weeks as training was temporarily interrupted for 7 days by the school's mid-term break after week 4. After the mid-term break, another training block of 2 weeks was performed. Under school rules, all participants were required to partake in the hockey training as part of the sport curriculum.

Exercise	**Sets**	**Repetitions**
High knees	1 x 15 metres	n/a
Heel flicks	1 x 15 metres	n/a
Russian marches	1 x 15 metres	n/a
Walking single leg deadlift	1 x 15 metres	n/a
Cariocas	1 x 15 metres on each side	n/a
Lateral shuffles	1 x 15 metres on each side	n/a
	60 second rest prior to plyometric program	
Countermovement jumps	**1**	**10**
Standing shoulder abductions	1	20
Countermovement jumps	**1**	**10**
Standing shoulder abductions	1	20
Bilateral forward hops	**1**	**10**
Quadruped thoracic rotations	1	20 each side
Bilateral forward hops	**1**	**10**
Quadruped thoracic rotations	1	20 each side
Unilateral forward hops	**1**	**5 each side**
Quadruped scapula push ups	1	30
Unilateral forward hops	**1**	**5 each side**

Table 2 Order and arrangement of warm up and plyometric protocol

The plyometric element of the warm-up was preceded by a number of dynamic mobility drills performed over a 15 m distance. Between each plyometric exercise, upper body mobility drills were performed to afford the lower body musculature adequate rest between each set of jumps or hops. **This equated to around 60 seconds of rest between each plyometric drill**. During the plyometric exercises, participants were encouraged to be as "explosive" as possible within the boundaries of their own capabilities, being requested to take a brief pause **(2 secs approx.)** between repetitions if required, or if elastically repetitive jumps proved difficult to perform. As their capabilities improved, participants were encouraged to undergo fewer pauses between repetitions and to transition seamlessly from one jump into the next. The entire warm-up took approximately 12 minutes to complete.

Statistical Analysis

Magnitude-based inferences were used to quantify changes in each group. Uncertainty in these estimates was represented by 90% confidence limits. Effect sizes were interpreted using outlined conventions (<0.2 = trivial; 0.2-0.6 = small, 0.6-1.2 = moderate, 1.2-2.0 = large, 2.0-4.0 = very large, >4.0 = extremely large) (19). These methods were preferred to traditional null hypothesis testing which can be ineffective in gauging practical importance (19). This is particularly relevant in studies of physical performance which have small sample sizes (46). The estimates were considered unclear when the chance of a beneficial effect (an improvement in performance of >0.20) was high enough to justify use of the intervention, but the risk of impairment was unacceptable. An odds ratio of benefit to impairment of <66 was representative of such unclear effects (33). This odds ratio corresponds to an effect that is borderline possibly beneficial (25% chance of benefit) and borderline most unlikely detrimental (0.5% risk of harm). This was calculated using an available spreadsheet developed by (20). Otherwise, the effect was considered as clear and was reported as the magnitude of the observed value, with the qualitative probability that the true value was at least of this magnitude (33). The scale for interpreting the probabilities was as follows: possible = 25–75%; likely = 75–95%; very likely = 95–99.5%; most likely>99.5% (19). Effects were considered unclear if the confidence interval overlapped thresholds for substantial positive and negative values. Otherwise, the effect was clear and reported as the magnitude of the observed value with a qualitative probability (19, 33). **Analyses were conducted within all groups to examine the effectiveness of the PT program and between training and control groups to examine effectiveness of the PT program at different maturity levels compared to the control condition**.

Reliability of performance measures was assessed using the intraclass correlation coefficient which was 0.94, 0.90 and 0.96 for the CMJ, 10 m and 30 m respectively.

Results

Effect sizes and their descriptors, in addition to likelihood estimates of beneficial effects for the respective analyses are shown in Table 3.

Within-group analysis showed that the PT program was **specifically** effective in enhancing 10 m performance in **the** Mid-PHV **group**. All performance parameters in the experimental groups were **at least** maintained with effects generally of greater magnitude in the Mid-PHV group. Control groups demonstrated performance decrements in most performance parameters **but this was more pronounced in the Pre-PHV group**. **Decrements were generally of a similar magnitude to performance improvements.**

Between-group analysis showed that the Mid-PHV group had small to moderate increases in all performance parameters with effects largest and most likely in CMJ and 30 m sprint. The Pre-PHV group showed performance decreases across all tests.

Variable	Group	Pre	SD	Post	SD	Effect size	Confidence limits	Likelihood effect is beneficial	Effect description	Odds ratio of benefit to harm
Countermovement jump (cm)	Pre-PHV Experimental	28.0	4.0	28.1	4.0	0.0	-0.7 to 0.8	0.0%	Trivial increase	9
	Pre-PHV Control	29.9	7.0	28.3	6.6	-0.2	-0.9 to 0.4	0.4%	Small decrease	0
	Mid-PHV Experimental	32.5	6.0	32.8	3.7	0.1	-0.8 to 0.9	0.0%	Trivial increase	25
	Mid-PHV Control	30.0	5.9	29.7	5.8	-0.1	-0.8 to 0.7	0.0%	Trivial decrease	0
10m sprint (s)	Pre-PHV Experimental	2.26	0.13	2.25	0.12	0.1	-0.6 to 0.9	22.8%	Trivial increase	296
	Pre-PHV Control	2.19	0.11	2.20	0.10	-0.1	-0.8 to -0.6	0.0%	Trivial decrease	0
	Mid-PHV Experimental	2.15	0.15	2.10	0.10	0.4	-0.4 to 1.2	80.3%	Small increase	341
	Mid-PHV Control	2.21	0.15	2.19	0.21	0.1	-0.7 to 0.9	1.1%	Trivial increase	125
30m sprint (s)	Pre-PHV Experimental	5.46	0.34	5.43	0.31	0.1	-0.7 to 0.9	4.6%	Trivial increase	196
	Pre-PHV Control	5.19	0.43	5.24	0.39	-0.1	-0.8 to -0.6	0.0%	Trivial decrease	0
	Mid-PHV Experimental	4.96	0.29	4.94	0.27	0.1	-0.8 to 0.9	0.4%	Trivial increase	54
	Mid-PHV Control	5.26	0.47	5.23	0.52	0.1	-0.7 to 0.8	0.2%	Trivial increase	69

Table 3 Pre and post scores, effect sizes, confidence limits, likelihood effects and odds ratios for performance data

Variable	Group	Effect size	Confidence limits	Likelihood effect is beneficial	Effect description	Odds ratio of benefit to harm
Countermovement jump (cm)	Pre-PHV	0.0	-0.8 to 0.7	0.0%	Trivial decrease	0
	Mid-PHV	0.6	-0.2 to 1.4	87.3%	Moderate increase	390
10m sprint (s)	Pre-PHV	-0.4	-1.1 to 0.3	0.8%	Small decrease	0
	Mid-PHV	0.6	-0.2 to 1.4	86.4%	Small increase	395
30m sprint (s)	Pre-PHV	-0.5	-1.3 to 0.2	1.4%	Small decrease	0
	Mid-PHV	0.7	-0.1 to 1.5	88.4%	Moderate increase	384

Table 4 Between-group effect sizes, confidence limits, likelihood effects and odds ratios for performance data

Discussion

We sought to examine the effects of a low-volume, and low-intensity PT program on sprint and jump performance in youth hockey players, comparing responses in Pre-PHV and Mid-PHV male participants. A second objective was to **examine the effectiveness** of a low-dose of PT that could be conveniently applied within a short timeframe **in conjunction with** primary sports training.

The finding of most interest **in the within-group analysis** was that the applied dose of PT **resulted in a larger increases in** 10 m sprint performance in the Mid-PHV than in the Pre-PHV group with the latter failing to exceed the ‘smallest worthwhile change’ of 0.2. Of note, 30 m sprint time and CMJ were maintained in both experimental groups whereas the control groups experienced decrements across most tests. **The between-group analysis indicated that the program was generally only effective in the Mid-PHV group suggesting that more mature players were more responsive to the PT stimulus.**

Marta et al. (30) recently demonstrated that a variable training stimulus that included PT was an effective way to improve CMJ (effect size: 0.22) and sprint performance

(0.45) over an 8 week period in prepubescent children. A similar study undertaken by the same research group (31), suggested that older children had no maturational-related advantage in terms of their sensitivity to the applied training stimulus. However, differences in the way that various researchers have traditionally assessed biological maturity is likely to influence the inferences that can be made from a study and more recently, several interventions which measured maturity with the offset method have shown different results (25, 33, 47).

In line with these latter interventions, the larger effects in the Mid-PHV group in the current study could be explained by the potential existence of a maturational threshold which is signalled by the development of hormonal profiles and the musculoskeletal system around the time of PHV, and which may regulate responses to training (33). In **youths**, the development of impulsive movement capability has been shown to increase in line with PHV (39). After the growth spurt, an increase in the cross-sectional area of type II muscle fibres could underpin impulsive performance increases in older youths (32). The lower concentrations of circulating androgens and growth factors in prepubertal youth could make morphological changes in the Pre-PHV group less likely. This is relevant to our analysis as lean leg volume, body mass, altered muscle architecture and greater neuromuscular coordination have been associated with enhanced impulsive movement performance in male youths (32). Rumpf *et al*. (48) showed that stretch-shortening cycle activity progressively increased as youths matured with vertical tendon stiffness (33.3%), leg stiffness (22%), eccentric muscle action (89.6%) and concentric muscle action (56.6%) all greater in Mid-PHV than they were in Pre-PHV. The authors found that the musculotendinous tissue of younger boys is more compliant than that of older boys, meaning that maturation exerts an effect on the ability to utilise the stretch-shortening cycle. It may be that the hormonal and musculotendinous profiles of the Mid-PHV group could have made them more receptive to the effects of the low volume PT stimulus.

The current results are **also** in line with previous longitudinal research in **youths** that suggests that sprint and jump performance improves in line with PHV (39). The authors of that study did imply that training could interact with maturation to have an effect on adaptations to exercise but the work generally referred to the natural development of physical performance only. In contrast, a recent review (36) suggests that jump performance during the Mid-PHV phase could be negatively affected by the emergence of growth spurt-related ‘adolescent awkwardness’ in some participants. Physical performance could also be inhibited due to a decrease in relative strength that is associated with increasing body size during the Mid-PHV period (37), a trend that can continue despite increases in absolute strength (53). However, in support of the current results, not all youths do experience disrupted sensorimotor abilities during growth and maturation (40) and it is not beyond possibility that our small sample size resulted in the Mid-PHV group being unaffected by this particular phenomenon. Similarly, the 7 week duration of the study may not have been long enough for any potential maturation-related decreases in relative strength to impact upon jump and sprint performance (17). It seems that independent of the potentially disruptive effects of these physiological processes, sprint and jump performance **may be more** likely to be enhanced by PT in Mid-PHV youths than it is in Pre-PHV youths (37, 39).

Another finding of interest was the small decrements in performance generally seen across the respective control groups of the Pre- and Mid-PHV cohorts. The extensive amount of physical activity of the study participants’ could have resulted in a temporary decrement in performance across the school term, with low volume PT being an effective means with which to offset this effect in the experimental groups. In the Pre-PHV control group, sprint and jump performance decreased in all measures whilst the Mid-PHV control group experienced decrements in CMJ. **Short-term decreases in performance in youths have been documented numerous times in the literature (12-14, 16, 35, 49, 50). It is possible that these decrements were due to fatigue (13) or an interference effect between multi-dimensional training modalities (13, 35, 49) resulting in a reduction of the effects of neuromuscular training. However, the concurrent execution of strength training and PT with sports training was sufficient to preserve CMJ performance in other studies (16, 49). This is in line with our results.**

A second objective of the current intervention was to examine the effectiveness of a minimum effective dose of PT in youths. Moderate volumes of PT can be as effective as higher volumes (3, 6) however there is little consensus on the size of 'low', 'moderate' and 'high' doses. An eight month intervention incorporating 300 jumps per session, twice per week showed only small effects in Mid-PHV boys. Lower volumes of PT have been associated with similar increases in jumping performance and greater training efficiency (5). Demonstrating this, Ramirez-Campillo et al. (45) applied a similar dose of PT to the current study over a 7 week period, reporting effect sizes of a similar magnitude in adolescent males. Our results support the addition of 60 foot contacts to the warm-up of sport training and this was found to be as beneficial as previous interventions of higher volume (52) and intensity (45). The applied stimulus was generally only effective in enhancing sprint performance in Mid-PHV over the 6 weeks of training. However, it did enable **all** training groups to maintain performance **regardless of maturation status** and may thus be suitable for an in-season training program when the volume of other training modalities is high.

This maintenance of performance occurred despite a one week break in the programme which could potentially have had a detraining effect on the experimental groups. Meylan et al. (33) found that a detraining period had a greater negative effect on

performance in Pre-PHV than in Mid-PHV, however those researchers documented these changes over an 8 week period of training abstinence. Over a shorter detraining period of two weeks in a training study on physical education students, Herrero et al. (18) found that jumping height decreased by 5.5% whilst sprint speed improved by 0.8%. If the one week detraining period in the current study did exert an impact on performance, the results of Herrero et al. (18) could explain why sprint speed was less affected than CMJ. These are important factors to consider for youth training within a school environment as our study demonstrates the intermittent nature of performance training due to vacation periods and planned breaks in the academic semester. We suggest that breaks of at least one week may not be detrimental to overall performance.

It is likely that coaches would need to prescribe higher volumes of PT to achieve greater changes in sprinting and jumping performance across maturity groups but this may be more relevant to off- or pre-season periods when competitive sport loads may be lower. **Coaches may also want to increase the volume of jumps that hockey players are exposed to: a deliberate feature of this study was that we sought to keep training volume fixed from week to week to establish a base dose of PT as a platform from which future research can build upon. This may have reduced the potential magnitude of the effect size and so coaches might consider the effects that a periodized approach could have on adaptive responses**. It is important to highlight that the nature of the PT program, which incorporated movements in a predominantly horizontal direction, may have been a factor in Mid-PHV participants increasing 10 m sprint to a greater extent than CMJ. **Also, it is likely that the nature of the PT program, which incorporated many slow stretch-shortening cycle movements, was the reason that improvements in sprint performance was restricted to the act of accelerating, rather than that of maximal speed running (15).** Regardless of training dose, PT should not be prescribed at the expense of safe exercise technique at any age and a program of integrative neuromuscular training may be required to address foundational strength and movement skills prior to the execution of more advanced training (10).

This study does have a number of limitations. It was not possible to randomise the participants because training had to be administered by the coaches within their own specific training groups. This is also a common drawback in many interventions studies. The utilised measurement of biological maturity status, though reliable, can lack precision (28) and may therefore be of more use if combined in a battery of maturity assessments which could include that of Khamis and Roche (23). Also, though the performance measures utilised showed differences between the maturity groups, they do not necessarily explain the mechanism of adaptation meaning more research in this area is required.

Conclusion

Low-dose PT, in the amount of 60 foot contacts on a twice weekly basis, can help to improve and maintain in-season short sprint **and jump** performance in Mid-PHV youth **hockey players**. **Such effects could be less likely to occur in in Pre-PHV hockey players**. This could be reflective of maturation-related differences between older and younger **players** but could also imply that the applied stimulus in younger children could be insufficient. Similar doses of PT have been proposed for injury prevention in youths (38) and there is no suggestion that the dose of PT in the current study would not be sufficient for that purpose. However, in the interests of **outright** performance improvement, youth **hockey players** may benefit from higher PT loads. This should not be at the expense of efficient movement technique and should be secondary to foundational fitness training which can act as a base for more complex forms of training at a later stage (10). To conclude, responses in the groups in this study indicate that a near-minimum effective dose of PT could have been found, though its successful application may be contingent on the maturity status of the **individual** and their volume of physical activity.

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Conflicts of interest

There are no conflicts of interest.

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