Title: Alternate leg bounding acutely improves change of direction performance in women's team sports players irrespective of ground type

Running head: Bounding and change of direction

Journal of Strength and Conditioning Research

Eleanor Dann [a]. Samuel Quinn [a], Mark Russell [b], Liam P. Kilduff [c,d], Anthony N. Turner [e], Samuel P. Hills [a]*

[a] Faculty of Health and Social Sciences, Bournemouth University, Bournemouth, United Kingdom

[b] Faculty of Health, Sport and Life Sciences, Leeds Trinity University, Leeds, United Kingdom

[c] Applied Sports Technology, Exercise Medicine Research Centre (A-STEM), Swansea University, Swansea, United Kingdom.

[d] Welsh Institute of Performance Science, Faculty of Science and Engineering, Swansea University, Swansea,

United Kingdom.

[e] London Sports Institute, Middlesex University, Faculty of Science and Technology, London, United Kingdom

*Corresponding author: Dr Samuel P. Hills

Figures: 1

Tables: 1

ABSTRACT

This study aimed to assess whether post-warm-up body mass only alternate leg bounding performed on grass or a hard surface acutely improves pre-planned change of direction performance in women's team sports players relative to a control condition and, if so, profile the time-course of such changes. On three occasions, 14 amateur women's team sports players performed 20 m pre-planned change of direction ('Pro-Agility') tests at 4 min, 8 min, and 12 min following interventions. Interventions were implemented immediately after a standardized warm-up and consisted of three sets of 10 repetitions of alternate leg bounding (five ground contacts per limb) on a hard indoor surface (HARD) or natural grass (GRASS), or a control condition involving ~75 s of continuous walking with no bounding (CON). Performance was similar between conditions at 4 min post-intervention. Performance at 8 min was greater in HARD (2.9%, $p = 0.015$), and GRASS (3.8%, $p = 0.029$) relative to CON, whilst GRASS also exceeded CON at 12 min post-bounding (5.2%, $p = 0.004$). All effects were large. No differences existed between HARD and GRASS at any timepoint. Alternate leg bounding performed with body mass only can acutely improve indices of change of direction performance in women's team sports players irrespective of the ground surface when an appropriate post-stimulus recovery period is provided. Bounding on grass or a hard surface represents a feasible match-day practice that enhances subsequent change of direction performance and could therefore be used as part of practically applicable pre-match, half-time, and/or pitch-side (re)warm-up activities.

KEY WORDS: Running, plyometric, football, power, agility, warm-up

INTRODUCTION

The capacity for muscular force production is influenced by the recent contractile history of a given muscle group (15). If potentiating effects exceed any co-existing fatigue, performing certain high-intensity muscle actions as a conditioning stimulus can acutely enhance subsequent exercise outcomes during explosive tasks such as jumps and sprints (27, 28, 31). This acute and temporary performance improvement, postactivation performance enhancement (PAPE), has been attributed to mechanisms including increased actin-myosin myofilament sensitivity to Ca^{2+}, enhanced motor neuron recruitment, increased body temperature, and/or more favourable central input to the motor neuron (2, 27, 31).

Many team sports such as the football codes are characterized by intermittent bouts of high-speed activity such as sprinting, jumping, and changing direction (25). Acknowledging that myriad factors contribute to overall team success, explosive physical actions are involved in many of the most decisive passages of play (6, 8). A player's ability to combine sprinting with rapid changes of direction, either as a pre-planned manoeuvre or in response to a stimulus, is an important indicator of physical performance (9, 22, 23) and can discriminate between playing levels in men's and women's soccer (17). The potential to acutely enhance high-intensity exercise performance means that targeting PAPE could be a worthwhile pre- or during-competition strategy to improve elements of sport-specific physical performance for team sports players.

Studies have often used moderate to heavy resistance exercise to elicit PAPE (27, 31). The greatest benefits have typically been reported in trained individuals using multi-set routines when ~7-10 min of rest separates the conditioning stimulus and subsequent exercise (15, 31). However, heavy resistance exercise may not always be feasible or desirable to implement within the practical, logistical, and regulatory constraints associated with pre- and within-competition practices of many team sports players. Identifying alternative methods of inducing PAPE that require less equipment and/or might be better tolerated by players and coaches on the day of competition may allow this strategy to be more widely implemented in practice.

Maximal isometric contractions may activate more motor units than dynamic movements and can therefore elicit PAPE in certain contexts (7, 10, 27), whilst ballistic and plyometric activities such as weighted jumps and throws may also be used as a conditioning stimulus due to their preferential recruitment of type II motor units (5, 11, 30). Turner et al. (28) observed that three sets of 10 repetitions of alternate-leg bounding on a hard indoor surface whilst wearing a weighted vest (equivalent to 10% of body mass) improved 10 m and 20 m sprint performance by 2-3% at 4 min and 8 min post-bounding, compared with a walking control condition. It would be valuable to ascertain whether the benefits of bounding can transfer to other important indices of team sports specific physical performance (e.g., movement sequences incorporating changes of direction), especially given that an isometric squat protocol has failed to enhance pre-planned change of direction outcomes in men's academy rugby players (16).

As plyometric exercises are characterized by rapid transfer from eccentric to concentric muscle actions and involve high ground reaction forces (4), the ground surface on which these movements are performed can affect the kinematics and physiological responses to such activities (18, 21). Whilst existing findings (28) suggest a potential benefit to incorporating bounding exercise within a pre-match, half-time, or pre-pitch-entry active warm-up for improving acceleration performance in plyometrically trained men's team sports players, it remains to be determined whether favourable responses also occur on softer surfaces more relevant to outdoor match-play (e.g., natural grass). Moreover, as very limited research has assessed PAPE in female athletes, exploring the efficacy of similar feasible conditioning strategies in women's team sports players would help to determine the value of such strategies for this population. This is especially relevant given that individual characteristics such as strength, speed, training experience, and proportion of type II muscle fibres may each influence the magnitude of the

PAPE response (10, 15, 31). Therefore, the aim of this study was to assess whether plyometric bounding exercise performed on natural grass or a hard surface with body mass only loading acutely improves subsequent change of direction performance in women's team sports players relative to a control condition and to determine the timeframe over which any PAPE may occur.

METHODS

Experimental approach to the problem

In a randomized, counterbalanced, cross-over fashion, participants completed three trials with approximately seven days between trials. On arrival at the testing venue on the day of each trial, participants completed a ~15 min standardized active warm-up which involved jogging (~5 min, moderate intensity) and lower-body dynamic stretching (~7 min, focusing on the musculature involved in the subsequent bounding and change of direction activities), before concluding with sprinting and changing direction at increasing intensities (~3 min, involving 10 m sprints including 180^{o} turns at near maximal intensities). The intervention stimulus followed immediately thereafter, which consisted of either a: a) walking control condition (CON), b) bounding on a hard surface condition (HARD), or c) bounding on grass condition (GRASS). A 20 m 'Pro-Agility test' was completed at 4 min, 8 min, and 12 min post-intervention.

Subjects

Following Bournemouth University ethics approval, 14 amateur standard women's team sports players (age: 20 ± 1 years, mass: 62.9 ± 7.6 kg, stature: 1.66 ± 0.06 m) volunteered to participate. *A priori* sample size calculation was completed using commercially available software (G*Power; Version 3.9.1.2, Germany). With an anticipated large effect size (28) and alpha set at 0.05, a sample of 12 was deemed sufficient for at least 80% power to detect significant effects. Participants were informed of the risks and benefits of participation and provided written consent before data collection. Eligibility required that participants had at least one year of plyometric training experience (i.e., performed specific plyometric exercises on average at least once per week over this period) and were active team sports players.

Procedures

Participants attended two familiarization sessions before the first trial to ensure familiarity with all exercise and testing procedures, which included performing bounding and multiple repetitions of the 'Pro-Agility test' with maximal effort. Trials were completed at the same time of day on each occasion to avoid the influence of diurnal variation in performance (26). For all trials, participants were asked to avoid alcohol, caffeine, or strenuous exercise in the preceding 24 hours and maintain consistent nutrition, hydration, and footwear on each occasion.

For HARD and GRASS, the standardized warm-up was followed immediately by three sets of 10 repetitions (i.e., five ground contacts per leg per set) of alternate leg bounding with no additional loading applied other than body mass. Participants were instructed to perform the bounding as per Turner et al. (28). After a three-step run-up, participants pushed off their preferred foot before flexing the hip to bring the opposite limb through so the thigh was approximately parallel to the ground with the knee flexed to ~90^{o}. Hip and knee extension followed to forcefully contact the ground with the foot and push off, before participants repeated this sequence until 5 contacts were completed on each leg. A 15 s active recovery separated each set. Participants were instructed to maximize distance per bound whilst minimizing ground contact time. The only difference between HARD and GRASS was that bounding in HARD was performed on a hard indoor sports hall surface, whereas bounding in GRASS was performed on a flat natural grass surface which had not been exposed to precipitation within the preceding 24 h. The warm-up in CON was followed by continuous walking for the equivalent duration of the bounding intervention in HARD and GRASS (~75 s). Walking was included rather than passive rest to minimize losses of warm-up induced body temperature in CON relative to HARD and GRASS.

At 4 min, 8 min, and 12 min after the respective intervention, change of direction ability was assessed using a 'Pro-Agility test' (Figure 1). This test was selected because it was anticipated to elicit minimal fatigue per repetition, combined acceleration, deceleration, and changes of direction, was similar to activities performed by many of the participants in sport-specific training, and has demonstrated good reliability (coefficient of variation; CV% = 1.8) in recreational standard women's team sports athletes (24). The current sample demonstrated test-retest CV% = 1.3 following familiarization. Participants began each repetition stationary in a neutral stance 0.3 m behind the start line. On hearing a verbal start command, participants were required to turn 90° to sprint to touch with their foot a line 5 m to their right. Having reached the line, participants changed direction (180° change) and sprinted to a line 10 m in the opposite direction, before a further 180° change of direction and 5 m sprint back to the start line (24). A single repetition was performed at each timepoint and time taken to complete the 20 m course was recorded using electronic timing gates (Brower Timing Systems, USA) at a height of approximately 0.8 m. All procedures for CON and HARD were performed in a temperature-controlled indoor sports hall (air temperature: 18.7 ± 0.6 $^{\circ}$C, relative humidity: 51.3 ± 0.9%), whereas the bounding in GRASS was performed outdoors on an area of natural grass immediately adjacent to the sports hall entrance. The standardized warm-up, recovery periods, and testing in GRASS were completed in the indoor sports hall.

****INSERT FIGURE 1 HERE****

Statistical analyses

Statistical analyses were conducted using SPSS software (Version 28; SPSS Inc, USA) and $p < 0.05$ was used as the threshold for statistical significance. Following checks for normality of distribution, two-way analysis of variance with repeated measures was used, with condition (CON, HARD, GRASS) and time (4 min, 8 min, 12 min) representing within-participant factors alongside their interaction.

Mauchly's test was consulted and the Greenhouse-Geisser correction was applied if the assumption of sphericity was violated. Significant main effects were explored using Bonferroni-adjusted pairwise comparisons, whilst significant condition x time interactions were broken down via simple effects analysis. Hedge's g effect sizes (ES) were calculated for significant comparisons and were interpreted as trivial (0.00–0.19), small (0.20– 0.49), moderate (0.50–0.79), or large (>0.80) (3).

RESULTS

Table 1 shows change of direction performance in each condition. There were significant effects of condition ($F_{(2, 26)}$ = 9.907, p < 0.001, partial eta-squared = 0.432), time ($F_{(1.36, 17.72)}$ = 10.496, p = 0.002, partial eta-squared = 0.447), and a significant condition x time interaction ($F_{(4, 52)}$ = 3.958, p = 0.007 partial eta-squared = 0.233). No difference between conditions existed at 4 min post-intervention but at 8 min performances in HARD (2.9%, p = 0.015, ES:1.17, *large*) and GRASS (3.8%, p = 0.029, ES: 1.18, *large*) were superior to CON. At 12 min, times in GRASS, but not HARD, remained faster than CON (5.2%, p = 0.004, ES: 1.64, *large*). Results were similar between HARD and GRASS throughout.

In CON, performance at 12 min was worse than that recorded at 4 min post-walking (p = 0.018, ES: 1.09, *large*). In HARD, times were faster at 8 min relative to both 4 min (p = 0.029, ES: 0.46, *small*) and 12 min (p = 0.002, ES: 0.85, *large*) post-bounding.

****INSERT TABLE 1 HERE****

DISCUSSION

This study assessed whether alternate leg bounding on grass or a hard surface acutely improved change of direction performance in women's team sports players. On both surfaces, completing three sets of 10 repetitions of body mass only alternate leg bounding improved pre-planned change of direction times at 8 min post-intervention compared with a walking control condition. Bounding on natural grass also elevated performance relative to the control after 12 min. These findings indicate that alternate leg bounding can acutely improve indices of change of direction performance in women's team sports players when ~8-12 min recovery is provided. Such data highlight the potential for this strategy to be incorporated where feasible into the match-day practices of this athletic population. Depending on the length of any post-warm-up transition period, bounding may be implemented as part of a pre-match warm-up, half-time rewarm-up, and/or pitch-side preparations for substitutes awaiting pitch-entry. Moreover, this strategy may be implemented at the beginning of training sessions that are targeted at improving physical capabilities such as speed and change of direction ability.

At 8 min post-intervention, change of direction performance was elevated by 2.9% and 3.8% in HARD and GRASS, respectively, compared with the same timepoint in CON. Whilst improvements in explosive physical performance following an appropriate conditioning stimulus have been well established (16, 27, 31), conditioning protocols have often involved using external equipment to facilitate appropriate loading. Given the practical and regulatory constraints that often exist on match-day, these strategies are unlikely to be feasible immediately before or during a match in many team sports. Plyometric or ballistic activities may offer more a practical alternative conditioning stimulus when compared with traditional methods of inducing PAPE (5, 11, 30). Improvements in change of direction performance after 8 min in the current study are of similar magnitude to previous observations of augmented 10 m and 20 m straight line sprint performance after trained men completed alternate leg bounding whilst wearing a weighted vest (with an additional 10% of body mass of loading) (28). This study therefore extends previous research to demonstrate a bounding-induced PAP effect on another crucial aspect of team sports match-play (i.e., change of direction) and without the need for any additional equipment.

Soft surfaces such as sand can dissipate ground reaction forces and reduce stretch-shortening cycle efficiency compared with the same activities performed on hard ground (18). Moreover, increased shock absorption and vertical deformation have been observed when running on natural grass relative to a hard asphalted running track (21). As exercises such as alternate leg bounding are characterized by rapid transfer from eccentric to concentric muscle actions and involve high ground reaction forces (4), the surface on which these activities are performed could plausibly influence the length of the amortization phase and thus the extent to which they have can elicit PAPE. However, no statistically significant differences in change of direction performance existed between HARD and GRASS at any timepoint. These findings suggest that alternate leg bounding performed on natural grass may be at least as effective for improving this performance outcome as the same intervention performed on a hard indoor surface. Moreover, the benefit relative to CON in GRASS extended to 12 min post-intervention whereas improvements in HARD were restricted to the 8 min timepoint. Although the reasons for this finding remain unclear, greater muscle activation has been reported during movements on softer compared with harder surfaces (18). Therefore, it is possible that the likely slightly softer natural surface may have led to greater muscle activation and thus a more sustained performance enhancement in GRASS than in HARD. Alternatively, or in conjunction, because exercises on grass have a greater metabolic cost than those performed on a hard surface (21), the bounding in GRASS could have led to a greater and/or more sustained elevation of muscle temperature than in both HARD and CON. Given the positive relationship between body temperature and explosive physical performance capacity (12, 19, 20), any such elevations could have contributed to significant performance elevations relative to CON at 12 min in GRASS but not in HARD.

Movement specificity alongside the intensity of the prior contraction may be an important factor influencing the PAPE response following a conditioning stimulus, whilst greater familiarity with a task could reduce ‘warm-up decrement’ (29). Turner et al. (28) reported greater improvements in 10 m and 20 m sprint performance at 4 min and 8 min following bounding with a weighted vest compared with the same volume of bounding performed without additional external loading. The authors speculated that increased ground contact time during each bound in the weighted condition had greater biomechanical specificity to the acceleration phase of sprinting. Similar considerations may have contributed to the performance improvements (i.e., relative to CON) persisting at 12 min post-bounding in GRASS if greater shock absorption on the natural grass surface led to longer ground contact time in this condition than in HARD (21). Indeed, short-duration acceleration and deceleration as required in the change of direction test involve maximizing horizontal orientation of forces (1, 13). Further research is needed to elucidate whether greater improvements in change of direction performance could be elicited by adding external loading (e.g., via a weighted vest or horizontally applied resistance) or incorporating conditioning movements in the frontal plane, and whether this bounding stimulus can simultaneously improve other valuable physical performance indicators (e.g., jumping activities with a more vertical orientation of force).

As well as the intervention itself (e.g., the type, duration, and intensity of exercise performed, alongside the subsequent recovery duration), characteristics of the individual participant can influence the PAPE response. Indeed, possessing superior strength, speed, training experience, and proportion of type II muscle fibres may allow an athlete to benefit from PAPE to a greater extent than those who are weaker or less well-trained (10, 15, 31). Whilst differences in PAPE between males and females have not been confirmed in the literature, current evidence is limited and many relevant characteristics typically vary between sexes (14). The fact that this study observed PAPE of change of direction performance relative to a control condition in recreational standard female athletes with typically ~1-2 years of plyometric training experience is therefore an important and novel observation. It is possible that greater benefits may have been experienced if participants had been more highly trained athletes. Notably, the more well-trained an individual, the greater volume and/or intensity of conditioning stimulus may be required to maximize PAPE (31).

Whilst this study demonstrated improved 'Pro-Agility test' performance in HARD and GRASS relative to CON, it is not possible to determine whether the bounding interventions elicited improvements in the specific change of direction component or the acceleration/deceleration component of the test. In addition, because physiological and electromyographical measurements were not taken, the precise mechanism(s) underpinning the acute performance enhancement observed cannot be conclusively determined. Nonetheless, this study has shown that a ~75 s long alternate leg bounding intervention completed with body mass only on either natural grass or an indoor hard surface can acutely enhance change of direction test performance in women's team sports players compared with a walking control condition.

This study involved between-condition comparisons, without including a pre-intervention baseline measurement. The findings must be interpreted as such. The lack of baseline measurement means that it is not possible to determine within-condition performance changes relative to pre-intervention. However, as the change of direction test was consistent across all three trials, the design of the current study avoids any potential confounding influence from the test itself producing a fatiguing and/or potentiation effect at subsequent timepoints (i.e., performances at 8 min and 12 min had been preceded in all trials by one and two repeats of the change of direction test, respectively). Performance in HARD and GRASS could thus be compared with responses produced in the absence of any bounding intervention (i.e., CON).

PRACTICAL APPLICATIONS

In women's team sports players, completing three sets of 10 repetitions of body mass only alternate leg bounding on either a hard indoor surface or natural grass elicited improvements in change of direction performance 8 min post-intervention when compared with a walking control condition. Improvements relative to the control were also seen at 12 min post-bounding when bounding was performed on grass. These findings suggest that players and coaches may consider implementing alternate leg bounding at specific timepoints during training or on match-day (e.g., at the end of the pre-match warm-up, at half-time, or for substitutes awaiting pitch-entry) as a means of potentially enhancing indices of sport-specific physical performance even if a suitable hard surface is not immediately available.

ACKNOWLEDGMENTS

No financial assistance was received for this study. The authors report that there are no conflicts of interest to declare. The results of the present study do not constitute endorsement of the product by the authors or the National Strength and Conditioning Association.

REFERENCES

1. Baena-Raya A, Soriano-Maldonado A, Conceição F, Jiménez-Reyes P, and Rodríguez-Pérez MA. Association of the vertical and horizontal force-velocity profile and acceleration with change of direction ability in various sports. *Eur J Sport Sci* 21: 1659-1667, 2021.
2. Blazevich AJ and Babault N. Post-activation potentiation versus post-activation performance enhancement in humans: historical perspective, underlying mechanisms, and current issues. *Front Physiol* 10: 1359, 2019.
3. Cohen J. Statistical power analysis. *Curr Dir Psychol Sci* 1: 98-101, 1992.
4. Davies G, Riemann BL, and Manske R. Current concepts of plyometric exercise. *Int J Sports Physiol Perform* 10: 760, 2015.
5. Desmedt JE and Godaux E. Ballistic contractions in man: characteristic recruitment pattern of single motor units of the tibialis anterior muscle. *J Physiol* 264: 673-693, 1977.
6. Dos' Santos T, McBurnie A, Thomas C, Jones PA, and Harper D. Attacking agility actions: Match play contextual applications with coaching and technique guidelines. *Strength Cond J*: epub ahead of print, 2022.
7. Duchateau J and Hainaut K. Isometric or dynamic training: differential effects on mechanical properties of a human muscle. *J Appl Physiol* 56: 296-301, 1984.
8. Faude O, Koch T, and Meyer T. Straight sprinting is the most frequent action in goal situations in professional football. *J Sports Sci* 30: 625-631, 2012.
9. Gabbett TJ, Kelly JN, and Sheppard JM. Speed, change of direction speed, and reactive agility of rugby league players. *J Strength Cond Res* 22: 174-181, 2008.
10. Hamada T, Sale DG, MacDougall JD, and Tarnopolsky MA. Interaction of fibre type, potentiation and fatigue in human knee extensor muscles. *Acta Physiol Scand* 178: 165-173, 2003.
11. Hilfiker R, Hubner K, Lorenz T, and Marti B. Effects of drop jumps added to the warm-up of elite sport athletes with a high capacity for explosive force development. *J Strength Cond Res* 21: 550-555, 2007.
12. Hills SP, Aben HGJ, Starr DP, et al. Body temperature and physical performance responses are not maintained at the time of pitch-entry when typical substitute-specific match-day practices are adopted before simulated soccer match-play. *J Sci Med Sport* 24: 511-516, 2020.
13. Hunter JP, Marshall RN, and McNair PJ. Interaction of step length and step rate during sprint running. *Med Sci Sports Exerc* 36: 261-271, 2004.

14. Hunter SK. The relevance of sex differences in performance fatigability. *Med Sci Sports Exerc* 48: 2247-2256, 2016.
15. Kilduff LP, Owen N, Bevan H, et al. Influence of recovery time on post-activation potentiation in professional rugby players. *J Sports Sci* 26: 795-802, 2008.
16. Marshall J, Turner AN, Jarvis PT, et al. Postactivation potentiation and change of direction speed in elite academy rugby players. *J Strength Cond Res* 33: 1551-1556, 2019.
17. Mujika I, Santisteban J, Impellizzeri FM, and Castagna C. Fitness determinants of success in men's and women's football. *J Sports Sci* 27: 107-114, 2009.
18. Pereira LA, Freitas TT, Marín-Cascales E, et al. Effects of training on sand or hard surfaces on sprint and jump performance of team-sport players: A systematic review with meta-analysis. *Strength Cond J* 43: 56-66, 2021.
19. Russell M, Tucker R, Cook CJ, Giroud T, and Kilduff LP. A comparison of different heat maintenance methods implemented during a simulated half-time period in professional rugby union players. *J Sci Med Sport* 21: 327-332, 2018.
20. Sargeant AJ. Effect of muscle temperature on leg extension force and short-term power output in humans. *Eur J Appl Physiol Occup Physiol* 56: 693-698, 1987.
21. Sassi A, Stefanescu A, Bosio A, Riggio M, and Rampinini E. The cost of running on natural grass and artificial turf surfaces. *J Strength Cond Res* 25: 606-611, 2011.
22. Sekulic D, Pehar M, Krolo A, et al. Evaluation of basketball-specific agility: applicability of preplanned and nonplanned agility performances for differentiating playing positions and playing levels. *J Strength Cond Res* 31: 2278-2288, 2017.
23. Sheppard J, Young WB, Doyle T, Sheppard T, and Newton RU. An evaluation of a new test of reactive agility and its relationship to sprint speed and change of direction speed. *J Sci Med Sport* 9: 342-349, 2006.
24. Stewart PF, Turner AN, and Miller SC. Reliability, factorial validity, and interrelationships of five commonly used change of direction speed tests. *Scand J Med Sci Sports* 24: 500-506, 2014.
25. Taylor JB, Wright AA, Dischiavi SL, Townsend MA, and Marmon AR. Activity demands during multi-directional team sports: a systematic review. *Sports Med* 47: 2533-2551, 2017.
26. Teo W, McGuigan MR, and Newton MJ. The effects of circadian rhythmicity of salivary cortisol and testosterone on maximal isometric force, maximal dynamic force, and power output. *J Strength Cond Res* 25: 1538-1545, 2011.
27. Tillin NA and Bishop D. Factors modulating post-activation potentiation and its effect on performance of subsequent explosive activities. *Sports Med* 39: 147-166, 2009.
28. Turner AP, Bellhouse S, Kilduff LP, and Russell M. Postactivation potentiation of sprint acceleration performance using plyometric exercise. *J Strength Cond Res* 29: 343-350, 2015.
29. Verhoeven FM and Newell KM. Unifying practice schedules in the timescales of motor learning and performance. *Hum Mov Sci* 59: 153-169, 2018.
30. West DJ, Dietzig BM, Bracken RM, et al. Influence of post-warm-up recovery time on swim performance in international swimmers. *J Sci Med Sport* 16: 172-176, 2013.
31. Wilson JM, Duncan NM, Marin PJ, et al. Meta-analysis of postactivation potentiation and power: effects of conditioning activity, volume, gender, rest periods, and training status. *J Strength Cond Res* 27: 854-859, 2013.

LEGENDS:

Figure 1. Overview of Pro-Agility test procedures

Table 1. Change of direction performance times (s) by condition and timepoint following intervention

Table 1. Change of direction performance times (s) by condition and timepoint following intervention

	4 min	**8 min**	**12 min**
CON	5.72 ± 0.10	5.76 ± 0.15	5.91 ± 0.22
HARD	5.66 ± 0.13	5.60 ± 0.12 *	5.71 ± 0.14
GRASS	5.58 ± 0.15	5.54 ± 0.21 *	5.60 ± 0.14 *

CON: Control condition (walking), GRASS: Bounding intervention on a natural grass surface, HARD: Bounding intervention on a hard indoor surface
Data are presented as mean ± standard deviation. *: Statistically significantly different from the equivalent timepoint in CON ($p < 0.05$, large effect size).