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Can Player Tracking Devices Monitor Changes in Internal Response During Multidirectional Running?

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ABSTRACT

Purpose: We examined the movement, physiological and muscle function responses to running with and without (i.e. linear) multiple directional changes to understand which measures of external demands better reflected changes in the internal response. **Methods:** Twelve team sport athletes completed a linear and multidirectional running trial during which movement characteristics, oxygen consumption ($\dot{V}O_2$), blood lactate (B[La]) and heart rate (HR) were measured. Isometric peak torque of knee extensors and flexors was also assessed before and after each trial. **Results:** High speed running distance was higher during the linear trial (p < 0.001), whereas time at high metabolic power (p = 0.046), number of accelerations (p < 0.001), summated HR (p = 0.003) and B[La] (p = 0.002) were higher during the multidirectional trial. Integrated external to internal ratios of high-speed running: summated HR and high-speed running: total $\dot{V}O_2$ were different between multidirectional and linear trials ($p \leq 0.001$). Conversely, high metabolic power: summated HR and high metabolic power: total $\dot{V}O_2$ were similar ($p \geq 0.246$). Small decrements in knee flexor (p = 0.003) and extensor torque (p = 0.004) were observed after both trials. **Conclusion:** Time at high metabolic power better reflects the increased internal response during running with more directional changes than high speed running.

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Accelerations; external: GPS; internal ratio; metabolic power

Monitoring the team sport athlete's training and match load requires an understanding of both the external demands and the corresponding internal responses (Impellizzeri et al., 2019). The external "load" reflects measures of distance, speed, and accelerations, while the internal "load" refers to the individual's psychophysiological and neuromuscular responses to the activity, e.g., $\dot{V}O_2$, heart rate (HR), perceived exertion, muscle function (McLaren et al., 2018). For intermittent team sports (e.g., football), the external and internal loads during match-play and training typically involve numerous high-speed efforts (~30–40), accelerations (~650) and decelerations (~600; Russell et al., 2016), with mean $\dot{V}O_2$ and HR responses of 70% and 85% of maximum, respectively (Bangsbo et al., 2006; Iacono et al., 2017), and losses in peak knee extensor torque of ~11–14% (Brownstein et al., 2017; Rampinini et al., 2011). Similar characteristics have also been reported in other sports, such as basketball, handball, and hockey (Taylor et al., 2017).

Given the multidirectional nature of team sports, how external activity influences the internal response has implications for programming of training and recovery. Movement patterns with more changes of direction have been shown to evoke a higher blood lactate concentration (Ashton & Twist, 2015; Buchheit et al., 2010), increased HR (Akenhead et al., 2015; Tang et al., 2018), greater decrements in peak knee flexor torque (Ashton & Twist, 2015) and increased muscular activity (Hader et al., 2014) when compared to linear running at a similar speed. However, it is unclear if the oxygen demand for running with more directional changes is greater (Hatamoto et al., 2014) or not (Ashton & Twist, 2015). Studies to date have also tended to use shuttle running protocols, that is, 180° turns, when studying the effects of directional changes on external and internal measures (e.g., Akenhead et al., 2015; Ashton & Twist, 2015). These studies therefore ignore the backward and lateral running movements associated with team sports (Taylor et al., 2017), which are known to elicit specific physiological responses (Gao et al., 2022). Examining the effect of directional changes on external demands and external responses using a more ecologically valid multidirectional running approach would be useful where considered management of training demands are imperative, for example, returning to play after injury (Taberner et al., 2019).

Associations between measures of external demands (high-speed distance) and internal response during team sport activity are varied (r = 0.13 *cf.* r = 0.71; Casamichana & Castellano, 2015; Delaney et al., 2018). It is therefore unclear if the external demands of activity reflect changes in the internal responses during running with directional changes. Correlating external demands with the internal response also fails to account for the between-participant variation in fitness, which largely dictates the internal response (Weaving et al., 2017). When expressed as a ratio, the external-to-internal ratio (quantified using measures of high-speed distance covered [external] and individualized training impulse [iTRIMP, internal]), has a moderate to strong relationship (r = 0.58–0.69) with measures of aerobic

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power during football (Akubat et al., 2014; Akubat et al., 2018) and has been recommended to assess a player's readiness to perform (Akubat et al., 2014). However, high-speed distance does not account for the numerous accelerations and decelerations performed during team sport match-play that are known to influence the metabolic response (Oxendale et al., 2017). Metabolic power, which accounts for both speed and acceleration, has emerged as an alternative metric to quantify high-intensity activity (Osgnach et al., 2010; Di Prampero & Osgnach, 2018) that reflects an individual's internal response (Oxendale et al., 2017; Polglaze et al., 2018). However, further work is required to better understand how running with more directional changes influences the external and internal demands of exercise and the utility of metabolic power to quantify the response. This information could help inform how practitioners monitor training demands and subsequently guide training prescription and return to sport processes. Therefore, the aims of this study were twofold: a) to examine the internal and external responses to linear and multidirectional running and subsequent changes in peak isometric torque of the knee flexors and extensors, b) to understand which parameters of external demands (i.e. high speed or power) better reflect changes in the internal response associated with linear and multidirectional running. We hypothesized that multidirectional running would elicit a greater physiological response than linear running and induce greater decrements in peak isometric torque of the knee flexors and extensors. In addition, integrated ratios using time at high power would be similar between multidirectional and linear trials, whereas integrated ratios using high-speed metrics would differ between trials.

Materials and methods

Participants

With institutional ethics approval (1001/15/CO/SES), seven male and five female participants (age: 20.8 ± 2.7 y; height: 176.0 ± 12.0 cm; body mass: 73.3 ± 12.8 kg; $\dot{V}O_{2peak}$: 45.2 ± 2.9 $ml.kg^{-1}.min^{-1}$) were recruited from university-standard team sports (rugby, football, hockey, and netball). Specifically, the same participants and data collection from Oxendale et al. (2017) are used in this study, however the variables assessed herein have not previously been reported. The sample size exceeds an *a priori* sample size calculation using estimated power and an effect size of 1.1 for differences in HR during running with an increased number of directional changes (Tang et al., 2018) All participants provided written informed consent to take part in the study and completed a health questionnaire to ensure no contradictions to exercise. Participants also abstained from performing any strenuous activity 48 hours before each trial. All procedures were conducted according to the Declaration of Helsinki.

Experimental design

In a repeated measures design, participants completed three visits to the laboratory on separate days. On the first visit, participants performed a multi-stage fitness test to ensure they met the inclusion criteria of possessing a maximal aerobic power >40 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ for females or >45 $ml{\cdot}kg^{-1}{\cdot}min^{-1}$ for males. Thereafter, participants were habituated to the multi-directional and linear trials and the assessment of isometric muscle function. In the subsequent two visits, participants completed the linear and multidirectional trials in a randomized order with 3–7 days between trials. During each trial movement was recorded using a player tracking device and measurements of oxygen consumption ($\dot{V}O_2$), blood lactate concentration (B[La]) and HR were taken; these data were used to calculate the external-to-internal ratio. Finally, peak isometric torque of the knee flexors and extensors was measured immediately before and after each trial.

Procedures

Multi-stage fitness test

The 20 m multi-stage fitness test involved running back and forth along a 20 m indoor linear course (Ramsbottom et al., 1988). The starting speed was 8.5 $km.h^{-1}$, which progressively increased by 0.5 $km.h^{-1}$ every minute until volitional exhaustion. During the test participants wore a pre-calibrated portable gas analyzer (Cosmed K4b2, Cosmrd S.r.I, Rome, Italy), with $\dot{V}O_{2peak}$ calculated as the highest value recorded over a 30s epoch.

Linear and multidirectional running

Both trials comprised eight bouts of ~60 s of work followed by 120 s of passive rest, with each bout covering 175 m. The multidirectional trial comprised accelerations, decelerations, sprinting, forwards and backwards jogging and lateral cutting maneuvers (see Figure 1 from Oxendale et al., 2017). The linear trial involved 3 × 35 m sprints interspersed with 2 × 35 m jogs along a linear course. All trials were conducted on an outdoor running track at a similar time of day (± 2 hours) to minimize diurnal variation. The coefficient of variation (CV) for total distance covered and time at high speed and high power during the multidirectional trial was 1.4%, 6.1%, and 4.3%, respectively.

Player tracking device and heart rate

Movement characteristics were recorded using an OptimEye S5 global positioning system (GPS) unit sampling at 10 Hz with a 100 Hz tri-axial accelerometer (Firmware 6.75, Team 2.5, Catapult Innovations, Melbourne, Australia). Total distance, distance, and time at high speed (>14.4 $km.h^{-1}$) and very high speed (>16 $km.h^{-1}$) during the whole trial, as well as mean speed during active bouts only (negating passive rest periods), were recorded. Two definitions of high speed were used to compare a common high-speed threshold used in the literature (>14.4 $km.h^{-1}$; Fox et al., 2017) and the speed equivalent of high metabolic power, during constant-speed running (>16 $km.h^{-1}$; Osgnach et al., 2010). The total number of accelerations and decelerations performed (>1.5 $m{\cdot}s^{-2}$), accumulated PlayerLoad™ and time at high metabolic power (>20 $W.kg^{-1}$) were also calculated during each trial, using the manufacturer's software (Sprint, Version 5.1.4, Catapult Sports, VIC, Australia). The same player tracking device was used throughout the study for all

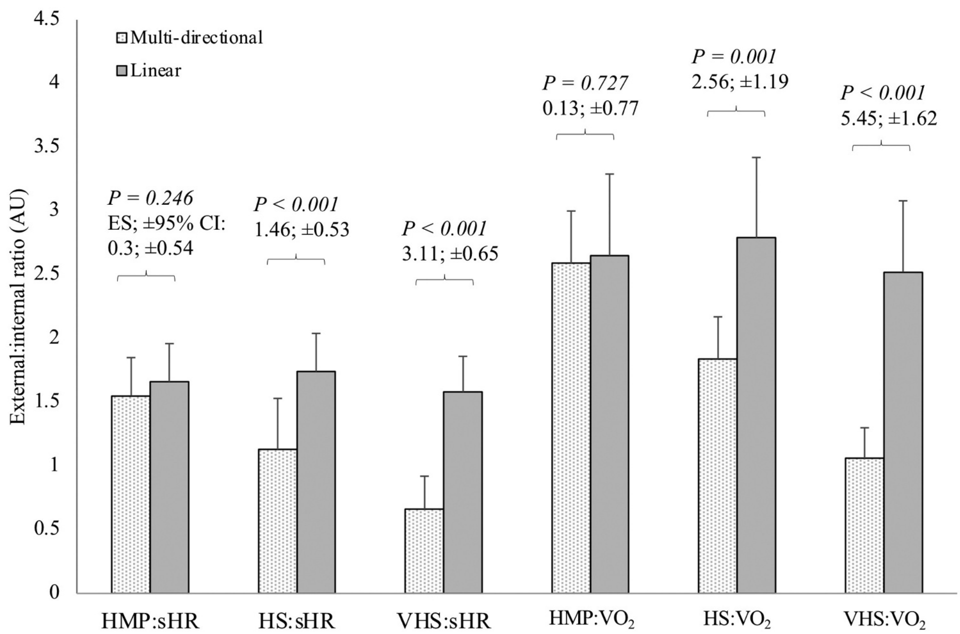

Figure 1. The external to internal ratio (external:internal) during the linear and multidirectional trials. Values are the p value, and the effect size; ±95% confidence intervals for differences in the external to internal ratio between trials. HMP: high metabolic power, HS: high speed, VHS: very high speed, sHR: summated heart rate, VO_2: oxygen consumption.

participants. The number of satellites detected by the player tracking device and the horizontal dilution of precision was 13.7 ± 0.8 and 0.7 ± 0.1, respectively.

Physiological responses

HR was measured at 5 s epochs throughout each trial using a HR monitor (Polar Electro, Oy, Finland) and recorded by the player tracking device using short-range telemetry to calculate mean and peak HR. Summated HR was also calculated based on the method devised by Edwards (1993).

During each trial, expired air was measured using a portable, breath-by-breath gas analyzer (Cosmed K4b2, Cosmed S.r.I, Rome, Italy) to calculate $\dot{V}O_2$. Before testing, the gas analyzer was calibrated in accordance with manufacturer guidelines. Mean $\dot{V}O_2$ (ml.kg^{-1}.min^{-1}) and total $\dot{V}O_2$ (L) over the duration of each trial was determined. Blood lactate concentration (B[La]) was measured from a fingertip sample (Lactate Pro, Arkray, Japan) immediately after bouts 4 and 8 of each trial.

External to internal ratio

External measures were divided by each measurement of internal response to calculate the external-to-internal ratio (external: internal) during each trial (Akubat et al., 2014). The external demand was quantified using time at high speed, very high speed and high power (s) and the internal response was quantified using summated HR (AU) and total $\dot{V}O_2$ (L). This integrated ratio was used to determine the extent to which measures of high speed and high power reflect changes in internal response. For example, a higher summated HR with multi-directional compared to linear running might also be accompanied by a greater time at high speed, and therefore the ratio between these two measurements should not be different between each running trial.

Peak isometric torque of knee extensors and flexors

After a 5-min warm up cycling at 90 W (model E834, Monark, Varup, Sweden), maximal isometric knee extensor and flexor torque at an angle of 80° knee flexion (0° indicating full knee extension) was measured (Biodex Medical, System 3, New York, USA). The dominant leg was fixed into the input arm of the dynamometer, and after two submaximal repetitions, participants performed three maximum efforts of knee extension and flexion for 4 s with 15 s passive recovery between each. Peak torque for each movement was taken for analysis. Participants were verbally encouraged to achieve maximum efforts and exceed target values achieved during habituation.

Statistical analysis

Descriptive data are reported as mean ± standard deviation. Comparisons of the internal, external demands and integrated ratios between multidirectional and linear trials were analyzed using paired sample *t*-tests and effect sizes with accompanying 95% confidence intervals (ES; ±95% CI). Changes in peak torque measurements (pre vs. post) across trials (multidirectional vs. linear) was directly compared using a two-way analysis of variance (ANOVA). No *post hoc* analysis was necessary as no interactions were observed. The effect size was calculated as the difference in means divided by the pooled standard deviation (Cohen's d). An effect size of 0.2, 0.6 and 1.2 were considered small, moderate and large, respectively. Significance was set at $p < .05$. Statistical analyses were performed using the Statistical Package for Social Sciences (SPSS, version 22; SPSS, Inc., IL, USA) and Microsoft Excel.

Results

The external demands and internal responses to linear and multidirectional running are presented in Table 1. Total distance, relative distance, distance covered at high speed and mean speed was higher during the linear compared to the multidirectional trial (Table 1; $p \leq .001$, large effect). Conversely, total accelerations and decelerations performed were lower during the linear compared to the multidirectional trial ($p < .001$, large effect). Time at high power ($p = .046$, small effect) and exercise duration ($p = .002$, moderate effect) were lower during the linear compared to the multidirectional trial. PlayerLoad^{TM} remained unchanged between trials.

Summated HR and bout 8 B[La] were lower during the linear compared with the multidirectional trial (Table 1; $p \leq .003$, moderate effect). Total $\dot{V}O_2$ ($p = .087$, small effect) and mean HR ($p = .099$, small effect) demonstrated a non-significant change between the linear and multidirectional trials. Bout 4 B[La], mean $\dot{V}O_2$ and peak HR were similar.

The external-to-internal ratio between linear and multidirectional trials are presented in Figure 1. Measures of very high speed: summated HR, high speed: summated HR, very high speed: total $\dot{V}O_2$ and high speed: total $\dot{V}O_2$ were different between the multidirectional and linear trials (Figure 1; $p \leq .001$, large effect). Conversely, measures of high power: summated HR and high power: total $\dot{V}O_2$ were similar.

Baseline values for peak isometric knee extensor ($p = .495$) and flexor torque ($p = .419$) were similar before both the multidirectional and linear trials. Thereafter, reductions in peak isometric knee extensor torque occurred after both trials ($p = .004$, small effect), albeit reductions were similar for linear and multidirectional running ($p = .26$; Figure 2). There were also differences in pre- and post-peak isometric knee flexor torque ($p = .003$, small effect), which also were similar between trials ($p = .811$; Figure 2).

Table 1. The external and internal demands of the multidirectional and linear trials.

	Multidirectional	Linear	ES; ±95% CI	P value
External				
Total distance (m)	1513.4 ± 59.6	1592.2 ± 90.4	1.2; ±0.8	0.001
Duration (s)	1428.3 ± 40.3	1381.7 ± 45.6	−1.0; ±0.7	0.002
Relative distance (m. min^{-1})	68.2 ± 3.0	74.7 ± 5.0	1.9; ±1.0	< 0.001
High speed distance (m)	416.5 ± 97.4	677.2 ± 57.5	2.4; ±1.2	< 0.001
Time at high speed (s)	85.5 ± 18.7	117.4 ± 5.9	1.5; ±0.9	< 0.001
Time at very high speed (s)	49.8 ± 15.0	106.6 ± 7.7	3.4; ±1.6	< 0.001
Total accelerations (n)	48.3 ± 21.5	7.2 ± 3.8	−1.7; ±0.9	< 0.001
Total decelerations (n)	38.8 ± 19.5	3.8 ± 6.3	−1.5; ±0.8	< 0.001
Mean speed (km.h^{-1})	9.7 ± 0.5	11.3 ± 0.9	2.9; ±1.5	< 0.001
PlayerLoad^{TM} (AU)	175.8 ± 17.4	173.8 ± 18.4	−0.1; ±0.6	0.7
Time at high power (s)	118.4 ± 11.7	111.5 ± 10.2	−0.5; ±0.6	0.046
Internal				
Bout 4 B[La] (mmol.L^{-1})	8.7 ± 1.9	7.8 ± 2.9	−0.4; ±0.9	0.314
Bout 8 B[La] (mmol.L^{-1})	10.2 ± 2.0	8.2 ± 2.6	−0.9; ±0.6	0.002
Mean $\dot{V}O_2$ (ml.kg^{-1}. min^{-1})	27.0 ± 2.6	26.0 ± 1.9	−0.4; ±0.6	0.237
Total $\dot{V}O_2$ (L)	46.9 ± 9.0	44.2 ± 10.1	−0.3; ±0.3	0.087
Summated HR (AU)	78.1 ± 10.5	69.1 ± 10.1	−0.8; ±0.5	0.003
Mean HR (b.min^{-1})	161.6 ± 10.8	158.3 ± 12.6	−0.3; ±0.3	0.099
Peak HR (b.min^{-1})	199.9 ± 14.5	201.8 ± 14.7	0.1; ±0.7	0.727

$\dot{V}O_2$: oxygen consumption, B[La]: blood lactate concentration, HR: heart rate.

Discussion

The movement characteristics, physiological and muscle function responses to linear and multidirectional running were examined in team sport athletes. Whilst both trials were matched for total distance, the GPS device reported that participants covered more distance during the linear compared with the multidirectional trial. This likely reflects the underestimation of distance measurements during rapid directional changes by ~3 ± 2.5% when using GPS (Rawstorn et al., 2014). Distance covered at high speed was also higher during the linear trial, which was expected given in team sport athletes peak acceleration does not occur until ~10 m (Brechue et al., 2010). Specifically, participants performed multiple directional changes over short distances (i.e. 10 m) during the multidirectional trial, meaning they were unable to achieve speeds comparable with the linear trial. More accelerations and decelerations were also performed during the multidirectional trial confirming directional changes as the primary cause of the observed higher internal response. We also observed a greater time at high metabolic power during the multidirectional trial, reaffirming a higher metabolic power (Di Prampero et al., 2005) and greater estimated energy cost (Stevens et al., 2015) at lower running speeds when performing more directional changes. Collectively, these data suggest speed-based thresholds do not account for discrete, short-duration acceleration movements. The measurement of metabolic power above 20 W.kg^{-1} might provide a more suitable measure of the high-intensity demands of multidirectional team sport activity when compared with high-speed running.

Similar PlayerLoad^{TM} in both trials is likely explained by more high-speed distance covered during the linear trial compared to more accelerations and decelerations performed during the multidirectional trial. We interpret this given accelerations and decelerations (12–16%; Dalen et al., 2016) and total distance covered (56%; Casamichana & Castellano, 2015) share considerably variability in PlayerLoad^{TM}. Although, similar triaxial accelerometer-based variables have been shown to differentiate between maximal and submaximal accelerations (Beato & Drust, 2021), we suggest PlayerLoad^{TM} might be unable to differentiate between different movement patterns performed by team sport players, which is consistent with previous findings (Green et al., 2022).

The small but non-significant difference in total $\dot{V}O_2$ between trials reaffirms previous findings (Buchheit et al., 2010). Accelerative running (Akenhead et al., 2015) and backwards movement (Williford et al., 1998) have previously been reported to increase $\dot{V}O_2$ when compared with forward running at the same speed. However, a non-significant change in $\dot{V}O_2$ in the present study means it is unclear if the oxygen cost of running is altered when more changes of direction are performed. A small to moderate effect for summated HR and B[La] was also observed between trials. This indicates an increased cardio-vascular strain (Akenhead et al., 2015) and

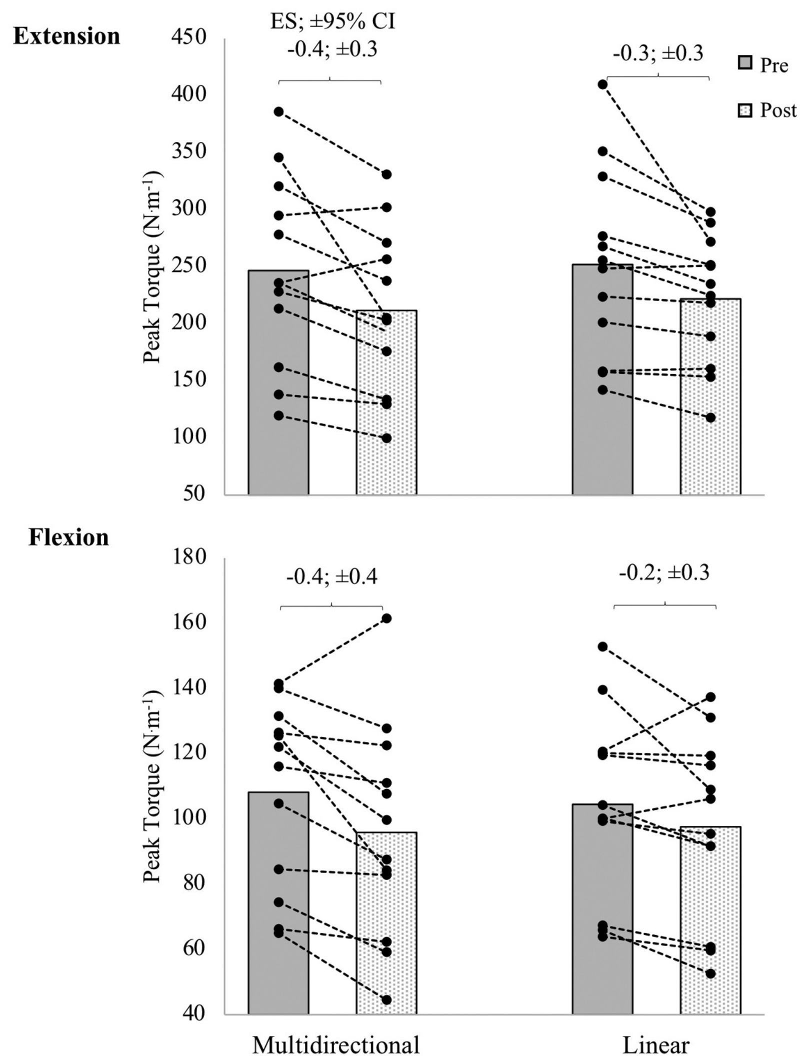

Figure 2. Mean and individual peak knee torque for flexion and extension before (pre) and after (post) after the multidirectional and linear trials. Values are the effect size; ±95% confidence interval.

a greater reliance on anaerobic metabolism (Akenhead et al., 2015; Ashton & Twist, 2015; Buchheit et al., 2010) when more directional changes are performed. Whilst the specific mechanism for this change is unclear, changing direction requires an increased recruitment of larger motor units, composed of type II muscle fibers with a high glycolytic capacity (Di Prampero et al., 2005). Higher HR responses have also been associated with increased acceleration intensity and might be necessary to repay the initial oxygen debt due to anaerobic glycolysis (Beato & Drust, 2021). Overall, these data indicate running with more directional changes causes small to moderate increases in the metabolic demands of exercise.

The external-to-internal ratio using time at high speed and very high speed demonstrated large differences between trials. Conversely, external-to-internal ratio using time at high metabolic power was similar. This suggests increases in summated HR and total $\dot{V}O_2$ (the "response") caused by altering running patterns (the "dose") reflect similar changes in time at high metabolic power but not time at high speed and very high speed. Our findings support studies reporting strong associations between measures of high metabolic power and internal response (r = 0.77–0.92; Delaney et al., 2018) and determinants of aerobic fitness (r = 0.54–0.67; Akubat et al., 2018). Taken together, integrated ratios using measures of time at high metabolic power provide a sensitive interpretation of an individual's response during linear and multidirectional movements.

The small decrements in peak knee extensor torque were observed after both trials. This likely reflects the increased activation of the quadriceps during running at higher speeds (Tsuji et al., 2015) in the linear trial and running with an increased number of directional changes (Besier et al., 2003) in the multidirectional trial. Despite different mechanisms, both would likely accelerate the accumulation of fatiguing metabolites (Mohr et al., 2004) and/or inhibit motor neurons, leading to a reduction in muscle function (Hader et al., 2014). Whilst peak knee flexor torque was lower after the multidirectional trial (~11.4%) compared with the linear trial (~6.6%), changes in peak flexor torque between trials were similar. Previous studies have reported more directional changes during intermittent running incur greater reductions in peak knee flexor torque, which appear to be more pronounced when exercise volume is higher (Ashton & Twist, 2015). Accordingly, multidirectional running could have implications for injury risk when combined into a more extended activity. However, as no difference in peak knee flexor torque was observed between trials, further research is required to assess muscular responses to running with more directional changes.

This study is not without limitations. Although the running courses used for both trials were matched for distance, we were unable to control for differences in running style and technique both within and between participants. Whilst we can confirm favorable reliability of the player tracking device for measuring distance, low- and high-speed distance and high metabolic power (<10%) during the multidirectional trial, repeatability of acceleration/deceleration metrics are known to be more variable. The internal responses of team sport training can differ between males and females (Clemente & Nikolaidis, 2016); thus, the combined use of male and female participants is a potential limitation. However, the use of integrated ratios accounts for individual variations in fitness and therefore internal responses to exercise. The underrepresentation of females in sport science research (Costello et al., 2014) also warrants their inclusion. Finally, whilst a small sample size has been utilized in this study, this exceeded an *a priori* sample size calculation. The effect size and 95% CI have been included to indicate the magnitude of the differences and the precision of estimate between linear and multidirectional running.

Practical implications

Practitioners should be wary of using high-speed metrics alone when monitoring team sport athlete training. Here, we propose the use of time at high metabolic power as a useful metric for practitioners managing team sport players' training, which can reflect an individual's internal response to multidirectional running. The use of integrated ratios using time at high metabolic power might offer a useful metric, particularly when transitioning between linear and multidirectional movement (e.g., rehabilitation and returning to play after injury).

Conclusion

Running incorporating multiple directional changes induces a greater physiological response when compared to linear running, despite the reduced mean speed. Time at high metabolic power reflected changes in internal response between trials, whilst measures of high speed and very high speed did not. Accordingly, time at high metabolic power is more suitable than high speed for monitoring an individual's response during multidirectional running. Decrements in peak knee extensor and flexor torque were similar after both trials, despite less high-speed running during the multidirectional trial.

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Data availability statement

The authors confirm that the raw data supporting the findings of this study are available within its supplementary materials.

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