Title: Planned vs unplanned shuttle sprint running: PlayerLoad™ differences and the response to fatigue in soccer players

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Abstract

The aim of this study was 1) to investigate the differences in PlayerLoad^{TM} (PL) between planned (PL_{SSR}) and unplanned (UP_{SSR}) maximal shuttle run and 2) to examine the differences in PL during UP_{SSR} pre- and post- an acute bout of fatigue (AFT). Seventeen soccer players (age 27.6 ± 0.3 years, height 175.5 ± 2.8 cm, mass 75.3 ± 3.3 kg) participated in the study. During study 1, 12 repetitions of PL_{SSR} and UP_{SSR} were performed one week apart under 3 different time conditions (1, 1.5 and 2s). During study 2, UP_{SSR} was performed pre- and post-AFT. The AFT consisted of 25m (2x12.5m) shuttle sprints interspersed with 20s rest. The test was ceased when a 5% decrement in sprint performance was reached. PL was examined from 100Hz integrated tri-axial accelerometers. Repeated measures ANOVA was used to compare temporal differences across the AFT and the magnitude of the effects was calculated. A paired-sample T-test was conducted to examine differences between pre- and post-fatigue. Results showed higher PL at 1s condition for unplanned task (d = 0.9 – 1.25). No differences in PL were observed between pre- and post- AFT ($p > 0.05$, d = 0.04 – 0.34). In conclusion 1s shuttle task is more taxing during UP_{SSR} and PL was not affected by fatigue.

Keywords: Change of direction, agility, acceleration, deceleration, sprint decrement.

Introduction

Change of direction (COD) is synonymous with planned activities (e.g. running around cones) while unplanned tasks are synonymous with reactive agility (Paul, Gabbett, & Nassis, 2015). Whether in response to a stimulus or not, COD seems to have a particular practical implication given 72% of the decelerations performed by soccer players during the game occur in less than 1s (Bloomfield, Polman, & O'Donoghue, 2007). Anecdotally it seems planned COD activities play a bigger part in training which might be different to actual match play which requires COD tasks being performed in response to an external stimuli (Sheppard & Young, 2006a). Several studies have shown planned and unplanned cutting maneuvers are distinct movements (Farrow et al., 2005; Sheppard et al., 2006b; Serpell et al., 2010; Henry et al, 2013; & Scanlan et al., 2014). The focus of such research has tended to be pertinent to differences between kinetic, kinematic and muscle activity. For example, during unplanned COD tasks greater varus/valgus and internal/external rotation moments in the knee joint as well as greater net muscle activation (20%) were observed to occur compared to directional changes under planned condition (Besier, Lloyd & Ackland, 2003). This is believed to place higher external load on the anterior cruciate ligament as well as the collateral ligaments and hence, increase injury risk (Besier et al., 2001; & Besier et al., 2003). Furthermore, the deceleration has been considered the most taxing phase during a COD task (Nedergaard, Kersting, & Lake, 2014). This is due to the higher eccentric muscle action required in the movement, inducing higher muscle damage and possible lower limb injury risk (Howatson & Milak, 2009). Whether similar differences in mechanical load exist between planned and unplanned COD tasks is unknown.

The inclusion of a cognitive stimulus can negatively impact the execution of movement or alter movement (Besier et al., 2003). Such impact seems to be increased with the presence of fatigue

(Borotikar, Newcomer, Koppes, & McLean, 2008). Fatigue is a phenomena that can impair performance and increase the likelihood of injury (Borotikar et al., 2008), hence much attention is given to this area. The etiology of fatigue is indeed a complex entity with the dominant mechanism likely dependent upon the details of the task being performed (Barry & Enoka, 2007). For sports like soccer which require intermittent sprints in nature, fatigue is likely to be driven from neural (e.g. decrease motor unit activation) and muscular (e.g. muscle excitability, limitation in energy supply and metabolite accumulation) factors (Bishop, 2012).

It is a common objective to examine the effects of fatigue following extended periods of activity (e.g. 45, 90 min). However, there is evidence that a short term fatigue inducing agility task (6min) is sufficient to elicit biomechanical changes such as decreased knee and hip flexion and increased knee internal rotation (Cortes, Quammen, Lucci, Greska, & Onate, 2012). Worryingly, peak knee abduction and peak internal rotation angles have shown to remain significantly elevated and fail to return to pre-fatigue levels before 20 min, and even 40 min during side stepping cutting maneuver (Tsai, Sigward, Pollard, Fletcher, & Powers, 2009). This is likely to have implications in execution of movement. Finally, whereas research has shown the physiological and perceptual response to vary dependent upon turn angle, it is unknown whether similar differences exist between planned and unplanned COD tasks (Buchheit, Hader, & Mendez-Villanueva, 2012). This is likely to have implications for training design and prescription, whereby the focus tends to be on closed skill and planned COD tasks.

High-resolution tri-axial accelerometers incorporated within micromechanical electrical systems (MEMS) devices, integrated into global positioning system (GPS) units are becoming a useful tool to monitor external load. A vector magnitude algorithm termed PlayerLoad™ (PL) derived from this device has emerged in the research literature (Boyd et al., 2011; Boyd et al., 2013; Wundersitz et al., 2013; Barret et al., 2014; Wundersitz et al., 2015; & Buchheit et al., 2015). The PL provides the rate of change in acceleration on the body in 3 different planes including vertical (PL_V), medio-lateral (PL_{ML}) and anterior-posterior (PL_{AP}). It has been used to quantify taxing activities e.g. jump, COD in team sports (Boyed et al., 2013; & Barret et al., 2014). More specifically, it has been used to quantify deceleration (Nedergaard et al., 2014), to measure locomotor efficiency owing to fatigue (Barret et al., 2015a; & Barret et al., 2015b) and recently has been demonstrated its usefulness for monitoring neuromuscular fatigue (Cormarck et al., 2013; & Buchheit et al., 2015). This piece of equipment has been demonstrated an acceptable signal: noise ratio (Boyd et al., 2011) test-retest (Barret et al., 2014), within- and between-device reliability (Boyd et al, 2011).

Accelerometer devices are often placed on the scapula (SCAP) in sports while center of mass (COM), which is located at the lower back may be better. Despite both location have been considered appropriate and reliable to quantify external load, differences between locations have been reported (Barret, Midgley, & Lovell, 2014). For example, PL derived from the COM were significant higher compared to SCAP during running activity i.e. particularly when the velocity was increased and during a simulated soccer game test whereas high-intensity accelerations and decelerations were performed (Barret et al., 2014; & Barret et al., 2015b). This is likely to have implications for training monitoring and subsequent prescription of stress-recovery balance. Whether similar results could be identified for devices positioned between the SCAP and at the lower extremities of the lower limbs (e.g. ankles) is not yet fully elucidated.

Knowledge about the acute responses to the mechanical loading of planned vs unplanned shuttle running and its response to fatigue is likely to have meaningful implications for specific team sport training prescription. Also, being able to quantify this using technologies that are used on a daily basis in many sports (soccer), such as accelerometers would be useful. Therefore, the aim of the present study was 1) to investigate the PL between planned (PL_{SSR}) and unplanned (UP_{SSR}) shuttle sprint running and 2) to examine the effect of an acute bout of fatigue (AFT) on UP_{SSR}. Differences in PL between accelerometer devices positioned on the upper back (PL_{SCAP}) and on the right (PL_{R}) and left (PL_{L}) ankles were observed. It is hypothesized that 1) the UP_{SSR} will induce a greater PL compared to PL_{SSR}; 2) PL will be modified during UP_{SSR} from before to after AFT and accelerometers positioned distally (PL_{R} and PL_{L}) will produce higher PL compared with accelerometer placed proximally (PL_{SCAP}).

Methods

Participants

Seventeen male semi-professional soccer players (mean ± SD age 27.6 ± 0.3 years, height 175.5 ± 2.8 cm, mass 75.3 ± 3.3 kg) volunteered to participate in this study. Participants had no soft tissue injury over the past 8 weeks that preceded the study and none of them had any previous history of knee or ankle injuries. The study took place at Aspetar - Orthopaedic and Sports Medicine Hospital, Doha, Qatar and was approved by the local Ethics Committee (Anti-Doping Lab Qatar Institutional Review Board). Participants received a clear explanation, including the risks and benefits, and signed a written physical activity readiness questionnaire (PARQ) and consent forms before participation in the study.

Experimental design

The study was performed in two separate experiments, study 1 (*n* = 7) and study 2 (*n* = 10). During study 1, PL was quantified between PL_{SSR} and UP_{SSR} tests. Participants involved in study 1 were required to visit the testing facility on two separate occasions and at the same time of the day to avoid the effect of diurnal variation. During the first visit, participants were instructed to perform the UP_{SSR} test, while one week later, the PL_{SSR} was performed. During study 2, PL was quantified during UP_{SSR} between pre- and post- AFT test. Participants involved in study 2 were requested to visit the testing facility just once.

During both studies, participants were oriented to carry out a 180° turn using their dominant leg (i.e. defined as the participants' kicking leg) as the turning foot. This testing design was chosen due to its severe neuromuscular and physiological overload (Buchheit, Bishop, Haydar, Nakamura, & Ahmaidi, 2010) as well as its complexity for controlling deceleration prior to turn.

The studies were conducted in an indoor sports facility under a controlled environment (22-24°C) and tests were performed over a wooden surface. Prior to all tests, a standardized warm up including general and sport specific exercises were performed followed by several practices of the movement task to familiarize the participants.

Study 1: Testing Protocol

The unplanned shuttle sprint running (UP_{SSR})

In a randomized order participants completed 12 maximal running efforts with 2mins passive rest between each effort. Each effort was started with an audio countdown and participants were instructed to begin on the final beep. Participants were oriented to aim to record their fastest 20m sprint time on each occasion, but if they heard a further beep during the sprint they had to execute a 180 degree COD as quickly as possible and sprint back to the start line. The 12 efforts were evenly distributed between 4 experimental conditions which differed by the amount of time between the start beep and the signal to change direction: 1 second ($C_{1.0}$), 1.5 seconds ($C_{1.5}$), 2 seconds ($C_{2.0}$) and no beep (CON).

High speed video camera and a photoelectric timing system were used to determine the distance covered in each unplanned task. The time to complete each task was measured using photoelectric cells placed at the start line ($C_{1.0}$, $C_{1.5}$ & $C_{2.0}$) and the finish line (CON).

The planned shuttle sprint running (PL_{SSR})

The PL_{SSR} testing protocol followed similar set up with the previous testing condition with the main difference that for this time participants did not respond to any external stimuli. Participants completed 12 maximal running efforts randomly allocated with 2mins passive rest between each effort. Each effort was started with an audio countdown and participants were instructed to begin on the final beep. Participants were also oriented to aim to record their fastest 20m sprint time on each occasion and during the sprint they had to execute a 180 degree COD at the designed cone as quickly as possible and sprint back to the start line. The distance travelled for each effort was matched with the distance travelled measured of each effort performed during the previous protocol (UP_{SSR}).

Study 2: Acute bout of fatigue test (AFT)

Participants performed maximal 12.5m shuttle sprints with 1 x 180° turn COD (total 25m per sprint) interspersed with 20s of passive recovery. They were encouraged to perform the fastest sprint possible for each trial. Participants continued the repeated shuttle sprint until a performance decrement of 5.0% was reached according to the equation recommended by Glaister, Howatson, Pattison and McInnes (2008). The end point was set when participants achieved two consecutive runs that met this 5.0% threshold. They were blinded to the number of sprints to be performed and the criteria termination in order to prevent pacing. It has been postulated that intersubject variability is reduced when the dose of the repeated sprint protocols is individualized (Morin, Dupuy, & Samozino, 2011). Moreover, despite the fact that a "gold standard" criteria have not been established yet to quantify fatigue during repeated sprints performance, percentage decrement calculation has been advocate as the most valid and reliable method (Glaister et al., 2008). The decrement score has been calculated from sprint times using the following equation: Fatigue = (100 x (total sprint time / ideal sprint time)) -100, where total sprint time = the sum of sprint times from all sprints while the ideal sprint time = is the number of sprints x fastest sprint time. This equation has also been used to calculate the decrement in PL during the AFT test. In order to evaluate the effect of fatigue on PL, participants were instructed to perform 6 repetitions of UP_{SSR} under the same previous conditions ($C_{1.0}$, $C_{1.5}$ and $C_{2.0}$ randomly allocated) prior and 2 mins after the AFT test. A 2mins of passive recovery between each UP_{SSR} was given to participants.

Measurements

PlayerLoad^{TM} (PL)

The PL was assessed with 100Hz integrated tri-axial accelerometer (Catapult S5, Catapult innovations, Canberra). The PL was calculated by the square root of the sum of the squared instantaneous rate of changes in acceleration in each of the three vectors: PL_V, PL_{ML} and PL_{AP} divided by 100 (Boyd et al., 2011). Expressed in arbitrary units, PL data were analysed using Catapult software. The devices were calibrated in accordance with the manufacture guidelines prior to the tests. Participants were fitted with 3 units of the device positioned at 3 different sites of the body in order to examine possible differences in loading patterns. The first unit was positioned on the posterior side of the upper torso between the scapulae fixed in a small pocket of a tight elasticized vest. The second and third units were placed inside custom made pocket holders positioned on each leg just above the right and Left ankle. The devices were fitted as tight as possible in order to avoid additional movements relative to the trunk and legs.

Speed

For all tests, sprint times were measured with photocells (Race Time 2, Microgate S.r.I., Via Stradivari, 4, 39100 Bolzano – Italy) with the time taken to complete the test as the performance measure. The timing gates were placed along 20m at 0m and 20m point.

Running pattern

For all tests, total distance covered was measured with Optojump Modular System (Microgate, Via Stradivari, 4, 39100 Bolzano – Italy) that were placed on the surface over 20m length and 1.5m width apart. The point of COD was identified with the longest contact time and confirmed using video analysis and calculation of number of steps.

Physiological and perceptual responses

Mean and maximal heart rate (Polar Team system, Polar Electro, Kempele, Finland) was recorded and rate of perceived exertion (Borg CR-10) (Impellizzeri, Rampinini, & Coutts, 2004) was taken from the participant's pre baseline measures and post for all testing conditions. In addition, recovery status was monitored by using perceived recovery scale (PRS) (Laurent, Green, Bishop, Sjokvist, Schumacker, Richardson, & Curtner-Smith, 2011). The PRS is a 0-10 scale with 0-2 being very poorly recovered and anticipated declines in performance, 4-6 being low to moderate recovered (with expected similar performance), and 8-10 representing high-perceived recovery (expected increases in performance).

Statistical Analyses

Data were presented in the form of mean ± standard deviation and statistical significance was set at $p < 0.05$ for all analyses. All data analysis were conducted using statistical software SPSS (IBM Corporation, version 22). For each dependent variable, repeated measures ANOVA was used to compare the mean differences in time points. A paired two sample for means T-test was used to compare the mean differences of PL and sprint decrement between pre and post fatigue test. The magnitude of effects (ES) were qualitatively calculated according to Cohen (1992) as follows: d = 0.2 – 0.5, small; 0.5 – 0.8, medium and > 0.8, large.

Results

Study 1: Differences in PL between planned and unplanned shuttle sprint running

Differences in PL between PL_{SSR} and UP_{SSR} were not significant, F (2, 11) =1.058, p = 0.38 for any testing condition i.e. $C_{1.0}$, $C_{1.5}$ and $C_{2.0}$. However, large ES (d = 0.9 – 1.25) indicated an increase in PL at $C_{1.0}$ during unplanned shuttle condition while small ES were found for $C_{1.5}$ (d = 0.24 – 0.43) and $C_{2.0}$ (d = 0.21 – 0.26). The PL profile for $C_{1.0}$, $C_{1.5}$ and $C_{2.0}$ between planned and unplanned shuttle run can be observed in Figure 1. The higher PL observed at $C_{1.0}$ during unplanned shuttle condition followed similar pattern between accelerometer units (Figure 2). An increase of 17.35%, 18.04% and 25.03% was found for accelerometers positioned at the PL_{SCAP}, PL_R and PL_L respectively.

No significant differences were found for time F (2, 11) = 0.672, p = 0.531, d = 0.0 – 0.11 to complete the tasks whether PL_{SSR} or UP_{SSR} were performed.

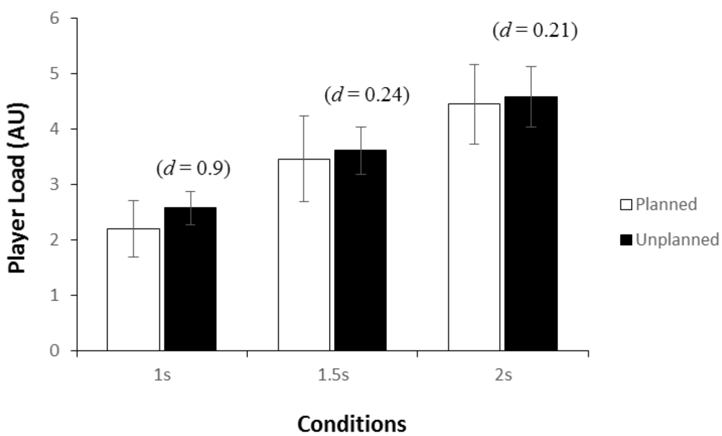

FIGURE 1. PL COMPARISON BETWEEN PL_{SSR} AND UP_{SSR}. HIGHER PL WAS OBSERVED AT C1 DURING UP_{SSR}.

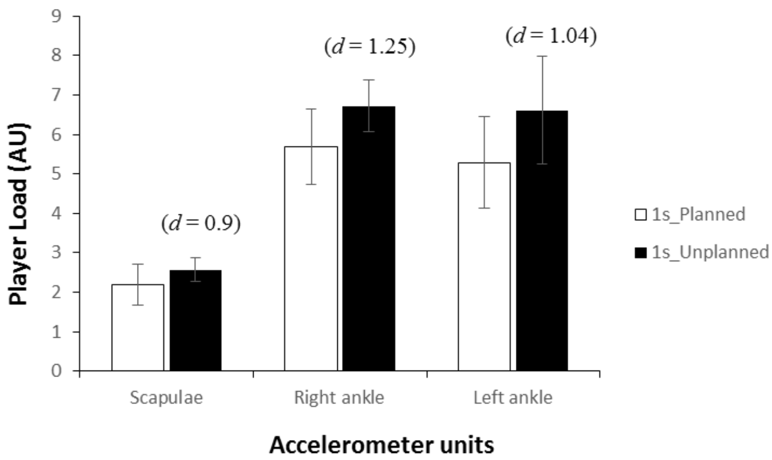

FIGURE 2. PL COMPARISON BETWEEN ACCELEROMETER UNITS AT C1 TESTING CONDITION.

NOTE: *D* = ES

Study 2: Differences in Player Load during unplanned shuttle sprint running between Pre- and Post- an acute bout of fatigue

Differences in PL between pre- and post-AFT were not significant F (17, 2) = 0.905, p = 0.42 for any testing condition $C_{1.0}$ (d = 0.34), $C_{1.5}$ (d = 0.05) and $C_{2.0}$ (d = 0.04). These results were similar for all accelerometers units. The PL profile for $C_{1.0}$, $C_{1.5}$ and $C_{2.0}$ between pre- and post-AFT test can be observed in Figure 3.

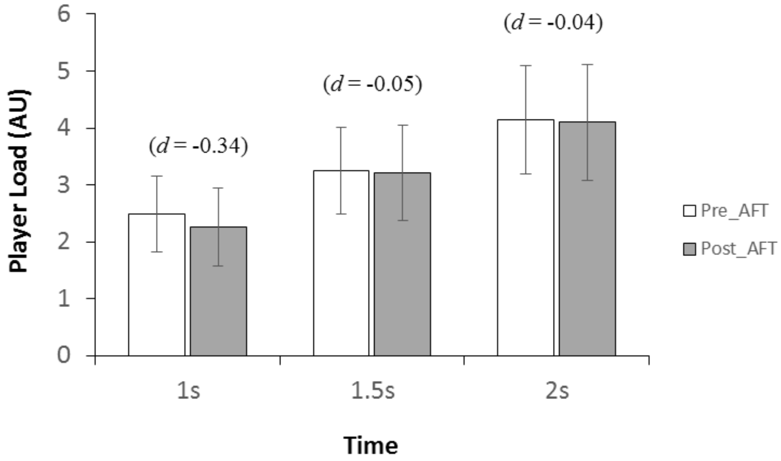

FIGURE 3. PL COMPARISON BETWEEN PRE- AND POST-AFT TEST. **NOTE:** *D* = ES

Participants completed 12.7 ± 4.83 shuttle sprint running during the AFT test. The mean decrement in sprint performance was 5.5% (range 4.08 to 7.08%). Sprinting time increased by 8.81% (range 5.31 to 13.09%) from the first to the last sprint t (9) = -8.95, p < 0.001, *d* = -2.78. The decrement in sprint performance can be observed in Figure 4.

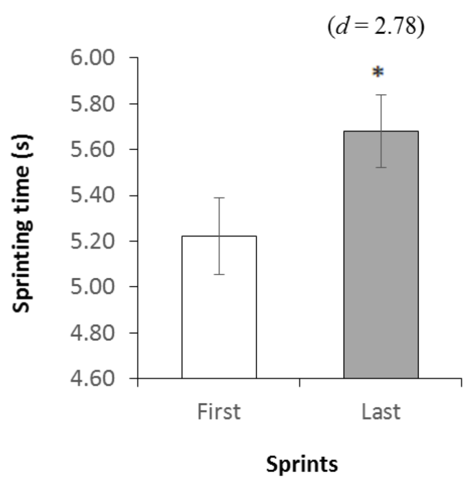

FIGURE 4. SPRINTING PERFORMANCE DECREMENT PRIOR AND AFTERWARDS THE AFT TEST.
NOTE: * SIGNIFICANT DIFFERENT ($P < 0.05$); *D* = ES.

Mean PL decrement was 12.58% (range 9.12 to 19.68%) during AFT test. As illustrated by Figure 5, mean decrease in PL was 20.65% (range 15.38 to 31.71%) from the first to the last sprint t (9) = 7.34, $p < 0.001$, $d = 1.61$. Similar results were found for all accelerometer units.

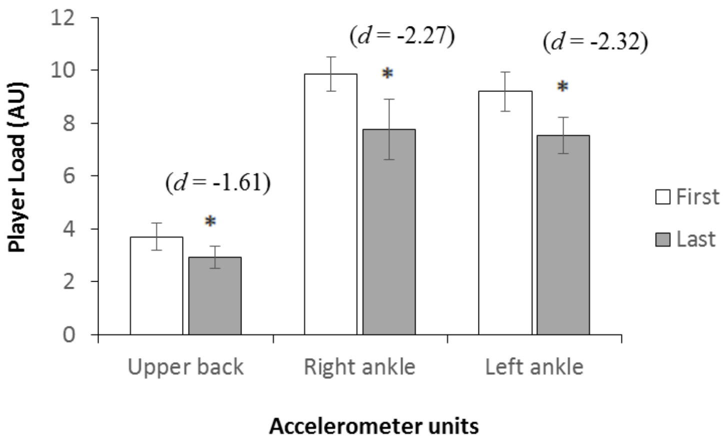

FIGURE 5. DECREMENT IN PL AMONGST ACCELEROMETER UNITS BETWEEN PRE- AND POST-AFT TEST.
NOTE: * SIGNIFICANT DIFFERENT ($P < 0.05$); D = ES.

Mean PRS immediately before the protocol began was 8.1 and decreased to 3.3 following the final sprint t (9) = 5.23, $p < 0.001$, $d = -2.06$. Mean RPE increased from 2.5 to 7.6 at the same time points t (9) = -6.19, $p < 0.001$, $d = 2.53$. The inverse relationship between PRS and RPE can be observed in Figure 6.

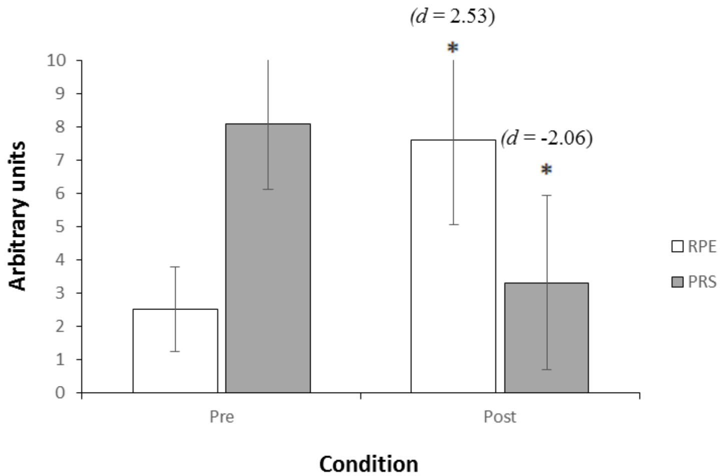

FIGURE 6. THE INVERSE RELATIONSHIP BETWEEN RPE AND PRS BETWEEN PRE- AND POST- AFT TEST.
NOTE: * = SIGNIFICANT DIFFERENT ($P < 0.01$); D = ES.

No significant differences were found for time F (2, 17) = 2.104, p = 0.153, *d* = 0.02 – 0.3 to complete the tasks between Pre- or Post-AFT.

Differences in Player Load between accelerometer units (PL_{SCAP} vs PL_R and PL_L)

Significant differences in PL were found between accelerometers placed on upper (PL_{SCAP}) and lower body (PL_R and PL_L) (Table 1). During study 1, the PL was on average 263% (range 250 to 272%) higher on the accelerometers placed on the lower body t (2) = -5.18, p = 0.03, *d* = 2.44 – 2.56. Similar results were found in study 2. Mean PL was 255% (range 233 to 273%) higher for the accelerometers placed on the right and left ankles t (2) = -5.91, p = 0.02, *d* = 2.49 – 2.95 compared with accelerometers placed on the upper back.

TABLE 1. DIFFERENCES IN PL BETWEEN ACCELEROMETER UNITS IN STUDY 1 AND 2.

	Player Load									
	Planned vs Unplanned					Acute fatigue test				
Unit / time	Planned	Unplanned	% Changes	P value	ES	Pre	Post	% Changes	P value	ES
SCAP										
1s	2.19	2.57				2.49	2.26			
1.5s	3.46	3.41				3.25	3.21			
2s	4.45	4.59				4.14	4.10			
Right										
1s	5.69	6.72	261	< 0.05	6.95	6.56	6.10	266	0.02	15.23
1.5s	9.12	9.62	272	< 0.05	23.8	8.61	8.46	264	0.02	65.86
2s	12.06	12.41	271	< 0.05	40.54	11.38	11.14	273	0.02	58.49
Left										
1s	5.29	6.61	250	< 0.05	5.21	5.78	5.31	233	< 0.05	12.22
1.5s	8.55	9.31	260	< 0.05	14.33	7.82	7.70	240	< 0.05	74.98
2s	11.68	12.12	263	< 0.05	32.04	10.81	10.41	258	< 0.05	32.59

Running pattern

No significant changes were found for any running pattern variable (i.e. number of steps and distance covered) amongst any testing conditions ($p > 0.05$). In study 1, the numbers of steps were higher during UP_{SSR} (8.33 ± 0.76, $d = 0.72$) compared with PL_{SSR} (7.73 ± 0.88) at $C_{1.0}$. In study 2, the number of steps (Pre: 15.20 ± 1.21 to Post: 14.35 ± 1.62, $d = -0.6$) and the distance covered (Pre: 16.31 ± 1.6m to Post: 15.52 ± 1.61m, $d = -0.5$) slightly decreased after AFT compared with before at $C_{2.0}$.

Discussion

The main findings of the current study were 1) large ES indicated that PL was higher when shuttle sprint running was performed under unplanned condition at $C_{1.0}$ for all accelerometer units (PL_{SCAP}, PL_R and PL_L) and 2) PL was not significant different between pre- and post- fatigue test. PL derived from the accelerometer units positioned distally i.e. ankles were 3-fold higher compared with the unit positioned proximally i.e. scapulae amongst all testing condition.

In study 1, we did not find any differences in the time to complete the tasks i.e. $C_{1.0}$, $C_{1.5}$ and $C_{2.0}$ during planned and unplanned shuttle sprint running. Previous studies have been reported similar findings (Farrow et al., 2005; Sheppard et al., 2006b; Gabbett, 2008; & Henry et al., 2011). According to Matlak, Tihanyi and Racz (2015), differences in time between planned and unplanned COD tasks occur when players are required to perform more than one directional change, rather than one solely. We found that PL was higher during $C_{1.0}$ when shuttle sprint running was performed under unplanned condition. Also, during this condition, participants showed a slightly increased in the number of steps. This indicates that shuttle sprint running at $C_{1.0}$ was more demanding when performed under unplanned condition compared to its planned counterpart. Anecdotally, we have observed that during this task, participants had insufficient time to adjust their body during acceleration, in particular their trunk position prior to turn. This might have contributed to increase the PL. Previous studies have reported the importance of the body position prior to perform a COD task. For example, Nedegaard et al. (2014) found that peak trunk deceleration was significant higher prior to 135° turn (“V cut”), particularly when speed was increased. According to the authors, an increase in peak trunk deceleration has contributed for a significant increase in PL at the last 2 steps that precede the final pivot step. In fact, foot placement and trunk lean have been considered the mechanisms used by the central nervous system to reoriented the COM into a new direction of movement during a locomotive directional changes (Delaney et al., 2015). Furthermore, a strong relationship between the displacement of the trunk and the time to complete a 180° COD task ($r = 0.61$, $p = 0.04$) amongst soccer players have indeed been reported (Sasaki, Nagano, Kaneko, Sakurai, & Fukubayashi, 2011). Therefore, the importance of body posture during the deceleration phase prior to turn cannot be neglected, particularly during a short period of time i.e. 1s.

We found $C_{1.0}$ unplanned condition more taxing compared with planned but no differences at $C_{1.5}$ and $C_{2.0}$ whether PL_{SSR} or UP_{SSR} tasks were performed. It seems that PL was not modified by these conditions (i.e. planned and unplanned) when the shuttle sprint running tasks were performed above 1s. Anecdotally, we observed that participants assumed a more upright position prior to decelerate during $C_{1.5}$ and $C_{2.0}$. This different body posture may allowed them to adopt different strategy during the deceleration phase and have better whole-body control prior to turn.

Whilst some studies have shown different biomechanical profiles between planned and unplanned tasks, we did not find differences in PL. Given the responsive / reactive nature of COD movements performed in the game, unplanned COD tasks have been considered more related to performance in invasion team sports compared to planned activities e.g. running around cones (Sheppard & Young, 2006a). Based on the findings of the current investigation, shuttle drills performed at $C_{1.0}$ condition showed to be more sensitive compared to $C_{1.5}$ and $C_{2.0}$ to the responsive / reactive nature of the sport since we observed higher PL response. Therefore, it is important to expose soccer players to this type of drill, which might increase sport transference and hence, improve game performance and decrease injury risk. In addition, shuttle drills performed at $C_{1.5}$ and $C_{2.0}$ conditions might be considered to build and/or develop loading tolerance and resilience capacity given PL level was not significant different between them.

While the first part of this study provides an understanding of the differences in PL between a shuttle task under planned and unplanned conditions, this finding is limited to a small population (n = 7) of soccer players. This limitation possibly decrease further statistical analysis. Also, we have examined PL during only one angle (180°) of directional change. Therefore, whether similar results could be found with different COD angles is unknown. More research is required to identify whether similar findings would be observed using different angles and additional number of directional changes.

In study 2, no differences in PL were found between Pre- and Post- AFT during UP_{SSR}. This was not expected given the changes in perceptual responses illustrated by an inverse relationship between RPE and PRS experienced by participants as well as the significant decrement in sprint performance and PL (12.58%) during the AFT test. The recovery period between each shuttle i.e. 2mins given to participants could be considered one of the mediating factors to maintain PL during unplanned shuttle tasks after AFT test similar to baseline levels. The maintenance of muscle power output during recovery period between sprints has been observed to be dependent of a faster rate of phosphocreatine resynthesis (Girard, Mendez-Villanueva, & Bishop, 2011a). Given the resynthesis of phosphocreatine and the recovery of power output follow similar time courses, a 2-min rest between each shuttle possibly allowed participants to initiate the next effort with an increased store of adenosine triphosphate and hence, being able to maintain their sprinting performance (Sahlin & Ren, 1989). Other factors such as the level of anaerobic i.e. ability to utilize the store of muscular glycolysis and aerobic i.e. VO_{2max} and the ability to utilize and transport O_2 capacities of participants might have also contributed to maintain PL levels similar between pre- and post-AFT test (Dawson et al., 1993; Gaitanos et al., 1993; Bishop et al., 2006; Brown et al., 2007; & Rampinini et al., 2009). However, these performance parameters were not quantified in the current study.

Looking at a mechanical point of view, it is possible that the level of fatigue experienced by participant during the current study was not sufficient to cause further changes in the spring mass behaviour, particularly in the vertical stiffness. Vertical stiffness is defined as the ratio of the maximal force to the vertical displacement (Girard, Micallef & Millet, 2010) and has been considered the mediating factor of neuromuscular decrement during fatigue state, particularly during repeated sprints (Girard, Racinais, Kelly, Millet & Brocherie, 2011b). Previous studies have reported such impairment. For example, Padulo et al. (2014) indicated that vertical countermovement jump performance decreased after a repeated bout of shuttle sprint running. Moreover, similar findings were observed in addition to two directional changes (Hader, Mendez-Villanueva, Ahmaidi, Williams, & Buchheit, 2014). In addition, soccer players were observed to reduce vertical stiffness by 15.9% during a repeated bout of sprint (Girard et al., 2011b).

In line with the vertical stiffness theory, the current study observed a slight decrement in the number of steps (d = 0.6) and distance covered (d = 0.5) during $C_{2.0}$ after AFT test. It seems that fatigue has been slightly affected the acceleration and deceleration capacity of the participants despite changes in PL between pre- and post-AFT were not significant. With this in mind, it seems longer shuttle efforts ($C_{2.0}$) that required players to cover longer distances (range 16 to 18m) were more affected by the decrements in PL identified during the AFT test compared with shorter shuttle efforts whereas players covered lower distances (range 5-7m). These findings might be considered when shuttle drills are prescribed in the training under a fatigue state.

Another possible explanation of why PL was not impaired between pre- and post-AFT test was the fatigue threshold (5.0% decrement in sprint performance) established as a target to be achieved. Despite the significant impairment in PL identified during the fatigue test, it seems that a 5.0%

reduction in sprint performance may not be as representative as the fatigue level experienced by soccer players during the real match scenario. For instance, previous investigations have been reported fatigue as a mediating factor to modify PL in soccer players. For example, Cormack et al. (2013) observed a significant reduction of the vertical axis contribution to the total PL during Australian Rules football matches. The vertical component impairment was identified upon 8% decrement in flight time: contraction time ratio from a countermovement jump test. In line with this finding, Barret et al. (2015a) reported a significant reduction in PL: total distance covered ratio towards the end of each half (i.e. 30 – 45 min) during a soccer match-play. Similarly, Barret et al. (2015b) reported a significant impairment of PL towards the end of each half during a game-related soccer test (SAFT [90]). Based on these findings, it can be postulated that acceleration and deceleration performance are impaired during soccer match-play when fatigue state is increased. Indeed, acceleration and deceleration capacity has been observed to be significant modified during soccer match-play. According to Akenhead, Hayes, Thompson and French (2013), a significant decrement in acceleration and deceleration distance covered during a soccer match-play towards the end of the first (13.2%) and second half (16.3%) as well as from the beginning until the end of the game (21%) occur. Moreover, they reported that higher accelerations (> 3 ms^{-2}) were observed to be 10.4% lower than mean values after a 5-min peak period of high acceleration. Taken all these finding together, it seems that PL and acceleration and deceleration capacity are modified with more prolonged period of fatigue during the real match scenario.

This seems to have significant impact in terms of injuries. It has been postulated that knee integrity and stability is highly impaired during fatigue state due to a decrement in lower locomotor efficiency (Borotikar et al., 2008). Previous studies have observed that performing COD tasks under a fatigue state would possibly increase the load at the knee joint and consequently increased the risk of anterior cruciate ligament injury (Borotikar et al., 2008). For example, Hader et al. (2014) reported a significant reduction of the electromyography activity of the hamstring muscles during 90° cutting under fatigue, which possibly compromise the stability of the knee during COD tasks. Also, a 17.9% reduction in peak knee flexion torque have been observed to occur during fatigue-induced repeated shuttle (Ashton & Twist, 2015). Interestingly, Tsai et al. (2009) reported an increased peak knee adductor moments and peak knee internal rotation immediately after an acute functional fatigue test and remained elevated after 20 and 40min of rest. However, the limitation of this study was that subjects were female recreational athletes. Whether such results can be extended to an elite athletes or soccer player is unknown. In addition, a significant increased on hip extension and internal rotation as well as peak knee abduction and internal rotation moments were observed to occur during landing tasks during fatigue state. This finding was more accentuated when athletes were required to respond to an unanticipated landing task (Borokitar et al., 2008).

It is important to highlight that PL can be monitored and quantified during an intensified bout of repeated sprints through an accelerometer device. Moreover, according to our fatigue testing protocol, a 12.5% decrement in PL during a bout of repeated shuttle sprint running did not affect subsequent unplanned shuttle activity. This finding has a potential practical application to prescribe an appropriate dose of sprint running relative to individual fatigue profiles. As consequence, this may allow higher neuromuscular adaptations, increased cognitive and resilience capacity while reduced injury risk.

To our knowledge, this is the first time PL is quantified amongst upper and lower body during high-intensity shuttle sprint running. The current findings revealed that accelerometers placed at the ankles elicited 3-fold higher PL compared with the unit placed on the upper back. This finding has been observed along all testing-conditions performed. It seems placing the accelerometer distally may provide better insight about the mechanical load placed on the body during high-intensity shuttle sprint running efforts. This was expected given that ankle and shank play an important role in shock absorption throughout the kinetic chain (Mercer, Vance, Hreliac, & Hamil, 2002). In fact, shock attenuation increased linear with running speed due to increased leg peak impact acceleration (Mercer et al., 2002).

Our findings are in line with previous studies that have indeed been reported differences in PL between unit locations. For example, Barret et al. (2014) compared the differences in PL between upper (SCAP) and centre of mass (COM) sites during treadmill running testing protocol (i.e. adding 0.1 km/h per second until exhaustion). They reported that PL derived from SCAP was 15.7% lower compared with COM. In line with this study, significant higher PL was observed at the COM than at the SCAP during a game-related test ($SAFT^{90}$) with soccer players (Barret et al., 2015b). In addition, Kim, Jung, Park and Joo (2014) compared the effect of accelerometers placed at 4 different sites (e.g. wrist, waist, upper arm and ankle) in adult healthy population during treadmill walk/running exercise. Placing accelerometers at the ankle at low (R^2 = 0.564) and high (R^2 = 0.559) speed and the waist at moderate speed (R^2 = 0.821) were considered the most appropriate sites to measure PL and energy expenditure.

In summary, based on the finding of the current and previous investigations, different values of PL can be obtained depending the site that accelerometer is positioned on the body. In the current study PL was higher for the accelerometer placed distally (i.e. ankles). Therefore, it seems that PL derived from the upper body may underestimate the total PL placed on the body during high-intensity shuttle efforts. However, whether accelerometer placed on the ankles are appropriate for soccer players in a real life setting is unknown. Given ankle and shank are very exposed during games and trainings in duals situations as well as during kicking, placing these devices distally might be incompatible.

Conclusions

In conclusion, this study has described the PL pattern between planned and unplanned shuttle tasks as well as its response to fatigue. In the study 1, PL and number of strides increased when shorter time shuttles ($C_{1.0}$) were performed during unplanned condition. On the other hand, PL remained similar and stable during longer shuttle tasks (e.g. $C_{1.5}$ and $C_{2.0}$) whether planned or unplanned.

In study 2, a 5.0% decrement in sprint performance elicited a significant reduction of 12.5% in PL. However, such decrement was not sufficient to modify PL in subsequent efforts of unplanned shuttles tasks. The number of steps and the distance covered was observed to be lower in comparison to baseline levels during $C_{2.0}$. This indicates that fatigue slightly modified running pattern when longer shuttle tasks were performed. Finally, this study observed that PL was higher at the ankles compared with upper back for all testing conditions. Based on the findings of the current study, accelerometers can be considered an important tool to monitor PL during shuttle tasks whether planned or unplanned as well as to monitor neuromuscular fatigue.

Practical implications

Adopting shuttle drills such as $C_{1.0}$ during soccer training seems to be useful given 72% of the decelerations performed in the game lasts for the same duration. However, the current data highlights that when this drill is performed under unplanned condition, PL was increased compared with its planned counterpart. This is likely to increase the risk of injury and therefore, it is important to implement such drill within training programme with caution. Shuttle tasks such as $C_{1.5}$ and $C_{2.0}$ whether planned or unplanned could be design for soccer players with the aim to build COD resilience given no differences in PL were found between them.

The current study highlights that 5% decrement in sprint performance did not affect PL. Based on this information, a dose-model of repeated shuttle activity can be adopted during soccer training programmes with the aim to replicate the high-intensity bouts of repeated sprints observed during the game without affect subsequent unplanned shuttle tasks. This allow soccer players to increase fatigue tolerance, improve cognitive and resilience capacities as well as decrease injury risk. However, some considerations need to be taken such as the type of activity and work: rest ratio before adopt this design.

According to the current finding, PL derived from the ankles may provide better insight of the total PL demands during shuttle drills compared with upper back. However, place accelerometers on the lower limbs of soccer players may not be appropriate given the high risk of injury.

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Appendices A. St Mary's Ethics Application Checklist

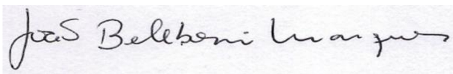
The checklist below will help you to ensure that all the supporting documents are submitted with your ethics application form. The supporting documents are necessary for the Ethics Sub-Committee to be able to review and approve your application.

Please note, if the appropriate documents are not submitted with the application form then the application will be returned directly to the applicant and may need to be re-submitted at a later date.

	Enclosed? (delete as appropriate)		Version No
Document	Yes	Not applicable	
1.Application Form	Mandatory		
2.Risk Assessment Form	Yes		
3.Participant Invitation Letter	Yes		
4.Participant Information Sheet	Mandatory		
5.Participant Consent Form	Mandatory		
6.Parental Consent Form		Not applicable	
7.Participant Recruitment Material - e.g. copies of Posters, newspaper adverts, website, emails	Yes		
8. Letter from host organisation (granting permission to conduct the study on the premises)	Yes		
9. Research instrument, e.g. validated questionnaire, survey, interview schedule	Yes		
10.DBS included		Not applicable	
11.Other Research Ethics Committee application (e.g. NHS REC form)	Yes		

I can confirm that all relevant documents are included in order of the list and in one PDF document entitled with you: ***Full Name, School, and Supervisor.***

Signature of Applicant:



Signature of Supervisor: 

Appendices B. Information Sheet

St Mary's University College

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www.stmarys.ac.uk

Section A: The research project

Title of the project:

Neuromechanical, physiological and perceptual differences between planned and unplanned agility performance: response to fatigue.

Purpose and value of the study:

The study will be conducted for the purposes of a) determining the demands placed on the body that discriminates planned and unplanned change of direction ability and b) how much fatigue affect these demands.

I invite you to take part in this research study organized by myself, Joao Beleboni Marques, postgraduate student of St Mary's University College. Hopefully, your participation in the study will provide us information that will benefit you and others in the future. The study will be conducted in ASPETAR – Orthopaedic and Sports Medicine Hospital, Doha, Qatar.

In case you have any problems or questions please contact:

Principal investigator: Joao Beleboni Marques

Email address: joao.marques@aspetar.com

Section B: Your participation in the research project

- You were selected as a possible participant in this study because you fall in the category of this research.
- Taking part in this study is totally your choice.
- If you refuse to participate, this will not affect any rights or benefits you normally have.
- You may stop being in the study at any time without any penalty or loss of benefits.
- If you decide to take part in this research study, you will be required to perform a shuttle sprint running test with change of direction (COD) at 180° turn. This test will be performed over 3 different conditions (unplanned, planned and unplanned under fatigue) separated by one week apart. Prior to perform the tests, you will be required to perform a standardized warming up as well as a familiarization with the testing procedures. In order to determine the differences between the testing conditions, you will be fitted with an accelerometer device. During your first visit, you are going to perform 12 repetitions of COD test under unplanned condition separated by 2 minutes of rest. This test will require you to change direction while sprinting over 20m length upon hearing an audio signal. This signal will occur at different time points for each repetition. During the second visit, you will perform 12 repetitions of COD test under planned condition separated by 2 minutes rest. During this condition, you will know the direction of travel before starting the test and hence you will not be required to respond to the audio signal stimulus. Finally, during the third and last visit, you are going to perform a repeated shuttle sprinting running (12.5m + 12.5m) separated by 25 seconds of rest in order to increase your fatigue level. You will be required to stop when the investigator identifies 5% decrement of your shuttle sprinting performance. Then, 2 minutes rest will be given to you prior to perform 4 repetitions of COD test under unplanned condition separated by 2 minutes rest.
- Questionnaires such as Rate of perceived effort (RPE) and recovery status will be used during this study. These questionnaires will be important to identify how you are responding to the stimulus and to ensure that you are not experienced any adverse effect.
- Your heart rate will be regular monitored in order to avoid any adverse effect.
- You will be given a description of potential risks, discomforts, or benefits that can reasonably be expected.
- If you choose to participate in the study, you will be told of any important information that is learned during the course of the study, which might affect your health, welfare or willingness.
- The investigator may still choose to stop your participation in this study if he thinks it is in your best medical interest.
- You will benefit from this study, given the results may possibly provide important information regarding your physical and cognitive level. This will allow better understanding of devising training interventions to improve your performance.
- Your identity and data relating to this study will be kept confidential and will not be given to anyone unless I get your permission in writing.
- You are free to ask any number of questions you may have about the study.

If you decide to take part in this research study, you will be asked to sign this form and will be given a copy for your records. It has information, including important names and telephone numbers, to which you may wish to refer in the future.

Appendices C. Practical activity consent form

Name of participant: ……………………………………………………………………………………..

Title of the practical activity: ……………………………………………………………………………….

Main coordinator and contact details: ……………………………………………………………………….

Participants of the practical activity:

1. I agree to take part in the above practical activity.
2. I have had the practical activity explained to me, and understand what my role will be. All of my questions have been answered to my satisfaction.
3. I understand that I am free to withdraw from the practical activity at any time, for any reason and without prejudice.
4. I have been informed that the confidentiality of the information I provide will be safeguarded.
5. I am free to ask any questions at any time before and during the practical activity.
6. I am aware that I can obtain a copy of this form, and the relevant Confidential Medical History and/or Physical Activity Readiness Questionnaire (PAR-Q) Form.

Data Protection: I agree to the University College processing personal data which I have supplied. I agree to the processing of such data for any purposes connected with the teaching activity as outlined to me.

Name of participant (print)………………………….Signed………………...….Date………………

Name of witness (print)……………………………..Signed………………...….Date………………

If you wish to withdraw from the practical activity, please advise the practical activity coordinator, and complete the form below.

Title of Project:

I WISH TO WITHDRAW FROM THIS PRACTICAL ACTIVITY

Name: ………………………………………

Signed: ……………………………………………Date: …………………………………