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Individual and situational factors affecting the movement characteristics and internal responses to Touch match-play during an international tournament

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ABSTRACT
Purpose: To examine the influence of individual and situational factors on the movement characteristics and internal responses of players to an international Touch tournament.
Methods: Using 47 International Touch players (25 men and 22 women), the associations between the movement characteristics and internal responses with individual (sprint, glycolytic test, Yo-Yo intermittent recovery test level 1 [Yo-Yo IR1], jump performance and well-being) and situational (sex, squad, position, competition day, points scored/conceded, result, and opposition rank) factors were examined using linear mixed modelling.
Results: Yo-Yo IR1 distance was associated with all movement characteristics and internal responses (r = −0.29 to 0.37), whilst sprint and glycolytic times only influenced mean heart rate (HR_{mean}) (r = 0.15) and high-speed distance (r = 0.10), respectively. Sex influenced high-speed distance (r = −0.41), whilst squad was associated with playing time and HR_{mean} (r = −0.10–0.33). Other associations included: playing position with all movement characteristics (r = −0.67–0.81); points conceded with relative distance (r = −0.14); winning with high metabolic power and session RPE (r = −0.07–0.09), and opposition rank with HR_{mean} and RPE (r = 0.11–0.35).
Conclusions: Individual and situational factors can influence the movement characteristics and internal responses to Touch and should be considered when developing the characteristics of players and interpreting responses to match-play.

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KEYWORDS
Linear mixed modelling; non-contact rugby; physiological demands; global positioning systems

Introduction

Touch rugby (Touch) is played at regional, national, and international standards, and is growing in popularity globally (Federation of International Touch 2010). A match involves 2 x 20-minute periods consisting of high-intensity activity interspersed with low-intensity activity or passive recovery during the unlimited interchanges (Beaven et al. 2014; Marsh et al. 2017; Vickery and Harkness 2017; Dobbin et al. 2020). Like rugby league, Touch players get 6 opportunities to advance the ball forward with the aim of scoring a try before a turnover occurs. However, unlike rugby league (and all other codes), Touch is played on a smaller pitch (70 x 50 m), involves fewer on-field players with an unlimited interchange rule, does not involve kicking, and contact is considered as any contact between the player in possession and defending player often with minimal force. A unique feature of Touch competition is its tournament format that requires teams to play several matches in 1 day over multiple days, ranging from 7 to 10 matches over a 4- to 5-day period. The movement characteristics and internal responses to tournament match-play have only been reported in two studies, which showed that the internal (e.g., heart rate) and movement characteristics (e.g., relative distance) fluctuate across a 4-day international tournament (Marsh et al. 2017; Dobbin et al. 2020). However, these studies have only considered two situational factors (tournament day and sex), thus limiting our insight into the independent effect of other situational factors on Touch.

Situational factors in rugby match play, such as location, opposition quality, match turnaround time, weather, and points scored/conceded, can alter the movement characteristics and internal responses to competition (Delaney et al. 2016; Kempton and Coutts 2016; Henderson et al. 2019a). For example, Henderson et al. (2019a) reported that points conceded, match outcome, and weather conditions were positively associated with their 'physical performance' component in rugby sevens. Further, Kempton et al. (2016) noted how matches won, played away from home, played at the start of the season, and with a short turnaround independently influenced relative distance and high-speed running in rugby league. However, the only situational factor that has been considered in Touch is the effect of playing position. Two studies have highlighted substantial between-position differences in the responses of Touch players (Vickery and Harkness 2017; Chow 2020), though we cautiously extrapolate this to international Touch due to a lower playing standard, shorter tournament/match format, and fewer squad players. Research exploring the effect of other situational factors on the movement characteristics and

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internal responses across a Touch tournament is currently absent, but would provide insight for those involved in physical, technical, and tactical development of players.

Recently, several studies have highlighted the role individual factors such as intermittent running ability, sprint ability, adductor strength, body mass, and wellbeing can have on the movement characteristics and internal responses to rugby league, rugby sevens, soccer, and tag rugby (Hogarth et al. 2015; Delaney et al. 2016; Kempton and Coutts 2016; Lovell et al. 2017; Henderson et al. 2019b). Collectively, the results of these studies suggest that measures of intermittent running ability (e.g., 30–15_{IFT}) were positively associated with movement characteristics across various team sports (Delaney et al. 2016; Kempton and Coutts 2016; Henderson et al. 2019b). Henderson et al. (2019b) reported that perceived muscle soreness and stress were positively associated with physical performance whilst body mass, perceived recovery and groin squeeze were negatively associated, albeit all effects were considered trivial. In the context of Touch, there are numerous individual factors (e.g., fitness, well-being and neuromuscular function (Dobbin et al. 2020)) that could influence the movement characteristics and internal responses to match-play. However, such factors have not been explored.

Few studies have investigated the responses to Touch match-play across an international tournament, with existing investigations (Marsh et al. 2017; Dobbin et al. 2020) examining the influence of situational factors in isolation without controlling for other confounding variables. No studies in Touch have investigated the influence of individual factors on the movement characteristics and internal responses across a Touch tournament. Deeper understanding of these factors will provide coaches and practitioners with information on how best to prepare Touch players tactically and physically as well as evaluate the usefulness of performance tests and in-tournament monitoring procedures. Therefore, this study aimed to use a multi-level mixed modelling approach to examine the independent effects of a range of individual and situational factors on the movement characteristics and internal responses to Touch match-play during an international tournament.

Materials and methods

Participants

Forty-eight international Touch players were recruited from three squads. One individual who competed for the men's open withdrew from the study due to some discomfort from the GPS and heart rate belt, leaving 47 players remaining and who were included in the study (Men: age = 25.2 [5.2] y, body mass = 76.5 [7.9] kg, stature = 177.6 [5.7] cm; Women: 26.5 [5.4] y, body mass = 60.5 [6.1] kg, stature = 163.1 [5.0] cm). Players competed in men's open (n = 15), women's open (n = 16) or mixed open (n = 16) categories, with all teams reaching their respective final of the tournament. Players were categorised as men (n = 25) or women (n = 22), and one of four playing positions: far winger (48 observations), box winger (26 observations), middle (199 observations) and link (171 observations). All players prepared for the tournament over 18 weeks, including formalised training, performance testing, and a skill-based programme. Informed consent was obtained from all participants and institutional ethics approval was granted by the Faculty of Health, Psychology and Social Care ethics committee at Manchester Metropolitan University (No. 1187).

Study design

A prospective observational study design was used, with data collected during a 4-day international tournament (European Championship) comprising 2 or 3 matches per day. Before the tournament, players underwent an assessment of physical characteristics. On each day of the tournament, players arrived at the venue between 07:30 and 09:00, at which point they completed two countermovement jumps (CMJ) and a wellbeing questionnaire. After the tournament, various contextual factors relating to match performance were collated.

Methods

Individual factors

Four weeks before the tournament, players attended a 'national camp' where final squad selection was made. On arrival, players completed a warm-up before completing two maximal 10 m sprints, a single 'glycolytic' change of direction test and the Yo-Yo intermittent recovery test level 1 (Yo-Yo IR1). Time to complete the sprint and glycolytic test were recorded using timing gates (Brower, Speedtrap 2; Brower Timing Systems, Draper, UT, USA). Players started both tests in a 2-point stance with their driving foot 0.3 m before the start line. The best of the two 10 m sprints (recorded to 0.01 s) was used in the analysis, with a combined typical error and smallest worthwhile time (TE +SWC) of 0.11 s (Dobbin et al. 2018). A single 'glycolytic' change of direction test was performed due to time restrictions and required players to complete a series of forward, backward and lateral movements over a 177 m course (TE+SWC = 1.80 s) (O'Connor 1992). A diagram and written overview of the glycolytic test can be found in Supplement 1. The YoYo IR1 was performed in accordance with Krustrup et al. (2003), with total distance recorded after the second failed attempt to reach the designated start line (TE+SWC = ~140 m) (Deprez et al. 2014). All players were habituated with testing procedures.

On each morning of the tournament, players completed a two CMJs on a force platform (600 × 600 mm uni-axial; HUR Labs, FP4, Tampere, Finland) sampling at 1200 Hz, with jump height taken from the second attempt. Players started upright before flexing at the knee to a self-selected depth, and then extending into the jump for maximal height keeping their legs straight throughout and hands on their hips. Jumps that did not meet the criteria were not recorded, and participants were asked to complete an additional jump. CMJs were completed before any warm-up or touch activity. Away from teammates and coaches, players provided a rating of perceived fatigue, mood, muscle soreness, sleep quality, and stress using a 1- to 5-point Likert scale, which were summed. Higher values were indicative of a positive response to the question, with lower values representing a negative response (e.g., 1 = 'very sore' to

5 = "feeling great). The TE+SWC for CMJ and well-being are 3.4 cm (Dobbin et al. 2018) and 1.9 AU (Fitzpatrick et al. 2019), respectively.

Situational factors

Two weeks before the tournament, the sex of the players, the competition days, opposition ranking (top, 1–3; middle, 4–6; and bottom, 7–10) and squad selection were recorded. Wet bulb globe temperature (WBGT) was recorded during the first match of the day, at midday and during the final match. The mean WBGT for the day was used in the analysis. Post-tournament, playing position, match outcome, time between matches, points scored/conceded were cross-checked and collated.

Movement characteristics and internal responses

During all matches, players wore the same 10 Hz microtechnology device (Optimeye, S5; Catapult Innovations, Melbourne, Australia), fitted into a custom-made vest positioned between the participant's scapulae. All devices were activated for the warm-up (40 min before the 'tap-off') to enable acquisition of satellite signals and avoid any disruption. Post-tournament, the raw data was visually inspected by the lead researcher with all outcome variables presented in a panel graph. This was done to ensure all data were captured for active players for the game. Then, the entire match period was selected and the HDOP and number of satellites recorded at 100 Hz was inspected. Periods of the match where HDOP and the number of satellites violated acceptable standard of > 2.0 (Shergill et al. 2021) and < 10 (Dalton-Barron et al. 2021), respectively, were highlighted. Our inspection revealed that there were 14 instances (matches) where HDOP exceed 2.0 with this lasting between 3 and 8 seconds. In such case, the data were removed and was estimated from linear interpolation (Dalton-Barron et al. 2021). The minimum, maximum, mean, standard deviation, for HDOP was 0.74, 2.45, 0.79 and 0.19, respectively. There were no instances where the number of satellites fell below 10 with a minimum, maximum, mean and standard deviation, of 10, 16, 12, and 0.9, respectively. Then, the data were truncated manually by the lead researcher based on the velocity trace to ensure only on-field was used for analysis (Sprint, version 5.1; Catapult Sports). Total playing time, relative distance (distance covered/playing time), relative high-speed distance (distance covered >14 $km{\cdot}h^{-1}$/playing time), and the time at high metabolic power (HMP) (> 20 Wkg^{-1}) were obtained. Players wore a heart rate monitor that transmitted to the GPS device continuously during the matches with mean heart rate (HR_{mean}) calculated. Twenty minutes after a match, players provided a rating of perceived exertion using a 10-point scale where 0 = rest and 10 = maximal exertion, which was then multiplied by playing duration (sRPE) (Foster et al. 2001).

Statistical analysis

Descriptive statistics included mean and standard deviation. A multi-level mixed model was used to examine the independent effects of individual and situational factors on the movement characteristics and internal responses. Before running each model (n = 6), assumptions of independence and collinearity were checked, and visual inspections of the data were carried out to using a Q–Q plot. The study included units of analysis (individual player match data) nested within a cluster of units (player) which, in turn, were nested within a playing position, squad and sex (Supplement 2). Random factors were included in each model to allow for random deviation for sex, squad, playing position and player from the overall fixed intercept and coefficients. A 'step-up' model construction strategy was employed beginning with an 'unconditional' model containing only a fixed intercept and the level 2 random factor (player) nested within level 3, 4 and 5 factors. Each level 1 fixed factor was introduced to the model and retained if significantly improving the model as determined by a chi-squared test (P < 0.05) on the maximal likelihood ratio test and degree of freedom of the current and previous model. Adding a fixed factor that increased the maximal likelihood ratio compared to the previous model, reduced the model fit and was excluded. All continuous-fixed factors were grand mean centred. Once the final model was derived, the t statistic and degrees of freedom were used to determine an effect size correlation (r) with 95% confidence intervals (Rosnow et al. 2000). Effect size correlations were interpreted as follows: < 0.10 (trivial), 0.10–0.29 (small), 0.30–0.49 (moderate), 0.50–0.69 (large), 0.70–0.89 (very large), 0.90–0.99 (almost perfect), and 1.0 (perfect) (Hopkins et al. 2009). All statistics were performed using Statistics Packages for Social Sciences Version 27 (IBM Corp, Armonk, New York).

Results

Descriptive statistics for the dependent variables and several individual factors with reference to sex, squad, playing position, playing day, match outcome and opposition ranking are presented in Table 1.

Individual factors

Distance covered in the Yo-Yo IR1 was negatively associated with playing time, mean heart rate and sRPE, and was positively associated with relative distance, high-speed distance and time spent at HMP (Figures 1 and 2). Ten-meter sprint time was positively associated with HR_{mean} whilst glycolytic change of direction time was positively associated with high-speed distance. Wellbeing was only trivially associated with mean heart rate, whilst jump height did not improve any of the models (P = 0.411–0.970), thus was not included in any final models. The full model output containing the effect of individual factors are presented in Tables 2 and 3.

Situational factors

Sex improved the model for relative high-speed distance (P = 0.01) only, with a moderate negative association observed for women (Figure 1). Playing squad improved the model for playing time (P = 0.04), HR_{mean} (P = 0.02) and sRPE (P = 0.02) (Figures 1 and 2). Compared to the mixed open, the women's open squad was negatively associated with playing time and sRPE, and was positively associated with HR_{mean}. Men's open was positively associated with playing time and sRPE, and negatively associated with HR_{mean}. Playing position improved the model for playing time (P < 0.001), relative

Table 1. Descriptive statistics for various individual factors and dependent variables across sex, squad, playing position, playing date, match outcome and opposition ranking.

	Age (years)	Playing Time (min)	Relative Distance (m·min^{-1})	Relative High Distance (m·min^{-1})	Time at HMP (s)	Heart Rate (b·min^{-1})	sRPE (AU)	10 m Sprint (s)	Glycolytic Change of Direction (s)	Yo-Yo IR1 (m)	CMJ Height (cm)	Wellness (AU)
Sex												
Men	25.4 ± 5.2	19.5 ± 6.9	128.9 ± 15.6	32.1 ± 10.0	132.7 ± 32.1	121 ± 19	85 ± 48	1.88 ± 0.10	41.60 ± 2.58	1846 ± 528	36.3 ± 5.0	17.3 ± 3.7
Women	26.4 ± 5.0	22.5 ± 8.9	118.6 ± 18.7	19.7 ± 10.7	110.8 ± 29.9	136 ± 19	111 ± 72	2.09 ± 0.16	47.37 ± 3.18	884 ± 312	26.3 ± 3.1	16.9 ± 2.8
Squad												
Men's Open	26.2 ± 5.7	19.9 ± 8.2	130.9 ± 15.7	30.3 ± 10.0	130.6 ± 32.3	115 ± 17	83 ± 51	1.91 ± 0.09	41.71 ± 2.70	2017 ± 467	35.7 ± 5.2	18.8 ± 2.6
Women's Open	26.8 ± 5.6	20.1 ± 7.7	122.3 ± 18.9	23.3 ± 10.5	113.6 ± 29.3	141 ± 18	94 ± 56	2.15 ± 0.13	46.92 ± 2.10	878 ± 373	26.2 ± 3.0	16.7 ± 2.3
Mixed Open	24.6 ± 3.6	22.7 ± 8.2	118.8 ± 16.8	24.7 ± 14.1	122.1 ± 34.9	128 ± 18	116 ± 73	1.88 ± 0.11	44.33 ± 4.99	1258 ± 505	32.5 ± 6.6	15.8 ± 4.0
Playing Position												
Far Winger	24.8 ± 3.5	36.7 ± 7.5	106.3 ± 12.8	8.5 ± 2.2	116.0 ± 35.7	128 ± 26	188 ± 84	1.89 ± 0.11	44.49 ± 2.75	919 ± 291	25.9 ± 2.4	18.9 ± 3.1
Box Winger	29.4 ± 4.5	25.1 ± 6.2	108.9 ± 16.8	12.7 ± 7.72	97.7 ± 23.1	139 ± 20	92 ± 52	2.16 ± 0.22	47.58 ± 1.99	880 ± 328	29.8 ± 4.7	17.5 ± 3.0
Middle	25.3 ± 5.3	17.5 ± 4.8	129.1 ± 15.9	31.5 ± 9.4	126.4 ± 32.5	129 ± 21	81 ± 39	1.98 ± 0.18	43.58 ± 3.72	1525 ± 648	33.4 ± 6.8	16.7 ± 3.7
Link	26.4 ± 5.2	19.9 ± 5.9	124.9 ± 17.5	26.4 ± 10.6	121.8 ± 32.2	126 ± 18	93 ± 57	1.99 ± 0.14	44.91 ± 4.75	1375 ± 672	30.7 ± 6.0	16.9 ± 2.7
Playing day												
Day 1	-	20.1 ± 8.8	124.7 ± 18.2	25.9 ± 11.8	117.9 ± 28.2	134 ± 18	87 ± 57	-	-	-	33.3 ± 6.5	19.1 ± 2.5
Day 2	-	21.7 ± 9.5	126.0 ± 21.7	24.8 ± 12.7	121.1 ± 36.9	132 ± 20	107 ± 68	-	-	-	30.2 ± 5.2	17.7 ± 2.3
Day 3	-	21.3 ± 7.4	119.4 ± 16.8	24.5 ± 11.1	120.0 ± 33.9	125 ± 20	91 ± 64	-	-	-	30.9 ± 6.5	16.3 ± 3.4
Day 4	-	20.8 ± 7.1	127.8 ± 14.7	29.2 ± 12.8	129.6 ± 31.9	126 ± 23	114 ± 59	-	-	-	30.8 ± 7.0	15.5 ± 3.5
Match Outcome												
Win	-	20.7 ± 8.0	124.4 ± 17.6	26.0 ± 11.7	121.7 ± 32.5	128 ± 21	91 ± 56	-	-	-	31.2 ± 6.4	17.4 ± 3.0
Loss	-	23.7 ± 8.9	119.1 ± 20.2	25.5 ± 14.7	123.3 ± 36.6	130 ± 20	149 ± 90	-	-	-	32.3 ± 7.3	14.5 ± 4.7
Ranking												
Bottom (7-10)	-	20.3 ± 7.6	126.0 ± 18.9	27.2 ± 11.5	122.3 ± 34.6	118 ± 21	74 ± 53	-	-	-	31.3 ± 6.7	17.3 ± 2.6
Middle (4-6)	-	20.9 ± 8.1	120.8 ± 14.8	25.0 ± 10.8	119.9 ± 28.6	130 ± 18	85 ± 51	-	-	-	31.7 ± 6.5	17.4 ± 3.2
Top (1-3)	-	21.5 ± 8.5	125.3 ± 20.0	26.1 ± 13.4	123.4 ± 35.5	133 ± 20	126 ± 67	-	-	-	31.0 ± 6.4	16.6 ± 3.7

*HMP = high metabolic power. sRPE = session rating of perceived exertion (0–10 rating * playing duration). CMJ = countermovement jump. Yo-Yo IR1 = Yo-Yo Intermittent Recovery Test level 1; AU = arbitrary unit.*

Table 2. Effect of individual and situational factors on playing time, relative distance, and high-speed distance.

Playing time	Coefficient (95% CI)	df	*t*	*P* value	*r* value (95% CI)
Intercept (min)	18.25	178	9.299	<0.001	-
Yo-Yo IR1 (m)	−0.002 (−0.004; 0.001)	47	−1.789	0.088	−0.25 (−0.50; 0.04)
Mixed open (ref)	-	-	-	-	-
Women's open	−2.37 (−5.11; 0.37)	46	−1.740	0.089	0.25 (−0.50; 0.05)
Men's open	1.49 (−1.41; 4.41)	48	1.033	0.307	0.15 (−0.14; 0.41)
Middle (ref)	-	-	-	-	-
Box winger	8.78 (4.38; 13.17)	52	4.008	< 0.001	0.48 (0.24; 0.67)
Far winger	17.69 (13.86; 21.52)	44	9.303	< 0.001	0.81 (0.68; 0.90)
Link	1.69 (−0.50; 3.88)	48	1.549	0.128	0.22 (−0.07; 0.47)
Relative distance	**Coefficient (95% CI)**	**df**	***t***	***P* value**	***r* value (95% CI)**
Intercept (m·min^{-1})	120.0 (111.9; 128.16)	73	29.356	< 0.001	-
Yo-Yo IR1 Distance (m)	0.005 (0.001; 0.009)	45	2.556	0.014	0.36 (0.07; 0.59)
Middle (ref)	-	-	-	-	-
Box Winger	−16.1 (−27.3; −4.9)	51	−2.890	0.006	−0.37 (−0.59; −0.11)
Far Winger	−18.5 (−27.7; −9.2)	39	−4.050	< 0.001	−0.54 (−0.73; −0.28)
Link	−4.2 (−9.7; 1.3)	44	−1.540	0.131	−0.23 (−0.49; 0.08)
Day 1 (ref)	-	-	-	-	-
Day 2	5.2 (−0.6; 11.1)	278	1.754	0.080	0.10 (−0.01; 0.22)
Day 3	−3.2 (−8.2; 1.9)	274	−1.246	0.215	−0.07 (−0.19; 0.04)
Day 4	5.8 (0.1; 11.4)	275	2.005	0.046	0.12 (−0.01; 0.24)
Points Conceded	−0.7 (−1.3; −0.1)	244	−2.210	0.028	−0.14 (−0.26; −0.01)
High-speed distance	***r* value (95% CI)**	**df**	***t***	***P* value**	***r* value (95% CI)**
Intercept (m·min^{-1})	33.9 (30.4; 37.5)	74	19.205	< 0.001	-
Glycolytic time (s)	0.2 (−0.4; 0.7)	44	0.648	0.520	0.10 (−0.21; 0.38)
Yo-Yo IR1 (m)	0.001 (−0.002; 0.005)	42	0.675	0.503	0.10 (−0.21; 0.39)
Men (ref)	-	-	-	-	-
Women	−10.4 (−16.4; −4.4)	59	−3.441	0.001	−0.41 (−0.60; −0.17)
Middle (ref)	-	-	-	-	-
Box winger	−14.5 (−20.9; −8.1)	49	−4.527	< 0.001	−0.54 (−0.71; −0.31)
Far winger	−16.9 (−22.7; −11.3)	44	−6.016	< 0.001	−0.67 (−0.81; −0.47)
Link	−2.5 (−5.8; 0.7)	45	−1.558	0.126	−0.23 (−0.49; 0.07)
Day 1 (ref)	-	-	-	-	-
Day 2	1.0 (−1.7; 3.7)	276	0.734	0.464	0.04 (−0.07; 0.16)
Day 3	−1.1 (−3.5; 1.2)	273	−0.962	0.337	−0.06 (−0.18; 0.06)
Day 4	2.8 (0.2; 5.4)	276	2.087	0.038	0.12 (0.01; 0.24)
Time between matches (min)	0.01 (−0.001; 0.04)	198	1915	0.057	0.13 (−0.01; 0.27)

Fixed factors not presented in the table did not significantly improve the model during the step-up procedure as determined by the likelihood ratio. m·min^{-1} = meters per minute. CI = confidence intervals. df = degree of freedom. t = t statistics. P value = probability. ref = reference group in the model.

distance ($P = 0.002$), high-speed distance ($P < 0.001$) and time spent at HMP ($P < 0.001$). Compared to middles, all other positions were positively associated with greater playing time, and negatively associated with relative distance, high-speed distance and time at HMP. The full model output containing the effect of situational factors are presented in Tables 2 and 3.

Playing day improved most models (P < 0.001–0.03). Compared to day 1, the second day of competition was positively associated with relative distance, high-speed distance, time at HMP and sRPE (Figures 1 and 2). Day 2 was also negatively associated with HR_{mean}. Compared to day 1, day 3 was negatively associated with relative distance, high-speed distance, time at HMP and HR_{mean}, but positively associated with sRPE. Day 4 was negatively associated with HR_{mean} and was positively associated with relative, high-speed distance, time at HMP and sRPE. The match outcome improved the model for time at HMP ($P = 0.003$) and sRPE ($P < 0.001$), with results suggesting a positive association between time at HMP and a negative association for sRPE. Opposition rank did not improve the model for any movement characteristics (P = 0.40–0.85), but did improve the model for HR_{mean} ($P < 0.001$) and sRPE ($P < 0.001$). There was a positive association between higher European ranking and HR_{mean} and sRPE. Points scored improved the model for sRPE ($P = 0.03$), and points conceded improved the model for relative distance ($P = 0.03$) both resulting in a negative association. Time between matches improved the model for high-speed distance ($P = 0.04$) with a positive association observed, whilst WBGT (mean 17.3 ± 1.4°C) did not improve any of the models (P = 0.09–0.96).

Discussion

This study used a multilevel mixed model approach to examine the independent effect of various individual and situational factors on the movement characteristics and internal responses to Touch match-play across an international tournament. The results of this study demonstrate that individual factors including wellbeing, sprint time, glycolytic change of direction time and distance covered during the Yo-Yo IR1, can influence the movement characteristics and internal responses of male and female players to Touch match-play. All situational factors except for WBGT were related to one or more of the movement characteristics and internal responses, though we do note that WBGT was stable and within a 'safe' category during the tournament, which might not always be the case (e.g., 2019 Malaysia World Cup).

Table 3. Effect of individual and situational factors on time at high metabolic power (HMP), mean heart rate and session RPE.

Time at HMP	Coefficient (95% CI)	df	*t*	*P* value	*r* value (95% CI)
Intercept (s)	110.0 (93.2; 126.7)	248	12.930	<0.001	-
Yo-Yo IR1 (m)	0.01 (0.003; 0.02)	48	2.732	0.009	0.37 (0.09; 0.59)
Middle (ref)	-	-	-	-	-
Box winger	−12.5 (−38.7; 13.8)	50	−0.956	0.344	−0.13 (−0.40; 0.15)
Far winger	−1.0 (−23.3; 21.4)	41	−0.088	0.930	−0.01 (−0.32; 0.29)
Link	−4.4 (−17.6; 8.7)	45	−0.678	0.501	−0.09 (−0.38; 0.20)
Day 1 (ref)	-	-	-	-	-
Day 2	8.5 (−2.4; 19.4)	268	1.527	0.128	0.09 (−0.03; 0.21)
Day 3	6.3 (−3.4; 16.0)	270	1.282	0.201	0.08 (−0.04; 0.20)
Day 4	13.4 (3.6; 23.3)	262	2.684	0.008	0.16 (0.04; 0.28)
Loss (ref)	-	-	-	-	-
Win	9.4 (−3.1; 21.9)	290	1.475	0.141	0.09 (−0.03; 0.20)
Mean heart rate	**Coefficient (95% CI)**	**df**	***t***	***P* value**	***r* value (95% CI)**
Intercept (b·min^{-1})	125 (116; 134)	84	27.377	< 0.001	-
10 m sprint (s)	19 (−18; 56)	44	1.031	0.308	0.15 (−0.15; 0.43)
Yo-Yo IR1 (m)	−0.01 (−0.02; 0.002)	45	−1.522	0.135	−0.22 (0.48; 0.08)
Total wellbeing (AU)	0.03 (−0.6; 0.7)	297	0.096	0.923	0.01 (−0.11; 0.12)
Mixed open (ref)	-	-	-	-	-
Women's open	16 (2; 29)	45	2.332	0.023	0.33 (0.04; 0.56)
Men's open	−5 (−17; 8)	52	−0.761	0.450	−0.10 (−0.37; 0.17)
Day 1 (ref)	-	-	-	-	-
Day 2	−3 (−8; 1)	261	−1.481	0.140	−0.09 (−0.21; 0.03)
Day 3	−9 (−13; −5)	267	−4.494	< 0.001	−0.27 (−0.37; −0.15)
Day 4	−8 (−13; −3)	269	−3.271	0.001	−0.20 (−0.31; −0.08)
Ranked bottom 4 (ref)	-	-	-	-	-
Ranked middle 3	7 (3; 10)	260	4.728	< 0.001	0.20 (0.08; 0.31)
Ranked top 3	9 (5.3; 13)	260	3.262	0.001	0.28 (0.17; 0.39)
sRPE	**Coefficient (95% CI)**	**df**	***t***	***P* value**	***r* value (95% CI)**
Intercept (AU)	57.2 (28.3; 86.0)	263	3.903	< 0.001	-
Yo-Yo IR1 (m)	−0.02 (−0.001; −0.04)	51	−2.132	0.038	−0.29 (−0.52; −0.01)
Mixed Open (ref)	-	-	-	-	-
Women's Open	−5.4 (−26.3; 15.6)	62	−0.511	0.611	−0.06 (−0.31; 0.19)
Men's Open	13.9 (−8.5; 36.2)	64	1.241	0.219	0.15 (−0.10; 0.38)
Middle (ref)	-	-	-	-	-
Box Winger	13.2 (−20.0; 46.3)	59	0.794	0.430	0.10 (−0.16; 0.35)
Far Winger	92.5 (65.1; 120.0)	46	6.799	< 0.001	0.71 (0.53; 0.83)
Link	11.9 (−4.0; 27.9)	53	1.502	0.139	0.20 (−0.07; 0.45)
Day 1 (ref)	-	-	-	-	-
Day 2	2.6 (−14.5; 19.7)	270	0.299	0.765	0.02 (−0.10; 0.12)
Day 3	13.7 (−0.8; 28.1)	267	1.862	0.064	0.11 (−0.01; 0.12)
Day 4	0.7 (0.2; 1.2)	265	2.257	0.025	0.14 (0.02; 0.12)
Loss (ref)	-	-	-	-	-
Win	−12.5 (−33.6; 8.7)	266	−1.161	0.247	−0.07 (−0.19; 0.05)
Ranked bottom 4 (ref)	-	-			
Ranked middle 3	14.3 (−1.0; 29.6)	269	1.837	0.067	0.11 (−0.01; 0.23)
Ranked top 3	47.6 (32.3; 62.8)	271	6.141	< 0.001	0.35 (0.24; 0.45)
Points scored	−0.05 (−0.11; −0.001)	370	−2.194	0.029	−0.11 (−0.21; −0.01)

*Fixed factors not presented in the table did not significantly improve the model during the step-up procedure as determined by the likelihood ratio. m·min^{-1} = meters per minute. CI = confidence intervals. df = degree of freedom. t = t statistics. P value = probability. ref = reference group in the model. sRPE = session rating of perceived exertion (0–10 rating * playing duration).*

A prominent individual factor was total distance achieved during the Yo-Yo IR1 test. The Yo-Yo IR1 is commonly used to evaluate the intermittent running ability of team sport athletes (Schmitz et al. 2018) and can influence the movement characteristics during (Hogarth et al. 2015; Delaney et al. 2016; Lovell et al. 2017; Henderson et al. 2019b), and internal responses to (Hogarth et al. 2015), team-sport activity. In this study, distance achieved by a player in the Yo-Yo IR1 was negatively associated with playing time and HR_{mean}, and positively associated with high-speed distance and sRPE. However, the magnitude of the effect for these fixed factors was considered trivial to small with confidence intervals incorporating a null association. In contrast, distance achieved during the Yo-Yo IR1 was positively associated with relative distance and time spent at HMP. The effect was considered moderate ($P < 0.05$), and results demonstrated that, for a 140 m change (≥TE+SWC) (Deprez et al. 2014) in Yo-Yo IR1 distance, a 0.7 m·min^{-1} and 1.4 s increase in relative distance and time at HMP, respectively, might be expected. The finding for relative distance supports that of Lovell et al. (2017) who also demonstrated a 120 m change in Yo-Yo IR1 was associated with an increase in relative distance of 0.8 m·min^{-1} during soccer. Similarly, Delaney et al. (2016) observed that for every 1 m·s^{-1} increase in $30{:}15_{IFT}$ final speed achieved by interchange rugby league players, an increase in relative distance and metabolic power of 1.4 m·min^{-1} and 3.3 W·kg^{-1}, respectively, could be expected. Whilst these findings support the notion that the development of intermittent running ability could translate to match-play, the size of the effect is unlikely to make a substantial impact on the outcome of a match based on a 140 m change. Indeed, based on the model, the far winger, who played the full 40 minutes, would be expected to cover additional 28 m per match. However, the

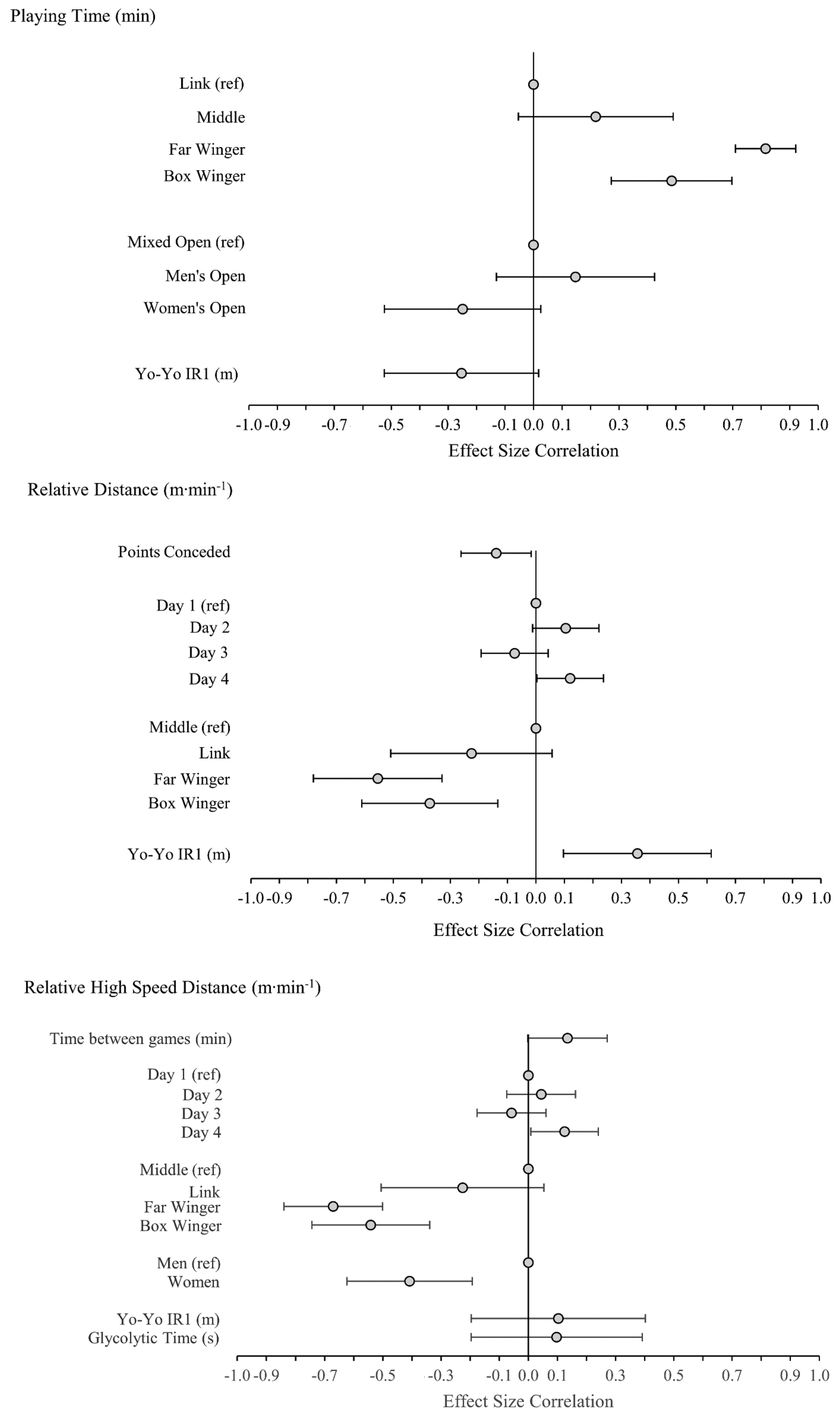

Figure 1. Effect of individual and situational factors on playing time, relative distance, and high-speed distance. Note: *Data are presented and effect size correlation ± 95% confidence limits. (ref) = reference group.*

cumulative effect of this across multiple players and over 9–10 matches could provide an advantage over the opposition, so may be practically worthwhile.

For other individual physical characteristics, 10 m sprint had a positive association with HR_{mean}, and glycolytic change of direction time had a positive association with high-speed distance. However, both associations were considered small with confidence intervals encompassing a null association. These results suggest that measures of CMJ, sprint and change of direction speed might not independently influence the movement characteristics and internal responses to Touch match-play, and that this lack of concurrent validity ought to be considered when evaluating the physical characteristics of Touch athletes.

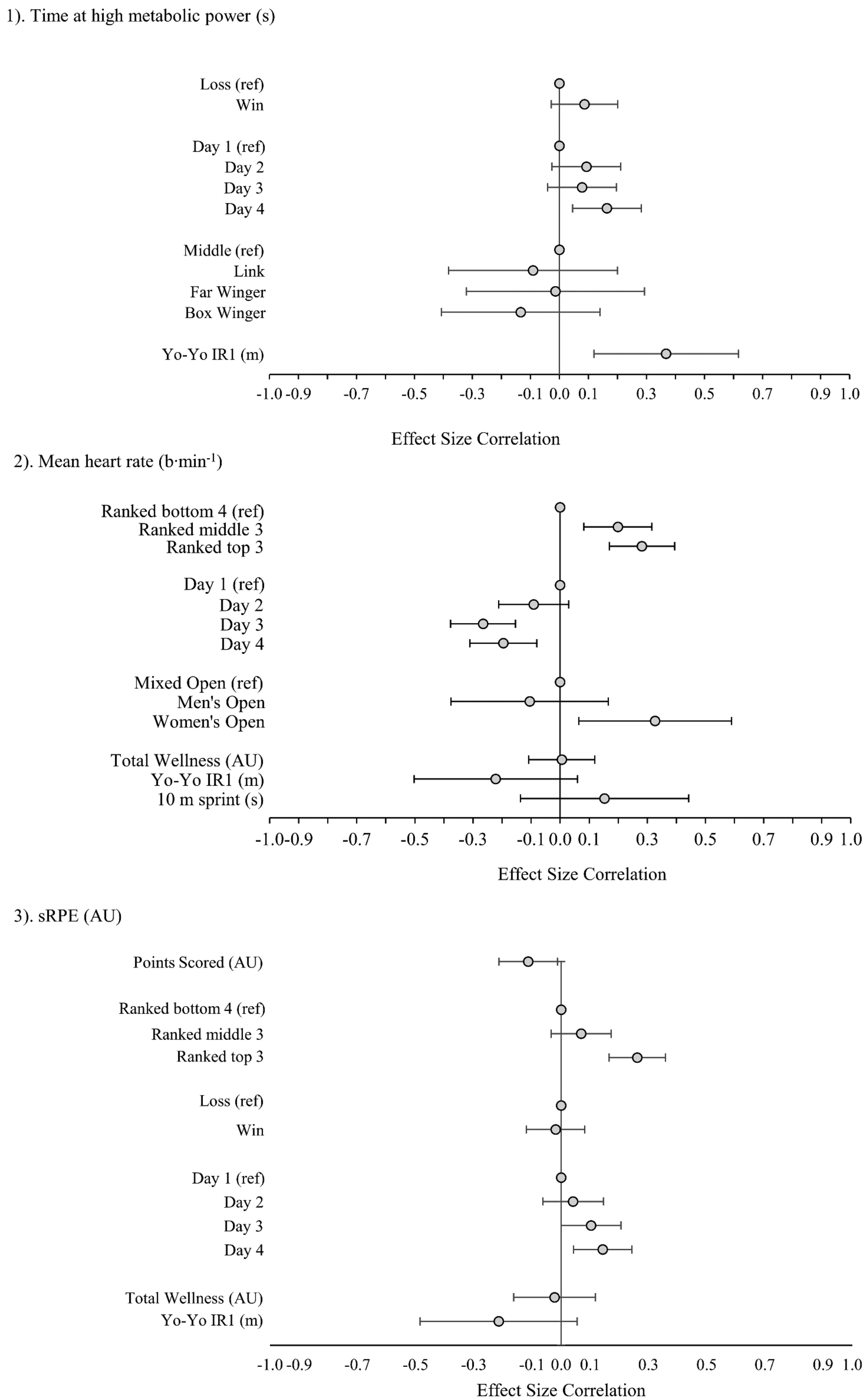

Figure 2. Effect of individual and situational factors on time spent at high metabolic power (HMP), mean heart rate, and sRPE. Note*: Data are presented and effect size correlation ± 95% confidence limits. (ref) = reference group.*

Players' wellbeing did not improve the model for all movement characteristics and was only trivially associated with HR_{mean} and sRPE, such that a 1.9 AU increase (> TE + SWC) (Fitzpatrick et al. 2019) in wellbeing would result in no measurable change in HR_{mean} or sRPE. Such findings question the usefulness of well-being questionnaires for monitoring athletes, despite being common practice (Watson et al. 2017; Fitzpatrick et al. 2019). The lack of association between wellbeing and the movement characteristics or internal responses to match-play support those of Henderson et al. (2019b) who recently reported trivial associations between soreness, sleep quality, stress, fatigue and perceived recovery with the physical and technical performance in rugby sevens. However, we highlight several points of caution here. First, the results of this study reflect data collected during an international tournament, whereby sports scientists, medical personnel and coaches worked collectively to ensure optimal athlete health and performance. As such, an athlete reporting a substantial reduction in wellbeing (e.g., −4 to −10 AU on day 3 vs. day 1) or a large (negative) change in jump height (e.g., −6 to −11 cm on day 3 vs. day 1) might have been withdrawn from one or more matches during that day of competition or additional components added to their warm-up. This approach to manage players during the tournament might also alter reporting behaviour of players given the implications of missing a match during in international tournament. The lack of association with CMJ height during a single jump might indicate a lack of sensitivity to detect potentially suitable change neuromuscular function and movement strategy. Second, we note that wellbeing and CMJ performance might provide valuable insight beyond that of influencing the movement characteristics and internal responses such as moderating injury risk (Watson et al. 2017) and informing readiness to compete (Gabbett et al. 2017), thus might still prove valuable during a tournament.

The movement characteristics for men and women indicated that only high-speed running differed, with women covering 4.4 to 16.4 $m{\cdot}min^{-1}$ less than men during a 40-minute match. This finding agrees with Dobbin et al. (2020), though their results also suggested a trend for differences between men and women for time at HMP, heart rate and sRPE not observed here. Vickery and Harkness (2017) reported a similar observation between men and women who play in the link position, with high-speed running, high-intensity efforts, maximum HR and sRPE differentiating between sexes. The lack of difference between the sexes in this study might be due the variation across squads. For example, Ogden (Ogden 2010) reported no differences between men- and women-only squads in a study of New Zealand Touch players, but did observe differences within the mixed squads, which in turn, is likely due to positional differences. In our study, the use of a linear mixed model controls for the independent effects of other factors, so could explain the lack of difference. The difference observed might also be explained by the use of an arbitrary threshold of 14 $km{\cdot}h^{-1}$ to differentiate between low- and high-speed. The decision to use a standard threshold might disadvantage those players who have a lower maximum speed, and potentially best explored in future research by using individualised speed thresholds based on a 'true' maximal speed.

The effect of squad was evident for playing time, suggesting that players in the women's open typically play ~2.4 minutes (144 s) less than mixed open players, whilst players in the men's open typically play 1.5 minutes (90 s) more, in agreement with previous studies (Ogden 2010). An effect of squad was also observed for HR_{mean}, with women's open players reporting moderately higher values (~16 $b{\cdot}min^{-1}$) compared to mixed open players, whilst the difference with men's open players was trivial (~5 $b{\cdot}min^{-1}$). Our results also provide insight into the effect of playing position on the movement characteristics and the lack of effect on HR_{mean} and sRPE during a 40-minute match. Data indicates thatthose in the wing position play substantially longer than all other positions, but as a result, cover less relative and high-speed running, and spend less time at HMP. This finding was expected for the far winger position, given in England, a tactical decision to not interchange the far winger was used at the time. Our data also provides insight into the difference between links and middles, which appeared to agree with the descriptive results of previous research (Vickery and Harkness 2017; Chow 2020). Collectively, these three situational factors provide support for the need to consider sex, squad and position when assessing or developing the physical characteristics of these athletes. For example, practitioners working with Touch players might consider that men complete greater high-speed running per minute; that each of the three squads appear to play for differing durations; and that the winger positions report distinctly different movement characteristics to the middle and link positions. As such, these findings should encourage the use of sex-, squad- or playing position-specific approaches to strength and conditioning as well as the interpretation and recommendation for desired physical characteristics.

The day of competition influenced the movement characteristics and internal responses to Touch competition, with the results showing a similar pattern to that previously observed (Marsh et al. 2017; Dobbin et al. 2020). Relative distance, high-speed distance, and time at HMP were negatively associated with day 3 of competition, whilst day 2 and 4 were positively associated. Interestingly, days 2–4 were associated with a lower HR_{mean} and higher sRPE compared to day 1. These results indicate a potential pacing profile across a 4-day tournament, where multiple factors such as perceived fatigue, exercise-induced muscle soreness, match significance and proximity to the end of the tournament likely play an important role (Waldron and Highton 2014). The reduction in movement characteristics on day 2 and 3 could be explained by players experiencing an increase in self-reported fatigue and muscle soreness specifically rather than total wellness (Dobbin et al. 2020), matches against lesser quality opposition, and the need to conserve energy for the final day of competition. In support, Dobbin et al. (2020) observed a reduction in sRPE on day 2 and 3 of a Touch tournament, potentially indicating a down-regulation in activity to conserve energy for day 4. On day 4, however, we observed a positive association with movement characteristics, possibly reflecting the opposition quality with finals played on day 4 and knowledge that this is the final day of competition. The physiological and psychological input during match-play likely explains the high sRPE values observed on day 4 before being multiplied by playing time (4.9 AU vs. day 2 and 3 = ~4.2 AU) This information can be used by practitioners and coaches in Touch to support the introduction of tactical changes (e.g., 2/3-pod system), player rotation within and between days, or recovery strategies between matches/days with a view of maintaining performance in the latter stages of a tournament. Furthermore, research investigating other factors (e.g., playing experience) that might influence the pacing profile of Touch athletes as well as strategies (e.g., interchange, selection/non-selection) to optimise the pacing profile used across a tournament is warranted.

Several other contextual factors were associated with the movement characteristics and internal responses observed in this study, though many resulted in confidence intervals encompassing a null association. First, points conceded showed a trivial negative association with distance covered, indicating that for every point conceded, distance drops by 0.7 m·min^{-1}. Points scored was negatively associated with sRPE, suggesting each point scored reduced the perceived effort recorded after the match, likely reflecting a reduced intensity during the latter stages of a match. Second, the time between matches appeared to influence relative high-speed running distance. Taking the minimum and maximum time between matches, results suggest a 90- and 200-minute recovery period increased relative high-speed distance by 0.9 and 2.0 m·min^{-1}, respectively. Thus, competition organisers might consider maximising the recovery time as a method to increase competition intensity. Third, a win was positively associated with time spent at HMP, and despite this effect being trivial, it might suggest that actions such as accelerating, decelerating, and changing direction reflect high intensity attacking and defending styles that should be considered when developing programmes and deriving a tactical approach to match-play. Indeed, the ability to accelerate and change direction are likely to be beneficial for scoring whilst "hard" accelerations and decelerations might be important to increase line speed during defensive play. Finally, opposition ranking revealed an incremental increase in HR_{mean} and sRPE as the opposition quality increased, though this had little influence on movement characteristics (Delaney et al. 2016; Kempton and Coutts 2016; Henderson et al. 2019a).

Whilst this is the first study to examine the individual and situational factors influencing the movement characteristics and internal responses to Touch, there are several limitations worth acknowledging. First, we highlight the use of arbitrary thresholds to define high-speed distance and HMP, which has implications when comparing sex and squads. Second, several other components of successful match-play such as tactical plays or technical skills were not included in this study. We also acknowledge that the data collected in this study was from a single international tournament, and whether these findings are consistent across tournaments (e.g. World Cup) remains unknown. Finally, Touch consists of many age-groups such as juniors and masters, but this study cannot be generalised to these. Future research in Touch should seek to address these limitations to support players, coaches and practitioners in-tournament.

Conclusions

The findings of this study highlight that distance covered in the YoYo IR1 influences male and female players' movement characteristics and internal responses, whereas wellbeing, 10 m sprint times and glycolytic change of direction time were included in few models and demonstrated trivial associations. Situational factors such as sex, squad, playing position and playing day were associated with movement characteristics and internal responses, whilst factors such opposition ranking, match result, points conceded and time between matches had minimal influence overall. Collectively, these findings can support practitioners working in Touch to improve current monitoring systems and focus physical preparations with consideration for sex, squad and playing position that promote high intensity intermittent running ability. The findings can also support coaches in their tactical preparations through improved understanding of factors associated with winning, pacing profiles exhibited, and interpretation of fitness or match data.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethics

Ethics approval was granted by the Faculty of Health, Psychology and Social Care ethics committee, Manchester Metropolitan University (1187).

Author contribution

All authors were involved in the study conceptualisation and design. ND, JH and CT collected the data. ND conducted all data analyses (processing and statistical) and wrote the draft manuscript. CTh, JH and CT reviewed and edited the manuscript. All authors approved the final submission.

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References

Beaven RP, Highton JM, Thorpe MC, Knott EV, Twist C. 2014. Movement and physiological demands of international and regional men's touch rugby matches. J Strength Cond Res. 28(11):3274–3279. doi:10.1519/JSC.0000000000000535.

Chow CCG. 2020. Global positioning system activity profile in touch rugby: does training meet the match-play intensity in a two-day international test match series? J Sport Sci Med. 19:613–619.

Dalton-Barron N, Palczewska A, McLaren SJ, Rennie G, Beggs C, Roe G, Jones B. 2021. A league-wide investigation into variability of rugby league match running from 322 super league matches. Sci Med Footb. 5(3):225–233. doi:10.1080/24733938.2020.1844907.

Delaney JA, Thornton HR, Duthie GM, Dascombe BJ. 2016. Factors that influence running intensity in interchange players in professional rugby league. Int J Sports Physiol Perform. 11(8):1047–1052. doi:10.1123/ijspp.2015-0559.

Deprez D, Coutts AJ, Lenoir M, Fransen J, Pion J, Philippaerts R, Vaeyens R. 2014. Reliability and validity of the Yo-Yo intermittent recovery test level 1 in youth soccer players. J Sports Sci. 32(1):903–910. doi:10.1080/02640414.2013.876088.

Dobbin N, Hunwicks R, Highton J, Twist C. 2018. A reliable testing battery for assessing physical qualities of elite academy rugby league players. J Strength Cond Res. 32(11):3232–3238. doi:10.1519/JSC.0000000000002280.

Dobbin N, Thorpe C, Highton J, Twist C. 2020. Sex-related changes in physical performance, wellbeing, and neuromuscular function of elite touch players during a 4-day international tournament. Int J Sports Physiol Perform. 15(8):1138–1146. doi:10.1123/ijspp.2019-0594.

Federation of International Touch. 2010. Evolution of the sport touch Accessed 06 02 2022. https://www.internationaltouch.org/about-fit/history/evolution-of-touch/

Fitzpatrick JF, Hicks KM, Russell M, Hayes PR. 2019. The reliability of potential fatigue-monitoring measures in elite youth soccer players. J Strength Cond Res. doi:10.1519/JSC.0000000000003317.

Foster C, Florhaug JA, Franklin J, Gottschall L, Hrovatin LA, Parker S, Doleshal P, Dodge C. 2001. A new approach to monitoring exercise training. J Strength Cond Res. 15(1):109–115.

Gabbett TJ, Nassis GP, Oetter E, Pretorius J, Johnston N, Medina D, Rodas G, Myslinski T, Howells D, Beard A. 2017. The athlete monitoring cycle: a practical guide to interpreting and applying training monitoring data. Br J Sports Med. 51(20):1451–1452. doi:10.1136/bjsports-2016-097298.

Henderson MJ, Fransen J, McGrath JJ, Harries SK, Poulos N, Coutts AJ. 2019a. Situational factors affecting rugby sevens match performance. Sci Med Footb. 3(4):275–280. doi:10.1080/24733938.2019.1609070.

Henderson MJ, Fransen J, McGrath JJ, Harries SK, Poulos N, Coutts AJ. 2019b. Individual factors affecting rugby sevens match performance. Int J Sports Physiol Perform. 14(5):620–626. doi:10.1123/ijspp.2018-0133.

Hogarth LW, Burkett BJ, McKean MR. 2015. Influence of Yo-Yo IR2 scores on internal and external workloads and fatigue response of tag football players during tournament competition. PloS One. 10(10):e0140547. doi:10.1371/journal.pone.0140547.

Hopkins WG, Marshall SW, Batterham AM, Hanin J. 2009. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 41(1):3–13. doi:10.1249/MSS.Ob013e31818cb278.

Kempton T, Coutts AJ. 2016. Factors affecting exercise intensity in professional rugby league match-play. J Sci Med Sport. 19(6):504–508. doi:10.1016/j.jsams.2015.06.008.

Krustrup P, Mohr M, Amstrup T, et al. 2003. The yo-yo intermittent recovery test: physiological response, reliability, and validity. Med Sci Sports Exerc. 35(4):697–705. doi:10.1249/01.MSS.0000058441.94520.32.

Lovell TWJ, Bocking CJ, Fransen J, Kempton T, Coutts AJ. 2017. Factors affecting physical match activity and skill involvement in youth soccer. Sci Med Footb. 2(1):58–65. doi:10.1080/24733938.2017.1395062.

Marsh N, Dobbin N, Twist C, Curtis C. 2017. Estimates of energy intake and expenditure in elite female touch players during an international tournament. Int J Sport Nutr Exerc Metab. 27(6):499–506. doi:10.1123/ijsnem.2017-0082.

O'Connor D. 1992. Glycolytic agility for rugby league and touch. Sports Coach. 15(4):8–12.

Rosnow RL, Rosenthal R, Rubin DB. 2000. Contrasts and correlations in effect-size estimation. Psychol Sci. 11(6):446–453. doi:10.1111/1467-9280.00287.

Schmitz B, Pfeifer C, Kreitz K, Borowski M, Faldum A, Brand S-F. 2018. The yo-yo intermittent tests: a systematic review and structured compendium of test results. Front Physiol. 9:870. doi:10.3389/fphys.2018.00870.

Shergill AS, Twist C, Highton J. 2021. Importance of GNSS data quality assessment with novel control criteria in professional soccer match-play. Int J Perf Anal Sport. 21(5):820–830.

Vickery W, Harkness A. 2017. Physical, physiological and perceptual match demands of amateur mixed gender touch players. J Sports Sci Med. 16 (4):589–594.

Waldron M, Highton J. 2014. Fatigue and pacing in high-intensity intermittent team sport: an update. Sports Med. 44(12):1645–1658. doi:10.1007/s40279-014-0230-6.

Watson A, Brickson S, Brooks A, Dunn W. 2017. Subjective well-being and training loads predict in-season injury and illness risk in female youth soccer players. Br J Sports Med. 51(3):194–199. doi:10.1136/bjsports-2016-096584.