Title: Using microtechnology to quantify torso angle during match-play in field hockey

Brief Running Head: Torso Angles in Field Hockey Match-Play

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ABSTRACT

Field hockey is played in a dynamic environment placing specific postural demands on athletes. Little research has been devoted to understanding the nature of player torso postures in field hockey match-play and its relationship with the perceptuomotor demands of the sport. We used commercially-available, microtechnology worn by sixteen athletes during a six-match national tournament to quantify torso flexion/extension angles. Orientation was derived using the inertial and magnetic sensors housed within Global Positioning System (GPS) devices, assessing torso angle in the sagittal plane from ninety-one individual match files. The main independent variable was playing position, while the dependent variable was torso flexion/extension, presented as a percentage of playing time spent in 15 × 10° torso postural bands ranging from ≥ 40° extension to ≥ 90° flexion. It was shown that these athletes spent 89.26% of their playing time in various torso postures, ranging from 20° to 90° of flexion. Defenders spent more time than Midfielders ($p=0.004$, ES=0.43) and Strikers ($p=0.004$; ES=0.44) in the posture-band of 10-20° torso flexion. While Midfielders spent more time between 20-30° of torso flexion ($p=0.05$; ES=0.32) than Strikers. Conversely, Strikers spent more time between 30-40° of flexion than Defenders ($p< 0.001$; ES=0.74). These results reflect the sport-specific and role-specific torso angles adopted by field hockey athletes during match-play. Coaching staff can use these data to gain insight into the postural demands of their sport and inform the preparation of athletes for the perception-action demands of competition.

Keywords: Global Positioning System, GPS, Inertial Measurement Unit, IMU, Team Sport, Torso Postural Demand

INTRODUCTION

Field hockey is played in a dynamic environment that places considerable demands on the perceptuomotor skills of participants. The nature of field hockey is such that teammates, opposition players and the ball are in almost constant motion through a complete 360° playing environment. This presents a range of competing opportunities that the athlete must consider in the guidance of their next course of action. Performing co-ordinated action in such dynamic environments demands that an individual continually gathers key information to guide the prospective control of movement (14, 32). A clearer understanding of the postural demands placed on field hockey athletes whilst performing sports-specific skills will inform coaching and sports science staff on how posture influences perception and action. Specifically, this knowledge would allow development of improved training drills and small-sided games that are representative of match-play and enhance development of the perceptuomotor skills necessary for competition.

Whilst there are multiple models that describe how individuals access and use information from their environment for the execution of sport skills (33), here we have adopted an ecological approach. In his earlier seminal research, Gibson (12) defined the opportunities for action in the surrounding environment as affordances. Subsequent investigations have further developed this concept, and define an affordance as a dynamic relationship that describes the opportunities for action available to an individual as a function of the capabilities of the performer and the features of the surrounding environment (8). For example, an athlete may perceive a gap between opposing players inviting a pass to a teammate (a feature of the current environment). If that individual can strike the ball such that it will pass though that gap to be received by the teammate (a capability of both performers), it is a currently available affordance. However, if the athlete cannot hit the ball, either because they can’t move it into position to hit or are perhaps too fatigued to impart enough speed on the ball to pass between the opposition, then it is not a currently available affordance. From an ecological perspective, movements performed to acquire perceptual information about the available affordances is an active process termed exploration (10, 13, 14, 27). In addition to allowing the performance of goal-directed actions (like the pass described above), manipulating the orientation of body segments enables the performance of exploratory actions. Specifically, the orientation and movements of the head and torso, in isolation or in synergy, enables the individual to manipulate their visual field altering their perception of the playing environment (14). Exploratory movements like these (along with their associated postures) are fundamental to success in both individual and team sport performance. Research has shown that these movements enable the athlete to gather information from the dynamic playing environment, providing the necessary aspects of the available affordances, and guiding prospective control of future goal-directed action (11, 23, 24).

Research examining exploratory behaviour in infants suggests that adopting a more upright posture of the head and torso is biomechanically advantageous for identifying opportunities for action and encourages visual exploration by allowing a greater range of motion through the neck and torso (31). Furthermore, investigations conducted in military personnel suggest that perceptuomotor performance is constrained by the postures adopted by the head and torso (19, 25). Pertinent to the current investigation, it was shown that a soldier’s visual perceptual field - termed *field-of-regard* - is reduced when their head and torso was oriented downward in the performance of a landing task, limiting their ability to identify targets in the environment (19). If we extrapolate these findings from research on military marksman and infant development to the execution of sports skills, it can be inferred that an individual’s head and torso posture during the performance of a task, influences their ability to explore and/or perform in the environment. Specifically, a more extended, upright torso with little or no forward flexion, results in a field-of-regard that is more optimal for visual exploration. On the other hand, an increase in spinal or hip flexion, will move the field-of-regard down to what is happening on the ground in front of the player. Unlike other invasion sports that are played in a (mainly) upright posture (such as football/soccer and netball) field hockey athletes must control the ball with a hockey stick. This task of maintaining possession places considerable postural constraints on the head and torso of these athletes leading to a substantial increase in physiological demand (28). Hence, further manipulation of the head and torso is limited and will likely influence an athlete's ability to explore and thereby limit their awareness of the changing landscape of available affordances.

It needs to be noted that generally the actual time spent in possession of the ball is relatively small compared to the total amount of playing time. For instance, in football it has been established that, on average, players are in ball-possession for less than 1% of the overall playing time (5). It is likely that in field hockey, players' ball-possession times are also relatively low. Given the importance of gaining possession in team ball sports as well as the decisions made when players are in possession, it is important to establish the time spent in torso-flexion. Further, deeper understanding of the time periods spent in torso-flexion might elucidate the potential impact of such postures on injury risk and inform how to better prepare players to cope with match demands (2).

The astute application of wearable microtechnology and associated analysis routines can provide insight into how field hockey athletes use their torsos to perform sport-specific skills and explore their surrounding environment. Global positioning system (GPS) technology has become ubiquitous in sporting applications over the last twenty years. Current commercially-available wearable microtechnology devices are generally held in-situ between the scapulae of the athlete housed in a tight-fitting lycra vest and include micro-electromechanical systems (MEMS) technologies that are triaxial accelerometers, gyroscopes and magnetometers identical to those contained in Inertial Measurement Units (IMU's). In a team sports context, this wearable microtechnology has been used to quantify the physiological demands associated with field hockey (16, 26). While the analysis of these inertial and magnetic data captured by the IMU sensors have enabled researchers to quantify the performance of sports-specific skills (1, 7) as well as the orientation and heading of the sensor (6). Work conducted by McGuckian, et al. (24) successfully used IMU sensors to collect ecologically valid inertial data to quantify head movements and orientations during match-play and training sessions in football players. However, despite the presence of an equivalent technology to IMU's, and its location on the torso of the athlete, comparatively little work has been published using the inertial and magnetic data collected by wearable microtechnology to quantify an athlete's torso orientation (4).

To gain insight into the perceptuomotor demands experienced by field hockey players, the purpose of the current investigation was to quantify the specific torso flexion/extension angles adopted by field hockey players, across different positional groups, and determine the time spent in this orientation during match-play. As torso flexion influences the field-of-regard (19), the first aim was to quantify the playing time of field hockey athletes and establish the range of torso postures (torso angle in the sagittal plane) adopted during match-play. Our second aim was to determine the distribution of playing time that players spent with their torsos in different degrees of flexion. The third aim was to investigate the influence that playing position had on this distribution. It was hypothesised that hockey players would exhibit a range of torso angles, but that the amount of time that they spend in different torso postures would be influenced by differences in their playing positions.

METHODS

Experimental Approach to the problem.

This observational study used data collected via commercially-available wearable microtechnology devices to examine torso postural demands in elite, male field hockey athletes. A repeated measures design was used, with data gathered during six matches played within a nine-day national level tournament. The participants were grouped by playing position with six defenders, five midfielders and five strikers. From the possible ninety-six individual match files collected across the tournament, five were excluded due to either technology failure or the player being permanently replaced for that match, leaving ninety-one files for inclusion in the analysis. Torso flexion in the sagittal plane was derived using the inertial and magnetic sensors housed within the GPS devices. The main independent variable was playing position, while the dependent variable was torso postural demands measured as a percentage of playing time spent in 15 × 10° torso postural bands ranging from ≥ 40° torso extension to ≥ 90° torso flexion.

Subjects.

Sixteen elite, male field hockey players (age: 24.6 ± 5.2 yrs; mass: 79.7 ± 9.1 kg; stature: 180.4 ± 6.9 cm; playing experience at this level: 2.4 ± 2.9 yrs) were recruited from a state level squad and agreed to participate in the investigation. Of the sixteen athletes participating, seven were either current, or have subsequently progressed to international competition, while a further four athletes were identified as participants in an international development squad. All participants consented to the data collection and were informed of the risks and benefits of participation. The study was conducted in accordance with the requirements of the Declaration of Helsinki and was approved by the Australian Catholic University Human Research Ethics Committee (2018-27N).

Procedures.

Data Capture:

During match-play, players wore individually assigned commercially-available microtechnology devices (MinimaxX S4 (13 units) or OptimEye S5 (3 units), Catapult Innovations, Melbourne, Australia) held in place between the athlete's scapulae in a manufacturer supplied vest. The use of two different GPS devices was unavoidable and driven by unit availability at the time. Investigation of the raw data collected by each of the device types revealed no differences in the variables examined. Each device contained a GPS chip sampling at 10Hz, as well as a triaxial accelerometer, gyroscope and magnetometer with sensing axes mutually orthogonally mounted and sampling at 100Hz. Raw location, inertial and magnetic data were downloaded from the devices for subsequent analysis. Video footage of matches was captured from behind the goal at one end of the pitch using an elevated, tripod-mounted camera (Canon XA30, Canon, Australia).

Data Reduction:

Individual player files were initially examined using manufacturer-supplied software (Sprint ver. 5.1.7, Catapult Innovations, Melbourne, Australia) to identify instances where the athlete was either permanently replaced for the match and/or data were missing due to technology failure. This software was also used in conjunction with the video footage to identify and mark the quarters of play during matches. The horizontal dilution of precision

(HDOP) parameter was used to determine the accuracy of the GPS horizontal positional signal (21), and any specific regions of the collected data files that corresponded with a HDOP variable >1.25 were excluded from the analysis due to the poor accuracy and reliability of the GPS positional data (22). This resulted in the exclusion of 1.1% of the playing time data collected across the tournament. The match analyses included all data that; i) were collected during the identified quarters of the match; ii) corresponded with a HDOP value of ≤1.25; and iii) came from a participant who was located within the field of play.

Data Analysis:

The accelerometry (forward/backward, up/down, sideways), gyroscopic (Gyr1, Gyr2, Gyr3), magnetometer (Mag Fwd, Mag Left, Mag Up) and HDOP data, along with the GPS latitude and longitude channels, were exported into Microsoft Excel (Microsoft, USA). Data were then imported into a custom-written MATLAB (Mathworks, MA, USA) script that incorporated an open source Attitude and Heading Reference System (AHRS) algorithm described by Madgwick, et al. (20). The AHRS algorithm mathematically fused the inertial and magnetic sensor data output from the microtechnology device and calculated its orientation in the sagittal plane with respect to a global reference frame and the Earth's magnetic field. This AHRS algorithm is accurate in dynamic situations, with a maximal root mean square (RMS) error of <1.7° when contrasted to optoelectronic motion capture (20) and has been applied successfully in numerous dynamic applications to accurately quantify sensor orientation, as well as distances covered, velocities and trajectories in both engineering (17) and sporting applications (29, 30). With the sensor positioned between the scapulae of the athlete, establishing its orientation in this fashion provides a valid measure of the thoracic torso posture (3, 4). For ease of presentation, torso angle was grouped into 15 bands; 13 of which spanned 10° of torso flexion/extension with 0° established when the device was orientated perfectly upright. While the first band included all torso angles ≥40° of torso extension, and the last band represented all torso angles ≥ 90° of torso flexion. (see Figure 1). The boundaries of the playing surfaces used during the tournament were established using the latitude and longitude information for each corner of the pitch. To enable comparisons of any differences across the playing surface, four individual zones of the playing surface were established using the latitude and longitude of each intersection of the 23-metre lines and the half-way line with the sidelines.

The outcome measures produced by the analysis routine included total playing minutes for the tournament and individual matches, and the amount of playing time each athlete spent in each of the torso angles in the sagittal plane (torso postural band) during match-play. To enable comparison between athletes who spent different amounts of time in play, the amount of playing time spent in each torso postural bands was expressed as a percentage of total playing time.

Insert Figure 1 about here.

Statistical Analyses:

To examine any differences between playing positions with respect to mean match playing time during the tournament (mins), a linear mixed model with an autoregressive first order (AR1) covariance structure and a fixed factor of playing position (3 levels) was employed. Likewise, to examine differences in percentage playing time spent in each torso postural band during a match (15 levels) between the different playing position groups (3 levels) and, the four identified zones of the playing surface (4 levels), a liner mixed model with an AR1 covariance structure was used. Where significant main effects or interactions were identified, post-hoc comparisons with Bonferroni corrections were conducted. To examine the meaningfulness of any differences presented, Cohen's d was reported as a measure of the effect size (ES). An ES of <0.41 was reported as small, 0.41-0.70 as moderate and >0.70 as large (9). All analyses were performed using SPSS (version 25, IBM, Armonk, NY) with statistical significance accepted at an alpha level of <0.05.

RESULTS

Playing Time and the Influence of Playing Position:

A description of the total playing time accumulated across the tournament, along with the minutes played per match for each playing position is presented in Table 1. Comparisons between each of the playing positions revealed no statistically significant differences ($F=2.58$, $p=0.106$) in the mean minutes played per match across the tournament.

Insert Table 1 about here.

Torso Angle:

An analysis of the postural data revealed that the mean torso angle adopted during match-play was 44.6° ± 23.7°. A comparison across the three playing positions highlighted little difference. During match-play, Defenders adopted a mean torso angle of 43.5° ± 24.2°, while Midfielders and Strikers displayed 44.2° ± 22.7° and 46.4° ± 23.8°, respectively. Figure 2 illustrates the percentage of playing time spent in the torso postural bands for all participants. A statistically significant effect was observed for postural band on the percentage of playing time ($F=101.41$, $p<0.001$). Table 2 displays the mean differences in percentage playing time spent in each of the measured torso postural bands for all participants and highlights the many differences between time spent in the various postural bands. The data presented illustrate that participants spent approximately 89% of their playing time in postures ranging from 20° to 90° of torso flexion.

Insert Figure 2 about here.

Insert Table 2 about here.

The distribution of percentage playing time across the torso postural bands for different playing positions is illustrated in Figure 3. There was a significant interaction identified between postural band and playing position ($F=1.70$, $p=0.015$). Post-hoc comparisons revealed significant differences in the '10° to 20°', '20° to 30°' and '30° to 40°' torso postural bands between the three positional groups. It was found that Defenders spent 6.2% more playing time in the '10° to 20°' postural band than Midfielders ($p=0.004$; ES=0.43) and 6.3% more time than Strikers ($p=0.004$; ES=0.44). While in the '20° to 30°' postural band, it was found that Midfielders spent 4.5% more playing time in the than Strikers ($p=0.05$; ES=0.32). In contrast, Strikers were shown to spend 8.8% more playing time than Defenders ($p<0.001$; ES=0.74) in the '30° to 40°' postural band. No significant differences were identified in the percentage playing time spent in each of the torso postural bands across the identified zones of the playing surface (F=0.086, p=1.00).

Insert Figure 3 about here.

DISCUSSION

The purpose of this study was to quantify the torso flexion/extension angles adopted by field hockey athletes during match-play and to establish the influence of playing position on these postures. It was shown that, although players exhibit a wide range of torso angles in the sagittal plane, they spend most of their playing time (89.26%) in postures requiring between 20° and 90° of torso flexion; with postures of between 30° to 40° and 40° to 50°of torso flexion most prevalent (26.39% and 26.28% respectively). Furthermore, differences exist in the distribution of playing time across torso postures dependent upon the playing position of the athlete. Clearly, field hockey players need to be capable of performing across a range of torso postures over the course of a game. The method of analysis presented here allows coaches and support staff to design drills and small sided games that more closely replicate the match demands placed on these athletes.

As an upright posture (0° to 20° torso flexion) orients vision and the field-of-regard to the horizon, these postures are likely related to off-the-ball activity in field hockey, such as running without possession and visual exploration of the playing environment. In contrast, larger torso angles which orient the field-of-regard towards the ground are more likely related to on-ball activities, such as controlling the ball, passing, trapping and tackling (28). The distribution of playing time illustrated in Figure 2 is a function of the time spent performing on- and off-ball tasks and the competing perceptuomotor demands presented to field hockey athletes during match-play. This finding suggests that field hockey athletes spend a significant amount of their playing time in postures that enable the performance of sport-specific skills, such as moving with and controlling the ball, but are likely to reduce their capacity to re-orientate their field of regard to the horizon and, hence, compromise exploration of the playing environment. Using the inertial and magnetic data available from microtechnology devices, future research will be able to establish an ecologically valid measure of the torso posture of athletes whilst they are performing specific tasks in-situ. Henceforth, with a clearer understanding of the skill-specific torso postural demands, researchers can investigate the impact that the performance of these goal-directed tasks has on the equally critical task of visual exploration of the playing environment.

Additionally, the results of this study also highlight that the playing position, or role that an athlete performs in the team influences the torso postures adopted. It is hypothesised that the differences observed between Strikers, Midfielders and Defenders with respect to playing time spent in postures between 10° to 40° of torso flexion is the direct result of the role-specific tasks being performed by these athletes, and the associated competing affordances presented to them. As participants in a high-intensity, intermittent sport, field hockey athletes need to cover ground quickly (15, 26) and may adopt more upright torso postures to do this efficiently. Additionally, due to the 360° nature of the game, they are required to visually explore the playing environment, and more upright postures are suggested to maximise their ability to move the head and torso to orient their visual field to the horizon-line. Further to the tasks of locomotion and visual exploration, field hockey athletes must use a hockey stick to control the ball, which is commonly on the ground. As such, players may be required to adopt more stooped postures to perform these tasks (28). Previous work has highlighted positional differences in the match demands experienced by field hockey players (15, 18, 26). These studies typically show that Defenders cover less total distance than other positions, with Midfielders and Strikers covering more high-speed distance, and generally having a greater playing intensity. As such, it is unsurprising that we have seen positional differences in torso postures adopted by players. However, perhaps the smaller differences seen in postural demands here compared to movement demands reflects a similarity in the specific involvements during match-play or an even spread of possession between positional groups in this tournament data.

It is expected that external factors, such as team tactics, quality of the opposition, progression of the match (i.e. accumulated fatigue) and score-line may all influence the torso angles adopted by players during match-play. An examination of these possible interactions is outside the scope of this initial study, but nonetheless present opportunities for future investigations. Further, the analysis routine used here assessed torso postures in the sagittal plane only. However, use of inertial and magnetic data with this method of analysis could equally be applied to the examination of postures and/or movement in both the coronal (lateral flexion) and transverse (rotation) planes. While beyond the scope of the current study, this provides another avenue for future research to create an ecologically valid three-dimensional representation of the torso postural demands placed on field hockey athletes during match-play. In the context of examining visual exploratory behaviours in team sport athletes, movements of the head must also be considered (23, 24). Further investigations are now able to use inertial sensors and apply this method of analysis to quantify the movements and postures of the head associated with the performance of sports-specific skills. This would allow for a more complete picture of the perceptuomotor demands associated with the performance of these tasks.

PRACTICAL APPLICATIONS

Wearable microtechnology has long been used to monitor player movements in team sports. Now this study shows that practitioners can use the inertial and magnetic data collected by microtechnology devices to also determine the torso postural demands of match-play and/or training. Field hockey players spend the majority of a game in a substantially flexed torso position. As such, training practices should reflect this with technical-tactical training reflecting the distribution and volume of torso flexion shown in this study. Physical conditioning focusing on trunk strength, including lumbo-pelvic control, and strength and mobility of the posterior chain muscles and spine is vital. This should be the case for all outfield positions.

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Figure Captions:

Figure 1: Torso postural bands established in 10° allotments. Zero set in the upright position.

Figure 2: Distribution of the playing time spent in each postural band during a match for all participants across the tournament. Note: The inset figures illustrate the range of torso postures bounded by the dotted lines.

Figure 3: Distribution of the playing time spent in each torso postural band during a match for the three playing position groups. * Significant difference between Defenders, Midfielders and Strikers, $p<0.05$. ** Significant difference between Midfielders and Strikers, $p\leq0.05$. *** Significant difference between Strikers and Defenders, $p<0.05$. Note: The inset figures illustrate the range of torso postures bounded by the dotted lines.

Tables:

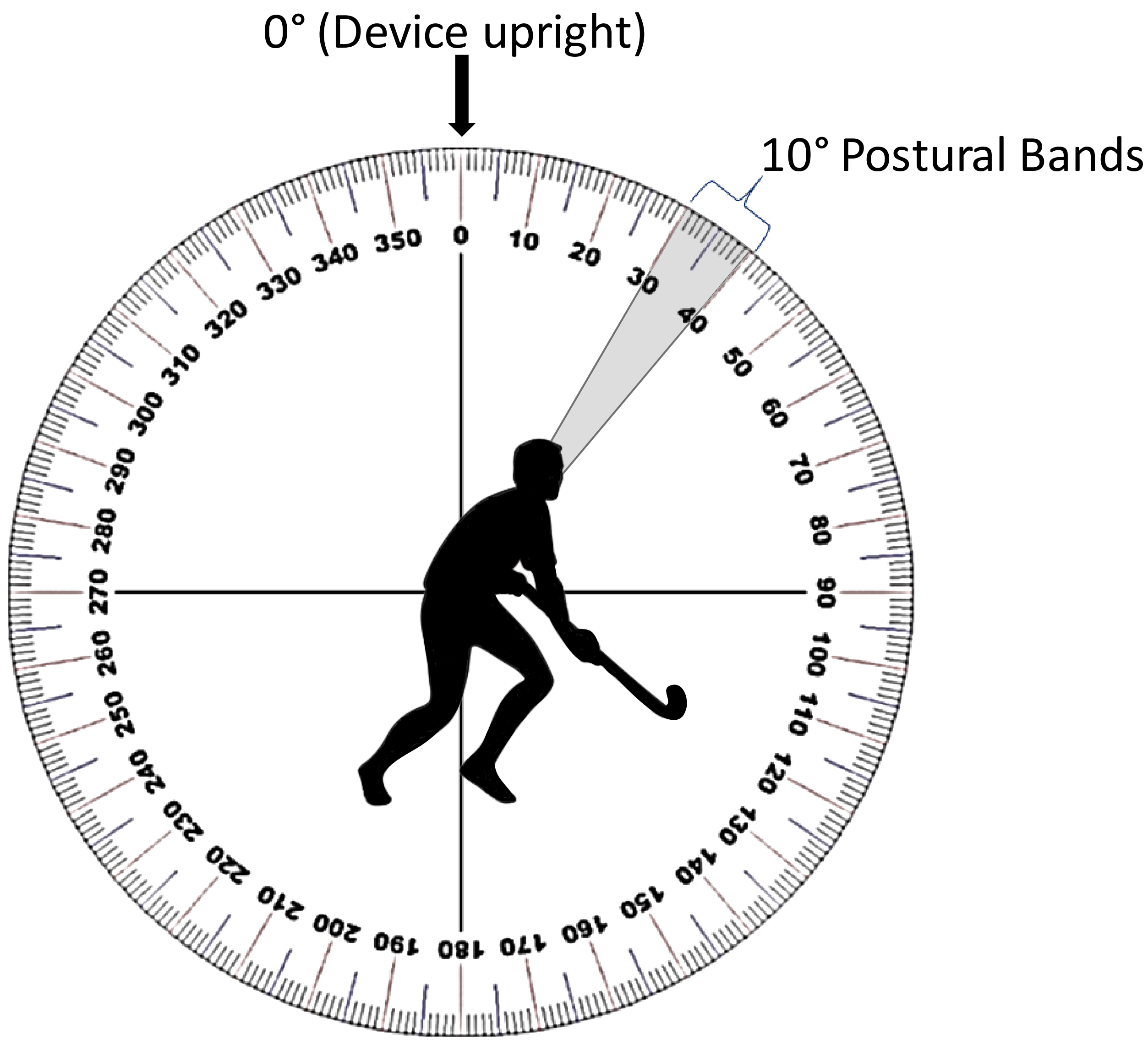
Table 1: Accumulated playing times (mins) for the tournament and mean for each match categorised by playing position.

Playing position	Accumulated playing time (mins)	Average playing time/player in a match (mins)
Defenders (n=6)	1538.17	45.24 ± 7.96
Midfielders (n=5)	1221.16	40.71 ± 5.93
Strikers (n=5)	1104.76	40.91 ± 8.20

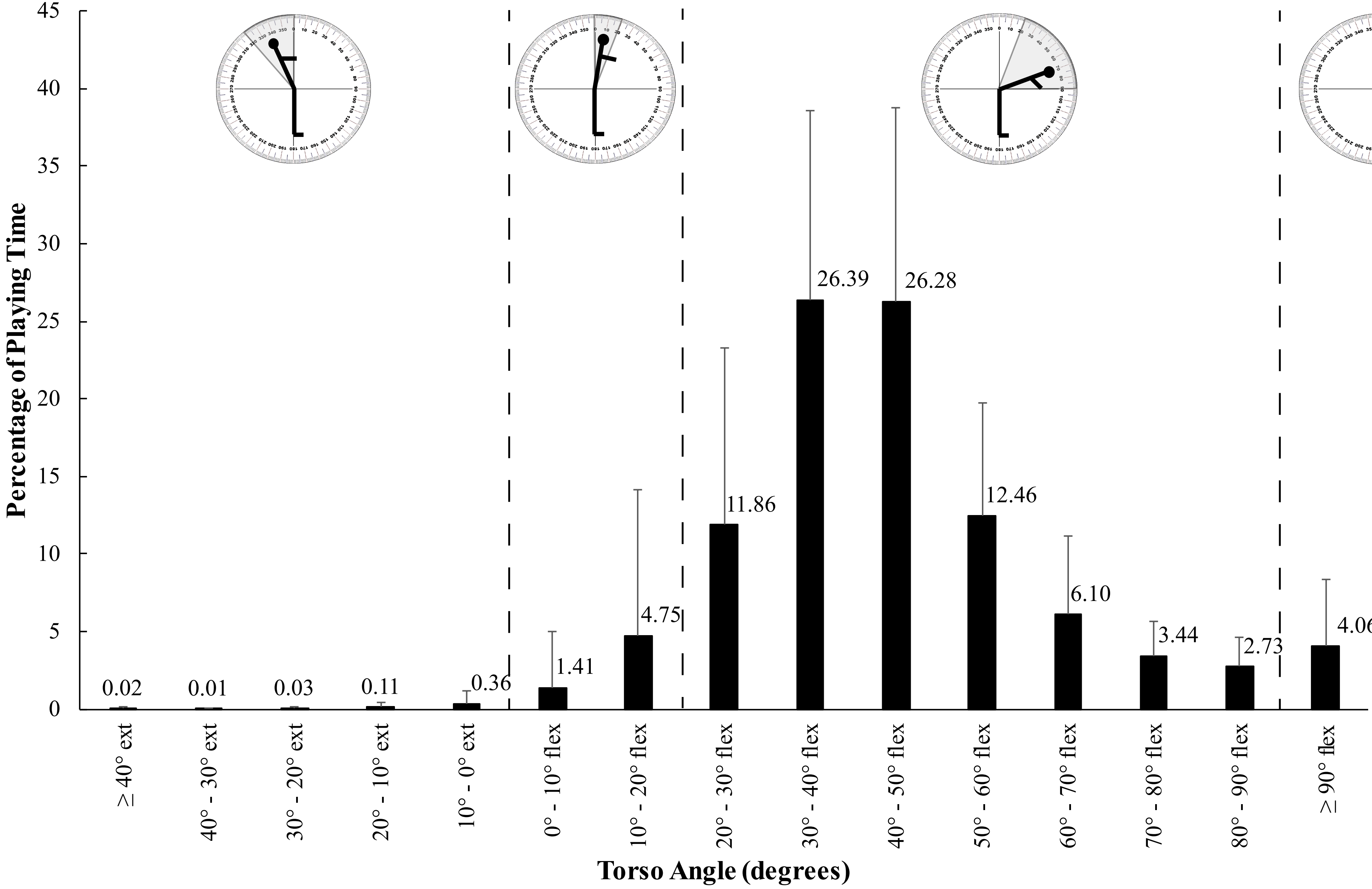
Table 2: Mean differences in the aggregate percentage playing time/match spent in each of the torso postural bands for all participants.

Torso Postural Band	Torso Postural Band														
	≥ 40° ext	**40° - 30° ext**	**30° - 20° ext**	**20° - 10° ext**	**10° - 0° ext**	**0° - 10° flex**	**10° - 20° flex**	**20° - 30° flex**	**30° - 40° flex**	**40° - 50° flex**	**50° - 60° flex**	**60° - 70° flex**	**70° - 80° flex**	**80° - 90° flex**	**≥ 90° flex**
≥ 40° ext		-0.02	0.01	0.09	0.33	1.38	4.72*	11.84*	26.37*	26.26*	12.44*	6.08*	3.42	2.70	4.04*
40° - 30° ext			0.02	0.11	0.35	1.40	4.74*	11.85*	26.39*	26.28*	12.46*	6.09*	3.44	2.72	4.05*
30° - 20° ext				0.08	0.32	1.38	4.71*	11.83*	26.36*	26.25*	12.43*	6.07*	3.41	2.70	4.03*
20° - 10° ext					0.24	1.29	4.63*	11.75*	26.28*	26.17*	12.35*	5.99*	3.33	2.62	3.95*
10° - 0° ext						1.05	4.39*	11.50*	26.04*	25.93*	12.11*	5.74*	3.09	2.37	3.70
0° - 10° flex							3.34	10.45*	24.99*	24.88*	11.06*	4.69*	2.04	1.32	2.65
10° - 20° flex								7.11*	21.65*	21.54*	7.72*	1.35	-1.30	-2.02	-0.69
20° - 30° flex									14.53*	14.42*	0.60	-5.76*	-8.42*	-9.13*	-7.80*
30° - 40° flex										-0.11	-13.93*	-20.29*	-22.95*	-23.66*	-22.33*
40° - 50° flex											-13.82*	-20.18*	-22.84*	-23.55*	-22.22*
50° - 60° flex												-6.36*	-9.02*	-9.73*	-8.40*
60° - 70° flex													-2.66	-3.37	-2.04
70° - 80° flex														-0.71	0.62
80° - 90° flex															1.33
≥ 90° flex															

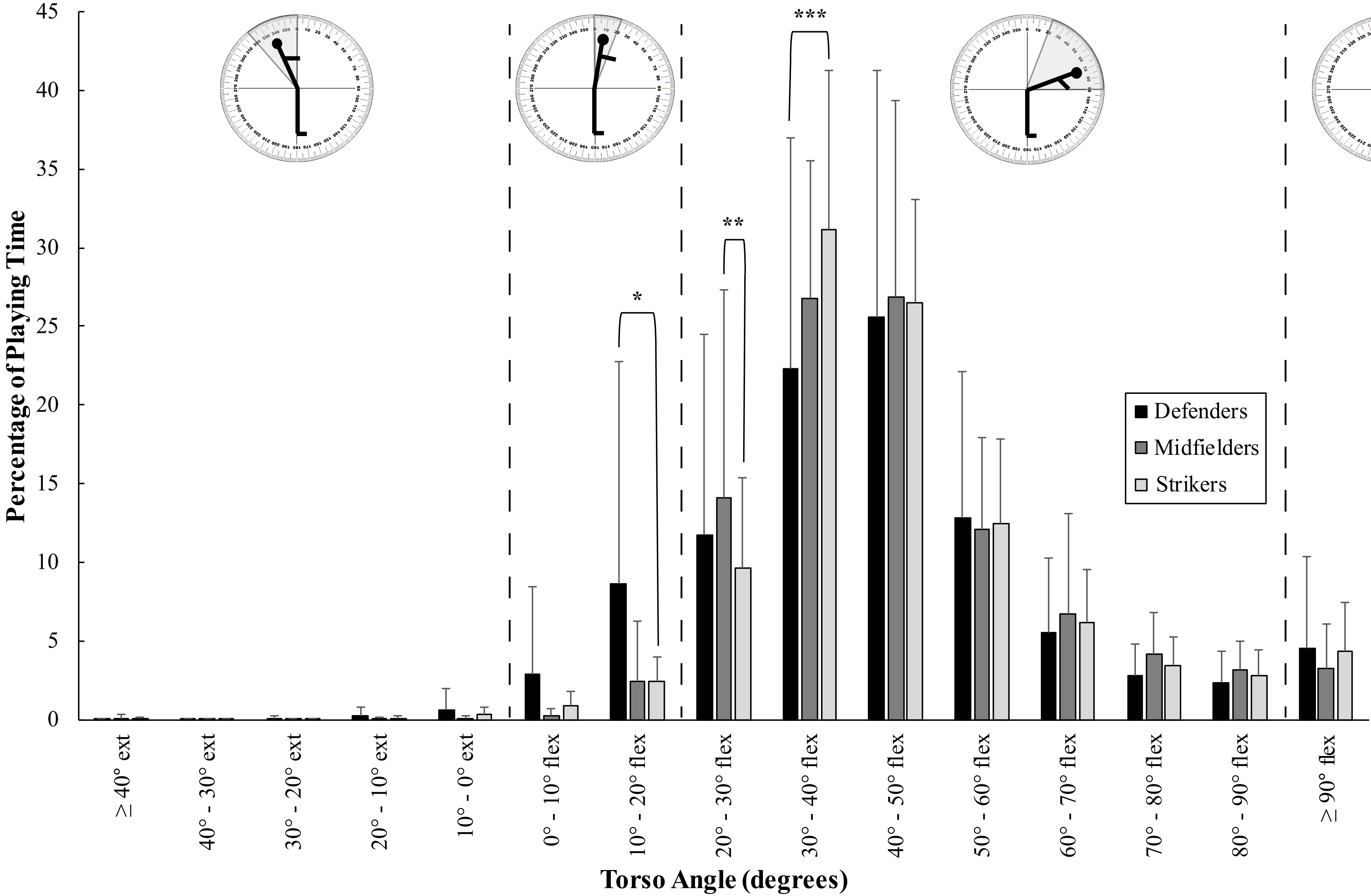
Notes: *Significant difference, $p<0.05$. Effect Size: Small ; moderate ; large .



0° (Device upright)
10° Postural Bands
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350



Percentage of Playing Time
Torso Angle (degrees)
45
40
35
30
25
20
15
10
5
0
0.02
0.01
0.03
0.11
0.36
1.41
4.75
11.86
26.39
26.28
12.46
6.10
3.44
2.73
4.06
≥ 40° ext
40° - 30° ext
30° - 20° ext
20° - 10° ext
10° - 0° ext
0° - 10° flex
10° - 20° flex
20° - 30° flex
30° - 40° flex
40° - 50° flex
50° - 60° flex
60° - 70° flex
70° - 80° flex
80° - 90° flex
≥ 90° flex



Percentage of Playing Time
45
40
35
30
25
20
15
10
5
0
*
**
***
Defenders
Midfielders
Strikers
≥ 40° ext
40° - 30° ext
30° - 20° ext
20° - 10° ext
10° - 0° ext
0° - 10° flex
10° - 20° flex
20° - 30° flex
30° - 40° flex
40° - 50° flex
50° - 60° flex
60° - 70° flex
70° - 80° flex
80° - 90° flex
≥ 90° flex
Torso Angle (degrees)