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**Abstract:**

International female team handball is a physically demanding sport and is intermittent in nature. The aim of the study was to profile high intensity events (HIE) in international female team handball matches, with regards to playing positions. **Methods:** Twenty female national team handball players were equipped with inertial movement units (OptimEye S5, Catapult Sports, Australia) in 9 official international matches. Players were categorized in four different playing positions: backs, wings, pivots, and goalkeepers (GK). Player Load™, accelerations (Acc), changes of direction (CoD), decelerations (Dec), and the sum of the latter three, HIE, were extracted from data raw-files, using the manufacture’s software. All Acc, Dec, CoD, and HIE >2.5 m·s<sup>-1</sup> were included. Data were log-transformed and differences were standardized for interpretation of magnitudes and reported with effect size (ES) statistic. **Results:** Mean number of events was  $0.7 \pm 0.4$  Acc·min<sup>-1</sup>,  $2.3 \pm 0.9$  Dec·min<sup>-1</sup>, and  $1.0 \pm 0.4$  CoD·min<sup>-1</sup>. Substantial differences between playing positions, ranging from small to very large, were found in the three parameters. Backs showed a most likely greater frequency for HIE·min<sup>-1</sup> ( $5.0 \pm 1.1$  HIE·min<sup>-1</sup>), than all other playing positions. Differences between playing positions was also apparent in Player Load·min<sup>-1</sup>. **Conclusion:** The present study shows that HIE in international female team handball are position specific, and that the overall intensity is dependent on the positional role within a team. Specific HIE and intensity profiles from match play provide useful information for a better understanding of the overall game demands and for each playing position.

**Keywords:** accelerometry, inertial movement units, team sport, physical demands

## Introduction

Performance in team handball is determined by many different factors, such as the players technical, tactical, psychological/social and physical characteristics<sup>1</sup>. In team handball, as in other team sports, a high level of physical conditioning is required for elite players to be able to exploit their technical and tactical qualities for the duration of an entire game<sup>2,3</sup>. Knowledge of the working demands in any type of sport is essential for many reasons. Firstly, understanding the physical demands of a sport is a precondition for the planning and execution of optimal training. Furthermore, it is relevant to examine to what extent differences exist in the physical demands imposed by various playing positions. In case of such differences, physical training should be organized in a more individualized manner, rather than providing a uniform type of training for all players regardless of playing position<sup>4</sup>.

The average running pace in male team handball is between  $53 \pm 7 \text{ m}\cdot\text{min}^{-1}$  and  $96 \pm 8 \text{ m}\cdot\text{min}^{-1}$ <sup>5-7</sup> which is low in comparison to other team sports such as basketball ( $115 \pm 9 \text{ m}\cdot\text{min}^{-1}$ )<sup>8</sup> or soccer ( $123\text{-}135 \text{ m}\cdot\text{min}^{-1}$ )<sup>9</sup>. Female team handball players are reported to cover a greater total distance per match when compared to male players, with an average running pace of  $77.8 - 79.6 \text{ m}\cdot\text{min}^{-1}$ <sup>10</sup>. Low-intensity activities, such as standing still and walking, constitutes the highest portion of playing time (34 – 81% of total playing time) in team handball<sup>5,7,10-12</sup>. It has also been shown that team handball players spend a low percentage of total playing time in high velocity locomotive actions. It has been reported that female players only spend 0.8% of total match duration in fast running and sprinting combined<sup>10,11</sup>. High intensity movements reported in the team handball literature typically refer to high running velocities, and thereby do not take into account all accelerations or high intensity actions that occur at low speed. The estimation of an athletes energy cost when accelerating during a soccer match suggest that a maximal acceleration,

although commencing from low velocity, is a high-intensity task<sup>13</sup>. However, it may not be classified as a high-intensity task, in traditional time-motion analysis. Research of soccer players show frequent maximal accelerations from low velocities during match play, suggesting a substantial underestimation of the amount of high intensity actions during a match<sup>13,14</sup>. This may hold true for team handball as well.

The development of small wearable inertial measure units (IMU) has provided new possibilities to investigate the physical demands in different team sports. The majority of commercially available GPS devices now contain IMU. These devices facilitate detailed movement analysis and provide an alternative to labor-extensive video coding. Research in many team sports has already integrated the use of IMU, such as in rugby<sup>15</sup>, and basketball<sup>16</sup>. However, there is to our knowledge, no studies that have used IMU in team handball. Therefore, the aim of this study was to investigate the position specific, high intensity events (HIE) in international female team handball matches with the use of IMU.

## **Method**

### **Subjects**

Match analysis was performed using data from twenty female national team players (mean  $\pm$  SD; age  $25 \pm 3.8$  y, stature  $175.3 \pm 4.5$  cm) competing in nine international matches. The nine matches were a part of the Golden League tournament (2014/2015 season), which is a series of three four-nation tournaments over one season. The team experienced four losses and five wins during the nine matches, with a mean goal difference of  $5.2 \pm 3.7$ . The analyzed players were each represented 2-9 times ( $4.9 \pm 2.8$ ), resulting in 97 match data samples. Players participated voluntarily, and the Norwegian Social Science Data Service approved data storage.

Players were divided into one of four playing positions; Back (left back, center back, and right back pooled together), wing (left wing and right wing pooled together), pivot and goalkeeper (GK). Some players rotate between every phase of ball possession, and thus only have on-field time in either offensive or defensive play. Players that were on field in both offence and defense are referred to as both-way players. Specialized players (e.g. only play in offence or defense) were categorized as a special player only if the specialization was consistent throughout the whole duration of the match. In the current study, there were no players specialized to the defense phase throughout the full duration of a game, and thus only specialized players in offence fulfilled this inclusion criteria. Thus, specialized players are hereby referred to as offensive players. Of the 97 match data samples collected, there were 44 backs, 25 wings, 14 pivots and 14 GK. 8 of the 44 backs were offensive players.

## Methodology

This was an observational study. Each player was equipped with an IMU (OptimEye S5, Catapult Sports, Australia). The IMU unit contains an accelerometer, gyroscope and magnetometer, all collecting data at 100 Hz. This technology allows for high frequency detection of unit orientation and direction, combining information about acceleration, deceleration, and rotation, and impact forces in an inertial movement analysis. The unit was located between the shoulder blades in a custom-made vest (Catapult Sports, Australia). The vest was located under the player's match jersey. To ensure a minimal effect on match performance, all players were familiarized with data collection procedures in training sessions prior to games. Apart from players wearing the device, the study did not intervene with any other aspect of the normal match or match preparation. The data collection was monitored in real-time using the Catapult Sprint (Version 5.1.4, Catapult Sports, 2014) software. Interchanges were manually tracked using this software to

ensure that only time spent on the field was included in the analyses. During time-outs, all players were inactivated. As interchanges were frequent and could involve several players, the interchange area was video-recorded and notes were made. Thus, uncertainties and eventual errors in interchanges and substitutions could be corrected post-match.

## Data processing

Player Load™, accelerations (Acc), changes of direction (CoD), and decelerations (Dec) were extracted from the raw-files, using the Catapult Sprint software. Briefly, Player Load™ is an accelerometer-based measurement of external physical loading of team sport athletes. Player Load™ is defined as instantaneous rate of change of acceleration divided by a scaling factor<sup>17</sup>, and is expressed as the square root of the sum of the squared instantaneous rate of change in acceleration in each of the three vectors (X, Y and Z axis) and divided by 100<sup>18</sup>. Acc, CoD, and Dec events are based on accelerometer (magnitude), gyroscope, and magnetometer (direction) data. The data were extracted from the aforementioned software. Brief summary of the processing; A Polynomial least squares fit is applied to the original acceleration data to smooth at a known frequency. This smoothed data is overlaid onto the original acceleration trace. Thereafter, the start- and end-point of each event is identified. This event is displayed as a change in velocity ( $\text{m}\cdot\text{s}^{-1}$ ) across the area of the medio-lateral and anterior-posterior acceleration. For each event the direction is calculated to display the direction of the force applied, and thus categories the events as either Acc, CoD, or Dec<sup>19</sup>. All events over  $2.5 \text{ m}\cdot\text{s}^{-1}$  were included as either an Acc, CoD, or Dec. The sum of all Acc, CoD and Dec events is referred to as HIE. All variables of interest were normalized per minute of on-field time, to minimize the variability of reporting absolute values with varying match length and individual on-field time.



Player Load<sup>TM</sup>·min<sup>-1</sup> has been validated as a useful measure of intensity for Australian football<sup>20</sup>, and the use of Player Load<sup>TM</sup> is supported in rugby union<sup>15</sup> for monitoring of physical performance. Unpublished data from our lab has demonstrates that the devices have a inter-device reliability of 3.9% coefficient of variation and ICC of 0.98 in HIE number (> 2.5 m·s<sup>-1</sup>), and a coefficient of variation of 0.9% and ICC of 0.99 for the parameter Player Load<sup>TM</sup>·min<sup>-1</sup>.

### Statistical analyses

Data are presented as mean ± SD. Differences between playing-positions were analyzed on log transformed data using Cohen’s effect size (ES) statistics and ±90% CL. ESs of <0.2, 0.2 to 0.6, 0.6 to 1.2, 1.2 to 2.0 and >2.0 were considered as trivial, small, moderate, large and very large<sup>21</sup>, respectively. The percentage likelihood of difference between groups was calculated and considered almost certainly not (<0.5%), very unlikely (<0.5%), unlikely (<25%), possibly (25-75%), likely (>75%), very likely (>95%), or most likely (>99.5%). A percentage likelihood of difference <75% was considered a substantial magnitude. Threshold chances of 5% for substantial magnitudes were used, meaning a likelihood of >5% in both a positive and negative direction was considered unclear<sup>21</sup>. All statistical analyses were completed in Microsoft® Excel® 2013, using a custom made spreadsheet<sup>22</sup>.

### Results

The mean match length was 71.9 ± 2.4 min, thus meaning an addition of 11.9 min of the 60 min official match time. The mean on-field time for individual players was 33.2 min (range 7-70 min). GK had the highest mean on-field time (42.2 ± 16.6 min) which was very likely greater than backs (98%; ES: 0.8) and wings (95%; ES: 0.7), and likely greater than pivots (79%; ES: 0.5). Backs (30.9 ± 16.0 min) had likely lower (78%; ES: 0.4) on-field time than pivots (34.4 ± 12.5

min). There were no clear differences between wings ( $31.4 \pm 14.7$  min) compared to backs and pivots.

Player Load<sup>TM</sup> data from all positions are displayed in figure 1A, both as means and as individual data. The mean value when combining all playing positions was  $8.82 \pm 2.06$  Player Load<sup>TM</sup>·min<sup>-1</sup>, and small to very large differences were found between playing positions. Backs and Pivots showed the highest Player Load<sup>TM</sup>·min<sup>-1</sup> values, while GK displayed the lowest values. Offensive backs showed higher values (difference: 2.2 Player Load<sup>TM</sup>·min<sup>-1</sup>) and were most likely different (100%) from two-way players (backs), with a very large effect size (ES: 2.2).

The mean from all players, when combining all HIE was  $3.90 \pm 1.58$  HIE·min<sup>-1</sup>. Backs had the highest values of HIE·min<sup>-1</sup>, followed by pivots, then wings, while GK displayed the lowest values (figure 1B). Offensive backs displayed higher values (difference: 1.7 HIE·min<sup>-1</sup>) than two-way players (backs), and were likely different (98%), with a large effect size (ES: 1.2).

The mean number of Acc, CoD, and Dec combined for all players were  $0.7 \pm 0.4$  Acc·min<sup>-1</sup>,  $2.3 \pm 0.9$  Dec·min<sup>-1</sup>, and  $1.0 \pm 0.4$  CoD·min<sup>-1</sup>, respectively. Trivial to very large differences between playing positions were found in the three parameters (table 1). Individual data from offensive players and two-way players (backs) are presented in figure 2.

## **Discussion**

To our knowledge, this is the first study to investigate HIE in team handball with the use of IMU. There were substantial differences between all playing positions in HIE in the present study. Overall intensity (Player Load<sup>TM</sup>·min<sup>-1</sup>) was also substantially different between playing positions, with back players displaying the highest values and GK showing the lowest values. In addition, this is the first study, to our knowledge, to include players that are specialized to the offensive actions of their team.

Wings are largely lower than backs in HIE·min<sup>-1</sup>, but only display a small difference when assessing the overall intensity (Player Load™·min<sup>-1</sup>). This suggests that wing players complete a relatively greater amount of lower-intensity accelerative actions e.g., running at a steady-velocity. This is in accordance with data in female team handball players showing a higher total distance covered by wings in match play, compared to backs<sup>11</sup>. However, there are studies in male handball, showing that back players is the position that display the highest total distance covered<sup>6,12</sup>. Differences in relation to player substitutions could explain some of the divergent results in this variable. Wings have also been shown to cover more distance at speeds defined as sprint<sup>6</sup>, possibly because wing players are frequently involved in fast breaks. This suggests that wing players require a different physical training than backs and pivots to mimic and potentially exceed the demands of match play.

The tactical role of the different playing positions could also affect the physical output of the players. As mentioned, wings may cover the greatest distance during a game, however, back and pivot players are more involved in the tactical play in both offence and defense. This could potentially explain the higher number of HIE and the higher intensity. In addition, players can be exposed for isometric actions that will not be registered by the IMU-unit, especially for the pivot players. Thus, an underestimation of the intensity of players, especially of pivots, might be present in the current study.

The accelerative nature of team handball is poorly investigated, however one study has been undertaken that included acceleration counts<sup>23</sup>, obtained via video-based analysis. Horizontal sprint accelerations were analyzed for all playing positions, and divided into eight accelerative categories ranging from <-4.5 m·s<sup>-2</sup> to >4.5 m·s<sup>-2</sup>. They found GK to be significantly different from all playing positions, which is supported by the current study. However, they found no

significant differences among the other playing positions, which is in contrast to our findings. The different methods for data collection may partially explain these differences<sup>24</sup>, although the range of the accelerative categories are also vastly dissimilar. Póvoas et al. (2014)<sup>6</sup> investigated five types of specific team handball playing actions in male players. They reported that backs and pivots had the highest number of CoD ( $37.9 \pm 9.2$  and  $35.4 \pm 11.1$  CoD per match for backs and pivots, respectively), which is partly supported by this study. Despite the difficulties for a direct comparisons between the current study, and other studies that have investigated physical demands in team handball, there appears to be little doubt that HIE actions are an important element for physical performance in both male<sup>6,25</sup> and female<sup>23,26</sup> team handball. This underlines the need for specific training for repeated HIE in addition to a need for well-developed muscle strength.

Heart rate measurements from team handball match play show some difference between playing positions<sup>6,11,23</sup>. Goalkeepers show lower values than all other positions<sup>23</sup>, which is in line with the lower Player Load<sup>TM</sup>·min<sup>-1</sup> shown in this study. In male handball, backs and pivots are shown to have higher mean heart rate, compared to wings<sup>6</sup>. However, in female team handball players<sup>11,23</sup>, its reported no difference between playing positions<sup>23</sup>, or that pivots have higher mean heart rate than both backs and wings<sup>11</sup>. The small differences in Player Load<sup>TM</sup>·min<sup>-1</sup> between wings and backs in this study is, thus, not supported by heart rate measurements. However, the large number of HIE in team handball match play proposes a substantial contribution of the anaerobic glycolytic system<sup>27</sup>, which may not be reflected in heart rate measurements. Blood lactate measurements show a large range and individual differences in handball match play<sup>25,28</sup>. The differences found in HIE between playing positions are expected to be reflected in the blood lactate values. However, this has not yet been investigated in a larger sample of players<sup>4</sup>.

Previous studies in team handball have aimed to elucidate the demands of full-time players, thus setting a high ( $\geq 70\%$ ) on-field time as an inclusion criteria<sup>1,5-7,11,12</sup>. In the current study, players with considerable reduced on-field time were included, thus considering all on-court players and a possibly wider range of intensities. The individual data plots (figure 1) show a considerable range between players within the same playing position. In addition, offensive players are located in the higher range in both variables, and show large to very large differences from the two-way playing backs. Differences in physical conditions or body anthropometry may contribute to these within playing position differences. Furthermore, the player's technical and tactical capacities could be an important factor, in addition to their positional role in the defense, which may vary from their offensive position. This change in positional roles from offense to defense was not taken into consideration in this study. By allowing for players with a wide range of on-field time, the time to recover will also vary between players. This could be a contributing factor for the range between players, which is especially relevant for the offensive players. However, this study was not designed to investigate the possible reasons for the range in these data, and further studies are required to examine the individual variances.

Offensive players are located in the higher range in both Player Load<sup>TM</sup>·min<sup>-1</sup> and HIE·min<sup>-1</sup>. Different playing strategies can not be excluded as a possibility. In fact, the playing strategies for players that are specialized to offence might be an explanatory factor for why they have this specialized role in their team. In addition, the need for rapid substitutions (both from and to the bench) could contribute to their higher values. To our knowledge, data for offensive players have not been published previously in team handball. Few studies have investigated international team handball, and it is proposed that international team handball may involve a larger portion of

specialized players than national team handball, due to a less homogenous playing standard in the national leagues<sup>12</sup>, which may explain why this has not been reported in previous studies.

Previous data has reported that male GK display the lowest distance per min of all positions<sup>7</sup>, in addition to the highest percentage of stand still time (86% of match). The notion that GK have the lowest intensity and lowest number of HIE of all playing positions is further supported by the current study. GK play in a dedicated zone on the court, and are only involved in the defensive play of their team. This is likely the main reason for the lower values. GK are in fact, in some studies, not included<sup>6</sup>, because of their obvious differences from other playing positions. However, GK had the highest mean on-field time, and thus the accumulated load over a match should not be underestimated, and neither the contribution of HIE to a GK match load. Further research on GK physical demands is needed to fully elucidate the load and HIE demands. For example, different inertial movement analyses variables may be more appropriate for GK than for the other playing positions.

### **Practical applications**

The results from this study demonstrate that elite female team handball players spend a considerable amount of energy in actions involving accelerations and decelerations, which underlines the intermittent nature of the game. Furthermore, the differences in HIE between all playing positions highlights the need for position-specific training programs. In order to do this, specific information is required to quantify the HIE during typical training drills, in addition to match play.

### **Conclusion**

This is the first study to use IMUs to investigate HIE in international female team handball. The use of IMUs in team handball match play provide useful information concerning HIE and

physical load. The present study demonstrates a high occurrence of accelerative events in match play for all playing positions. Differences in HIE were present between all playing positions, where backs show the highest amount of HIE, and are followed by pivots and then wings. Positional differences were also found in Acc, CoD, and Dec, thus highlighting the position specific demands in female team handball. The within playing position range also show that other factors than playing position contribute to the amount of HIE and Player Load™, and thus individualization of training and recovery programs are important.

### **Acknowledgement**

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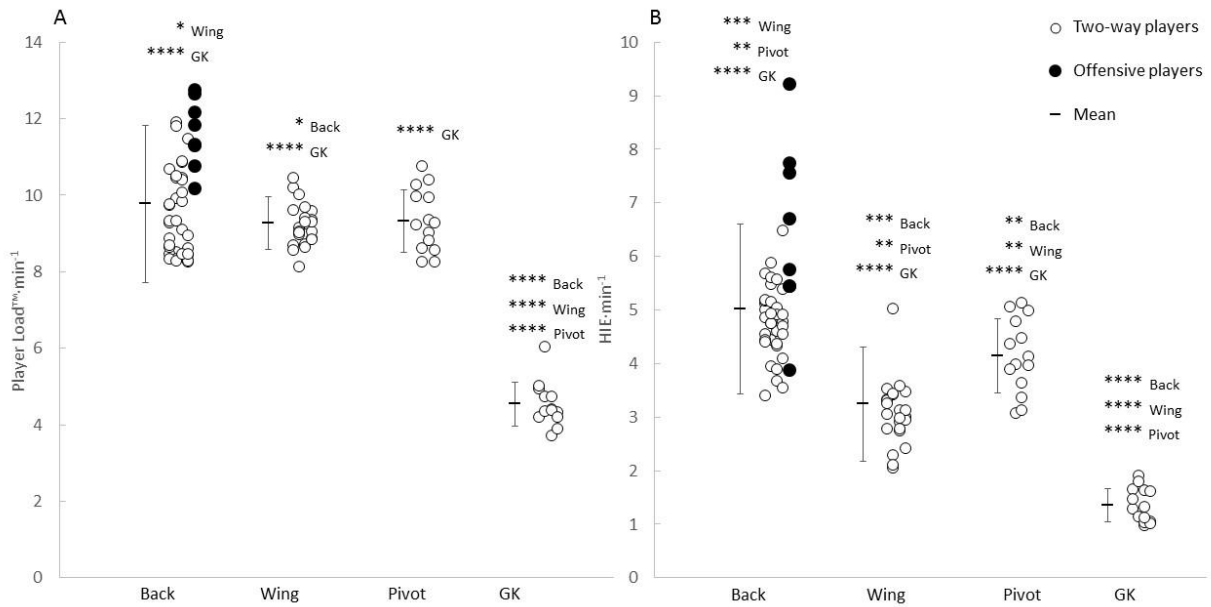
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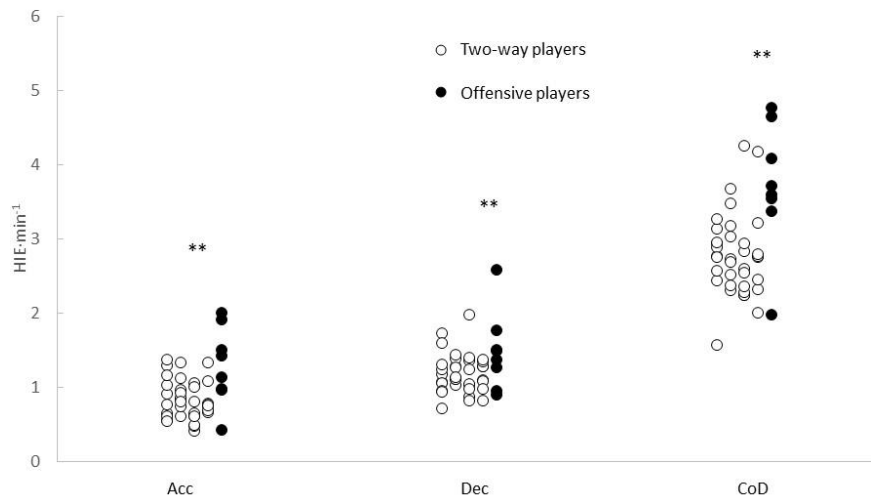


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**Figure 1:** Mean  $\pm$  SD and individual data for all playing positions are shown for Player Load  $\cdot \text{min}^{-1}$  (A) and HIE  $\cdot \text{min}^{-1}$  (B). Effect size (ES) between different playing positions is indicated by the stated symbols and are marked with position name. Only ES with a substantial likelihood of difference ( $> 75\%$ ) are shown. \* = small, \*\* = moderate, \*\*\* = large \*\*\*\* = very large. GK = goalkeeper, HIE = high intensity events.



**Figure 2:** Individual data for accelerations (Acc), decelerations (Dec) and changes of direction (CoD) for two-way players and specialized players. Only data from backs are shown. Effect size (ES) between the two are indicated by the stated symbols. Only ES with a substantial likelihood of difference (> 75%) are shown. \*=small, \*\*=moderate, \*\*\*= large \*\*\*\*=very large. HIE = high intensity events.

**Table 1:** Accelerations ( $\text{Acc}\cdot\text{min}^{-1}$ ), changes of direction ( $\text{CoD}\cdot\text{min}^{-1}$ ), and decelerations ( $\text{Dec}\cdot\text{min}^{-1}$ ) for back, wing, pivot, and goalkeeper (GK), with comparisons between playing positions. Substantial likelihood of difference between playing positions: \* likely, \*\* very likely, and \*\*\* most likely.

	Mean $\pm$ SD		Magnitude of differences	
			Effect size	Rating
<b>Accelerations (<math>\text{Acc}\cdot\text{min}^{-1}</math>)</b>				
<b>Back</b>	0.90 $\pm$ 0.35			
		vs wing	1.43***	Large
		vs pivot	0.75**	Moderate
		vs GK	3.73***	Very large
<b>Wing</b>	0.51 $\pm$ 0.28			
		vs pivot	0.96**	Moderate
		vs GK	2.28***	Very large
<b>Pivot</b>	0.68 $\pm$ 0.16			
		vs GK	3.51***	Very large
<b>GK</b>	0.17 $\pm$ 0.08			
<b>Changes of direction (<math>\text{CoD}\cdot\text{min}^{-1}</math>)</b>				
<b>Back</b>	2.90 $\pm$ 0.65			
		vs wing	1.50***	Large
		vs pivot	1.21***	Large
		vs GK	4.56***	Very large
<b>Wing</b>	1.97 $\pm$ 0.73			
		vs pivot	0.54*	Small
		vs GK	2.75***	Very large
<b>Pivot</b>	2.22 $\pm$ 0.45			
		vs GK	3.68***	Very large
<b>GK</b>	0.79 $\pm$ 0.24			
<b>Decelerations (<math>\text{dec}\cdot\text{min}^{-1}</math>)</b>				
<b>Back</b>	1.22 $\pm$ 0.34			
		vs wing	1.93***	Large
		vs pivot	0.00	Trivial
		vs GK	4.03***	Very large
<b>Wing</b>	0.76 $\pm$ 0.20			
		vs pivot	1.64***	Large
		vs GK	2.38***	Very large
<b>Pivot</b>	1.24 $\pm$ 0.41			
		vs GK	3.57***	Very large
<b>GK</b>	0.39 $\pm$ 0.12			