UPPER-LIMB KINEMATICS AND COORDINATION OF SHORT GRIP
AND CLASSIC DRIVES IN FIELD HOCKEY

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Abstract
The aim of this study was to compare the upper-limb kinematics and coordination of the short grip and classic drives in field hockey. Ten elite female players participated in the experiment. The VICON™ system was used to record the displacement of markers placed on the stick and the players’ joints during five short grip and five classic drives. Kinematic and coordination parameters were analysed. The ball’s velocity was recorded by a radar device that also served as the drive target. Kinematic differences were noted between the two drive conditions, with shorter duration and smaller overall amplitude in the short grip drive, explained by the shorter lever arm and the specific context in which it is used. No differences were noted for upper-limb coordination. In both types of stick holding, an inter-limb dissociation was noted on the left side, whereas the right inter-limb coordination was in-phase. Moreover, the time lag increased in the disto-proximal direction, suggesting wrist uncocking before impact and the initiation of descent motion by the left shoulder. Medio-lateral analysis confirmed these results: coordination of left-right limbs converged at the wrist but dissociated with more proximal joints (elbows and shoulders).
Introduction

Field hockey games are often characterised by a high density of players in certain parts of the field, which puts the players under intense temporal pressure. Long propulsions usually serve to give velocity to the game and to pass the ball to players in free spaces. The two most common drives used to send the ball long distances are: the classic field hockey drive, with the hands joined together on the top of the stick, and the short grip drive, with the hands also joined but held lower on the stick hose (the highest part of the stick that players grip). Experts can perform these two drives, which serve two main purposes: shooting for goal and passing to players several meters away. Although cultural factors seem to influence the choice of one drive rather than the other, the principal factor is a tactical consideration in response to temporal pressure. With a shorter lever arm, the short grip drive is often chosen for rapid actions to counter-balance the opposing defence, while the classic drive is more often used for placed attack schemes. Thus, the mastery of these drives also depends on the player’s field position. Mid and forward positions impose high pressure from opponents, because the density of players is greatest in these parts of the field. Moreover, the passes in this field section are shorter. Players in these positions use the short grip drive more frequently than players in the back field, who benefit from more time to play and thus often choose the classic drive to give more velocity to the ball. The advantage of the classic drive seems to be in power, whereas the interest of the short grip drive lies in its short duration, especially from the beginning of the drive to the impact with the ball.

There is little information in the scientific literature on these drives and their uses. The few studies on the biomechanics of field hockey have essentially been kinematic analyses of the classic drive (Burgess-Limerick et al., 1991; Faque, 1987; Francks et
al., 1985; Kusuhara, 1993; Whitaker, 1992). Little is known about limb organisation.

Notably, Francks et al. (1985) reported that the drive is performed in a manner similar to that of a golf or baseball swing (i.e. a biphasic movement consisting of an initial backswing, followed by a downswing). Some authors have emphasised a third phase just after ball impact, the follow-through or finish, even though the stick is no longer in contact with the ball (Faque, 1987; Kusuhara, 1993; Whitaker, 1992). These authors assume that this last part of the drive has an impact on ball direction and precision, and plays a role in reducing injuries. The results concerning phase duration and variability in the stick’s movement through space have been conflicting. Burgess-Limerick et al. (1991) and Francks et al. (1985) observed that experts show great spatial and temporal variability in their attempts to produce a consistent and accurate downswing. Conversely, Kusuhara (1993) showed greater spatial and temporal drive reproducibility for intermediate and trained players than for beginners. But, first, the methods used were different and the cycle was not clearly defined by key points. Second, several types of drive are used to hit the ball. These conflicting results thus suggest the complexity of the field hockey drive and the need for not only a clarification of its kinematic features, but also a coordination analysis, by a comparison of the two types of drive.

In fact, coordination analysis would provide further insight into the study of these drives, because it is an explanatory feature of complex skills and expertise analysis. Haken et al. (1985) pointed out the interest of inter-limb coordination analysis and modelled coordination dynamics to better understand motor control when the control parameter was changed. The dynamic approach was extended from bimanual coordination to various complex skills in order to analyse the motor control of subjects as they used a ski simulator (Delignières et al., 1999; Nourrit et al., 2000;
Nourrit et al., 2003; Vereijken et al., 1992) or performed swings under the parallel bars in gymnastics (Delignières et al., 1998) and serves in volleyball (Temprado et al., 1997). In these activities, coordination differences were noted between novices and experts, with a release of degrees of freedom for experts. For the volleyball serve, experts used anti-phase shoulder-wrist coupling, suggesting limb dissociation (Temprado et al., 1997). In gymnastics, experts developed partial decoupling in order to overcome spontaneous tendencies highly constrained by the intrinsic dynamics of the system (Delignières et al., 1998). The coordination of the upper-body limbs in field hockey has been described as a succession of segmental accelerations, proceeding from the most proximal to the most distal and serving to maximize the stick speed at ball impact (Faque, 1987), but no published study has analysed the upper inter-limb coordination during drive performance.

Therefore, the aim of this study was to compare the upper-limb kinematics and coordination of the two expert field hockey drives (classic and short grip). We hypothesised that the two drives would show kinematic differences but similar upper-limb coordination. More specifically, we expected that 1) the short grip drive would require less time to perform than the classic drive, thus being more effective in the context of temporal urgency, and 2) the expert players would adopt upper-limb dissociation in both drives to maximize the final velocity given to the ball at impact.

Methods

Subjects

Ten female field hockey players participated in the study (age: 23.9±4.8 years, height: 168.2±6.3 cm, and mass: 60.1±7.2 kg). All played at the elite national level and either had been or still were on the national team. All had been training for
12.3±5 years. The players provided informed written consent to participate in the study, which was approved by the University ethics committee.

Protocol

A radar speed detection device (Speed Chek™, Tribar Industries Inc., Ontario, Canada) was used to obtain ball velocity after impact. The VICON™ optoelectronic system (Oxford Metrics, Oxford, UK) measured the kinematic parameters during the drives, with five cameras operating at 50 frames per second placed around the player (Atha, 1984). According to Shannon’s theorem (movement frequency must be equal to or greater than twice the signal frequency) (Shannon & Weaver, 1963), 50 Hz was sufficient to analyse the field hockey drive, which is a 1-Hz frequency movement. The calibrated volume resolution was 2 m (Z or vertical axis) / 2 m (X or medio lateral axis) / 3 m (Y or anterio-posterior axis), in order to record all phases of the drive. The experimental space was statically and dynamically calibrated and passive reflective markers were fixed with double-face adhesive tape on the following anatomical sites: the left and right acromio-clavicular joints (Lsho and Rsho), the epicondyles of each arm (Lelb and Relb), and the left and right apophysis styloïd radius (Lwri and Rwri). With the VICON system, at a sampling frequency of 50 Hz, the maximal error was 1° for the two large angle cameras and 0.5° for the three other cameras. Errors due to skin movements were reduced by placing the markers where the skin is thin and therefore primarily moves with the underlying bone structure (Dujardin et al., 1997). Two other markers were placed on the stick, one at the head (croB), and one 45 cm away from the first (croH). The hockey players were dressed in shorts and bras, wore their own hockey shoes, and used their own sticks, in order not to disturb their drives. However, all the
sticks were similar in height, weight, and composition to ensure equal shooting conditions. Each subject performed ten drives while standing with her left foot next to the ball, which had been placed on a mark on the floor. Five drives were classic (hands joined at the top of the stick) and five were short grip (hands joined lower on the stick hose). Practice trials were allowed to ensure that the players were comfortable with the experimental procedure. Each subject was asked to hit the ball as if she were passing the ball to a player situated about 20 m away (distance representative of field hockey match passes). They were asked to aim at the radar device, which was on the floor, just behind the nylon indoor protection net (1.2 m high and placed 1.6 m away from the player to prevent accidental damage to equipment), and served as the target. Trials in which the ball landed 0.05 m or more from this target were not analysed because these were considered not to respect the precision conditions. In this case, subjects performed additional trials to record ten accurate drives. Each drive was also assessed in terms of the ball velocity measured by the radar. Synthetic carpet was placed on the ground to reproduce match conditions.

The drive was divided into the following three phases:

1. Backswing, corresponding to the stick motion away from the ground. The players were allowed to begin their swing wherever they wanted as long as the stick motion was away from the ground.

2. Downswing, corresponding to stick motion in the opposite direction, from the highest point to impact with the ball.

3. Follow-throw or finish, from impact to the end of the drive, which corresponded to the highest point reached by the stick at the end of the movement just before the player became relaxed.
For the two drives, the left hand is placed higher than the right one on the stick hose (the highest part of the stick that players grip). The left arm then guides the stick motion (lead arm), whereas the right one serves as a support to the movement (trail arm).

The kinematic analyses were based on the right wrist displacements in the frontal plane during the entire stroke, and the ball velocity. Analyses in the three planes were performed before the experiment and the greatest variations in amplitude were observed in the vertical plane. The choice was thus made to concentrate on this macroscopic variable of the movement, which best typifies the coordination, in accordance with the principles of dynamic approaches (Kelso, 1984 for bimanual coordination). The absolute duration of each drive and each phase was then established, using the right wrist height peaks as the reference to delimit the phase of the movement (Gatt et al., 1998). In fact, at 50 Hz, the data losses for the two markers placed on the stick were too numerous to permit the use of the stick as the reference for determining the beginning and end of each drive phase. To compare the drives, the relative duration of each phase was then calculated, in percentage of cycle.

Upper-limb coordination was analysed by punctual (measures made at discrete instants) estimations of the relative phase (RP) calculated at ball impact, according to Kusuhara (1993) who showed that this point was a determinant factor of expertise. These punctual estimations of RP were used to analyse the proximo-distal and medio-lateral couplings between the different joints: 1) proximo-distal coupling:

\[ \text{RP} = \left( \frac{t_{\text{distal}}}{t_{\text{proximal}}} \right) \times 360 \],

where \( t_{\text{distal}} \) and \( t_{\text{proximal}} \) are the time for the distal and the
proximal joints to reach their minimal height, and 2) medio-lateral coupling:

\[ \text{RP} = (t_{\text{right}}/t_{\text{left}}) \times 360, \]

where \( t_{\text{right}} \) and \( t_{\text{left}} \) are the time for the right and the left joints to reach their minimal height (Hamill et al., 2000). The data are circular so a 360° angle corresponds to a 0° angle. For all values superior to 360, the formula 360-value was used in order to have all angles between 0° to 360°.

Concerning the right proximo-distal analysis (trail arm), five levels of coupling were examined using the following markers: PD1 for croB and croH coupling, PD2 for Rwri and croH coupling, PD3 for Relb and Rwri coupling, PD4 for Rsho and Relb coupling, and PD5 for Rsho and Rwri coupling. For the left proximo-distal analysis (lead arm), these five levels of coupling were also examined using the left markers.

For medio-lateral coordination, three levels of coupling were compared: L1 for the Rwri and Lwri relationship, L2 for the Relb and Lelb relationship, and L3 for the Rsho and Lsho relationship.

According to Dietrich and Warren (1995), the in-phase mode of coordination corresponds to 0±30° values of RP and the anti-phase mode corresponds to 180±30° values of RP. For field hockey analysis, values between 30° and 330° correspond to an out-of-phase mode, whereas 0±30° values correspond to an in-phase mode.

Statistical analysis

For kinematic parameters, normal distribution (Ryan Joiner test) and homogeneity of variance (Bartlett test) allowed parametric statistics.

A one-way ANOVA [condition (2 levels: short grip drive, classic drive)] was performed on the values of ball velocity after impact, the absolute total duration, the relative duration of each phase (backswing, downswing, and finish) and the right
wrist/subject heights ratio at each key point (beginning of the drive, highest point, impact, and end of the drive).

Mean and SD were calculated for each variables. RMS (root Mean Square) was established for the displacement measures, in order to estimate the magnitude of the varying quantity, using the formula: \( \text{rms} = \sqrt{(x_1^2 + x_2^2 + ... + x_n^2)/N} \); with \( x_1, x_2...x_n \) = the \( n \) values of the variable studied, and \( N = \) the number of values.

Linear data processing was performed with Minitab 14.10 (Minitab Inc., 2004).

For upper-limb coordination parameters, Watson Williams F-tests [proximo-distal (five levels: croB/croH, croH/wrist, wrist/elbow, elbow/shoulder, wrist/shoulder) and medio-lateral (three levels: wrists, elbows, shoulders)] were used to compare RP, in order to determine:

- The differences between the short grip drive and the classic drive for each level of coupling,
- The differences between the proximal and distal joint coordination, and between the medial and lateral joint coordination, for each condition.

Circular data processing (Baschelet, 1981) was performed with Oriana 2.0 (W. Kovach Computing Services, 1994-2003).

For all tests, the level of significance was set at 0.05.

**Results**

First, kinematic parameters will be presented, followed by coordination estimates.

The way the stick was held did not change the ball velocity after impact (71.98±1.33 km.h\(^{-1}\) for the short grip drive and 71.09±1.75 km.h\(^{-1}\) for the classic drive) (\( F_{1,88}=0.2, p=0.7 \)).
As well, the short grip drive took significantly less time to perform than the classic drive (0.96±0.03s vs. 1.04±0.02s) ($F_{1,82}=7.2$, $p<0.05$).

Differences between short grip and classic drives downswing relative duration was not significant. As a result, the backswing of the short grip drive had a shorter relative duration than with the classic drive ($F_{1,82}=0.8$, $p<0.05$), conversely the finish of the short grip had a longer relative duration ($F_{1,82}=1.8$, $p<0.05$).

Insert Table 1

Wrist/subject height values were significantly lower with the short grip drive at each key point: for the beginning of the drive (short grip: mean of 0.46±0.09cm, RMS=0.47, vs. classic drive: mean of 0.48±0.09cm, RMS=0.49; $F_{1,82}=1.4$, $p<0.05$); the highest point (0.6±0.06cm, RMS=0.6 vs. 0.63±0.07cm, RMS=0.63; $F_{1,82}=4$, $p<0.05$); the impact (0.34±0.02cm, RMS=0.34 vs. 0.38±0.02cm, RMS=0.38; $F_{1,82}=49$, $p<0.05$); and the end of the drive (0.58±0.08cm, RMS=0.6 vs. 0.63±0.08cm, RMS=0.6; $F_{1,82}=5.5$, $p<0.05$).

Few differences were observed concerning the proximo-distal and medio-lateral coordination parameters.

For the five levels of coupling, the right (trail) proximo-distal coordination was in-phase (RP values between 0° and 30° or between 330° and 360°). Significant differences were observed only between the stick and the body parts ($F_{4,39}=9.4$ and $F_{4,39}=7.6$, respectively, for the short grip drive and the classic drive, $p<0.05$). There were no significant difference between the two conditions ($F_{1,12}=0.383$; $F_{1,12}=1.144$;
Concerning left (lead) proximo-distal coordination, for the two conditions, significant differences were noted between the stick and joints, and between the different joints ($F_{4,39}=32.18$ and $F_{4,39}=16.5$, respectively, for the short grip drive and the classic drive; all $p<0.05$) (see Table 2 and Fig. 2). Here the coordination was out-of-phase (RP values between 30° and 330°).

There were no significant difference between the two conditions ($F_{1,12}=0.383; F_{1,12}=1.202; F_{1,18}=0.262; F_{1,18}=0.006; and F_{1,18}=0.133$, respectively, for PD1, PD2, PD3, PD4, and PD5; all $p>0.05$)

Finally, no significant difference in the medio-lateral organisation was noted between the two conditions. Therefore, Figure 4 illustrates the couplings of the right and left joints for the mean of the two conditions. The coordination between the left and right wrists was in-phase whereas the coordination between the left and right elbows, and between the right and left shoulders, was out-of-phase (see Table 3). This time lag in the coupling was greater at the proximal levels ($F_{2,27}=62.9$ and $F_{2,27}=32.5$, respectively, for the short grip drive and the classic drive; all $p<0.05$).
Discussion

Results showed no influence of stick holding on the ball velocity. Nevertheless, with a shorter duration and a smaller overall amplitude, the short grip drive should have presented a smaller ball velocity at release. But in the present experiment, in order to prevent accidental damage to equipment, the subjects were asked to hit the ball as if they were passing it to a player situated about 20 m away. Without this instruction, players may have hit the ball stronger with the classic drive. For passing the ball, the short grip drive seems to have produced a similar final ball velocity, with a smaller absolute total duration, which offers strategic advantages.

The shorter total time to perform the short grip drive (0.99s vs. 1.04s for classic drive) can be explained by the position of the hands on the stick. Kusuhara (1993), in his study comparing the classic drive in experts, intermediates and novices, reported a longer total time than that of this experiment (1.12s vs. 1.04s). But these results should be interpreted with caution because time decomposition is difficult, especially for the beginning and end of the drive.

Concerning the relative temporal parameters, the general organisation of the stroke was similar to that described by Kusuhara (1993), with the shortest phase being the downswing, followed by the finish and then the backswing, and this for the three levels of practice: beginner, intermediate and trained. This suggests a higher velocity and / or shorter displacement during the downswing.

The comparison of the short grip and classic drives showed significant differences only for the relative durations of the backswing and finish. These results agree with the literature regarding the influences of uncertainty and material constraints on a field hockey drive or a golf swing. Burgess-Limerick et al. (1991) and Francks et al. (1985) reported that experts maintained the temporal consistency of the downswing...
until impact with the ball. In golf, Nagao and Sawada (1973) and, more recently, Egret et al. (2003) reported similar results, with temporal consistency in the downswing but spatial variability in the backswing, in relation with the use of different clubs. Delay et al. (1997) also showed that for long target distances, players increase the downswing amplitude (spatial parameter) but maintain the same movement time in order to increase club velocity at ball contact. In this study, the subjects were constrained by a technical parameter: holding the stick. This had an influence on the kinematic parameters, but, as in the studies presented above, temporal consistency of the downswing was preserved. The backswing phase was shorter in the short grip drive than in the classic drive, and, as a consequence, the short grip finish phase was longer. These results can be explained by the different ways the two types of drives are used. The short grip drive is often used for rapid actions in a context of temporal pressure, i.e. the offense / defence challenge. In response to this pressure, players reduce their preparation time, which is represented by the backswing, in order to hit the ball as quickly as possible and thus reduce telegraphing their intentions to the opposing players. The time saved by reducing the relative duration of the backswing is then used for the finish to adjust ball direction and accuracy.

To complete the kinematic analysis, a spatial parameter, the right wrist/subject height ratio was used. The results showed that values were significantly lower with the short grip drive than with the classic drive. The hands were placed lower on the stick hose in the short grip drive, so they were closer to the ground, giving a smaller overall amplitude.
In summary, the kinematic parameters revealed differences in the short grip and classic drives that justify their use in different contexts in relation with tactical intentions.

In order to better understand the complexity of the movement, a coordination analysis was performed on the upper-body limbs: no significant difference was noted in the proximo-distal and medio-lateral organisation of the upper limbs between the two conditions of drive.

In many throwing sports, final velocity is maximised by an inter-limb dissociation. Fradet et al. (2004) reported several studies in which the fastest throwing action is accomplished with a proximal-to-distal progression. This proximo-distal sequence can be illustrated by the study of linear or angular velocities with maxima of the proximal segments appearing before those of distal segments. This movement organisation is considered to be the most efficient for mechanical and muscular reasons. Gonzalez and Dietrich (2003) introduced a biomechanical model for analysing javelin throw movement to determine how the maximal velocity at release time is reached. The linear joint velocity study showed a successive rise in the speed peaks, from the hip to the javelin, passing by the shoulder, the elbow and the wrist of the throwing arm. Mero et al. (1994) found similar results that they attributed to a transfer of kinetic energy, allowing progressive and successive summation of one body limb to another. This concept of energy flow was also advanced for the handball overarm throw (Jöris et al., 1985). The consecutive actions of the body segments, from the proximal to the distal segments, were demonstrated to be important for the optimal flow of energy to the ball during the last phase of the throw. In our study, vertical joint displacements were used to obtain RP estimation at ball impact. The results showed that, for the right side, joint displacements were in-
phase, meaning that the minimal heights of the joints were reached simultaneously (RP=0° or 360° ±30°). The proximo-distal differences were significant only between the stick and body parts, which can be explained by stick rotations in the hands. For the left side, the same stick/body differences were observed, but the inter-limb coordination was out-of-phase (i.e. the minimal heights of the joints were reached at different moments in the movement, RP values between 30° and 330°). This indicated a time lag between the left shoulder and elbow, shoulder and wrist, and between elbow and wrist. This time lag increased significantly in the disto-proximal direction, which means that the stick descent motion until ball contact was initiated by the left shoulder (lead arm), right arm (trail one) serving to support the movement. This inter-limb dissociation agrees with the findings of Temprado et al. (1997), who studied the volleyball serve by comparing the upper inter-limb coordination of novices and experts. The novices used their arms as a single rigid limb, whereas the experts displayed spatial and temporal inter-limb dissociation. This was revealed by in-phase couplings for the novices and an anti-phase coordination (RP=180°) between the shoulder and wrist for the experts. This shoulder-wrist relationship implies wrist uncocking (rapid movement from full wrist extension to flexion) in order to ensure a mechanically effective movement. In our study, the relationship between the shoulder and wrist was not in anti-phase. But, statistical analysis showed a significant difference between the coupling of these two joints and the other pairs, indicating a longer time lag. The left shoulder initiated the movement of the stick and arrived earlier at ball contact. Thus, wrist uncocking can also be assumed for the field hockey drive, which would agree with Whitaker’s description (1992). He observed wrist uncocking just before ball impact, which served to accelerate the movement. Similar results were advanced by Faque (1987), who reported a time lag
effect for the arms. This was shown by successive accelerations to give a greater
final velocity to the ball. In golf, Egret et al. (2004) showed the same phenomenon,
indicating that the swing should start with movements of the more proximal
segments and progress with faster movements of the more distal segments to
optimise final speed. For the field hockey drive, studies on left wrist velocity and
acceleration are needed to confirm wrist uncocking just before the impact with the
ball.

The results for medio-lateral coordination were similar to those for proximo-distal
coordination. Indeed, whereas the left and right wrists were in-phase, the shoulders
and elbows were out-of-phase. Significant differences were noted between the levels
of coupling, revealing a greater time lag between the two shoulders than between the
two elbows. Given the focal boundary condition of the hands on
the stick, coordination of the left-right segment converged at the wrist but dissociated
with more proximal joints (elbows and shoulders).

In summary, the short grip and classic drives in field hockey differ kinematically.
With a shorter lever arm, the short grip drive requires less time and has a narrower
range of movement than the classic drive. These characteristics explain why field
hockey players more often use this drive for rapid actions, in the context of intense
temporal pressure. One consequence of its use in this type of context is that less time
is given to the backswing than is given in the classic drive. Despite these kinematic
differences, the upper inter-limb coordination was similar in the two drive
conditions. A proximo-distal dissociation was noted on the lead side, with a
relatively long time lag between the shoulder and wrist, suggesting medio-lateral
dissociation. This left wrist delay suggests wrist uncocking before impact with the
ball but further research is needed to confirm this. To confirm these results, it would be interesting to perform the same experiment on a field hockey pitch. The protection net would no longer be necessary as risks of damage to equipment would be eliminated. This would make the task more realistic but would also require portable equipment for the motion analysis.
References


Tables legends

Table 1. Means and SD of the relative durations of the three phases with the short grip and classic drives.

Table 2. Means and SD of the right and left proximo-distal RP for the two conditions of drive (short grip and classic)

Table 3. Means and SD of the medio-lateral RP for the two conditions of drive (short grip and classic)
### Table 1

<table>
<thead>
<tr>
<th>Phase</th>
<th>Relative duration (in percentage of cycle) of short grip drive</th>
<th>Relative duration (in percentage of cycle) of classic drive</th>
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<td>Downswing</td>
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<td>Finish</td>
<td>35.6±7.8</td>
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a: significant difference between drive types (p<0.05).

### Table 2

<table>
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<tr>
<th>Condition</th>
<th>Right PD (proximo-distal)</th>
<th>RP (°)</th>
<th>Left PD (proximo-distal)</th>
<th>RP (°)</th>
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a: significant difference with previous level of PD, b: significant difference with PD3, c: significant difference with PD2, d: significant difference with PD1
<table>
<thead>
<tr>
<th>Condition</th>
<th>L (medio-lateral)</th>
<th>RP (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short grip drive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1 (Rwri/Lwri)</td>
<td>8.8±6.0</td>
<td></td>
</tr>
<tr>
<td>L2 (Relb/Lelb)</td>
<td>52.6±15.6</td>
<td>a</td>
</tr>
<tr>
<td>L3 (Rsho/Lsho)</td>
<td>122.5±32.1</td>
<td>a b</td>
</tr>
<tr>
<td>Classic drive</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1 (Rwri/Lwri)</td>
<td>18.0±23.2</td>
<td></td>
</tr>
<tr>
<td>L2 (Relb/Lelb)</td>
<td>64.1±28.2</td>
<td>a</td>
</tr>
<tr>
<td>L3 (Rsho/Lsho)</td>
<td>133.0±35.2</td>
<td>a b</td>
</tr>
</tbody>
</table>

*a*: significant difference with previous level of L,  
*b*: significant difference with L1
Figures legends

**Figure 1.** Schematic description of field hockey drive movement.

**Figure 2.** Vertical displacement of the stick and right upper limb during the field hockey drive, showing that the inter-limb coordination is in-phase.

**Figure 3.** Vertical displacement of the stick and the left upper limb during the field hockey drive. The time lags between the minimal heights of the joints indicate that the coordination mode is out-of-phase.

**Figure 4.** Vertical displacement of the right and left wrists (a), elbows (b), and shoulders (c) during the field hockey drive.
Figure 1.
Figure 2.
Figure 3.
Figure 4.