TITLE: A kinematic analysis of rugby lineout throwing

Authors: Grant Trewartha[1], Remy Casanova[2], Cassie Wilson[3]

Affiliations:
[1] Sport & Exercise Science
School for Health
University of Bath
Bath
BA2 7AY

[2] Laboratory of Aerodynamics and Biomechanics of Motion.
University of the Mediterranean
Marseilles.
Remy.casanova@univmed.fr

[3] Cardiff School of Sport
University of Wales Cardiff
Cyncoed Campus
Cyncoed Road
Cardiff
CF23 6XD
CWilson@uwic.ac.uk

Correspondence:
Dr Grant Trewartha
Sport & Exercise Science
School for Health
University of Bath
Bath
BA2 7AY

Tel: +44 (0)1225 383055
Fax: +44 (0)1225 383275
Email: g.trewartha@bath.ac.uk

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Running Title: Lineout throwing technique

Keywords: technique analysis, rugby

ABSTRACT

To characterise rugby union lineout throwing technique, three experienced male rugby players performed throwing trials under varying conditions of distance and trajectory. Motion analysis permitted the recovery of joint centre coordinates at 120 Hz and the construction of a three-dimensional linked segment model for calculation of joint angle and centre of mass time histories. All participants exhibited greater accuracy at shorter throwing distances although the accuracy decrement was less in players of superior playing level. Participants demonstrated different technique alterations in order to perform throws of longer distances; either showing increased magnitudes of upper body joint angle velocities (less accurate thrower) or lower body joint velocities (more accurate thrower). The most elite thrower exhibited greater consistency in timing of peak joint angle velocities, with an overall standard deviation of 0.008 s compared with 0.027 s for the least accurate thrower. Data from participants of lesser ability suggest that changes are made to both magnitudes and timing of joint kinematics which leads to increased variability in performance. Implications for players / coaches include the need to develop core strength to permit limited changes to timing and magnitude of upper body joint actions whilst allowing sufficient end-point velocity to be imparted on the ball.

INTRODUCTION

The lineout in rugby union is the means of restarting play when the ball has left the field of play. The lineout throw is executed by one player (normally the 'hooker') who throws the ball into the field of play towards units of jumpers / lifters / support players who attempt to regain possession against fair competition from the opposing team. A number of factors interact to determine lineout success, including communication and timing between thrower and jumpers, and the effectiveness of the opposition. However, one fundamental requirement for a successful lineout is an accurate throw. The lineout throwing action can therefore be considered an important individual skill within rugby union.

The lineout is an important source of primary possession for a rugby team which can often lead to scoring opportunities. At the elite level, the team in possession retains possession in approximately 80% of their own throws and in the last Rugby World Cup (2003) 26% of all tries were scored following possession being gained from a lineout (International Rugby Board, 2003).

Basic lineout throwing technique will require many of the fundamental aspects of throwing skills found in other sports, such as soccer throw-ins and basketball shooting. However, lineout throwing technique is less regulated by the laws of the game than its counterpart in soccer and this means that there is obvious variation in technique between throwers at the same playing level. For example, the throw is normally, but not always, executed with an overhead action, the throw can be primarily 1-handed or semi or fully 2-handed, throwers may maintain a stationary base during the throwing action (tandem or semi-tandem) or indeed take a step forward with the ipsilateral or contralateral leg. One feature of skilled lineout throwing is the ability to throw accurately under conditions of varying distance (normally between 5-15 m horizontally) and trajectory (e.g lob or flat). Changes to destination and trajectory are required to maintain an element of surprise over the opposition and to provide an advantage to the team with the throw. Different types of throw should be executed with a similar technique, so that body actions do not portray too much information to the opposition in terms of the intended throw location.

A limited amount of previous research has been conducted on lineout throwing technique. McClymont (2002) provided a general description of lineout throwing technique and emphasised some important biomechanical principles for coaches / researchers to relate to lineout throwing. Sayers (2004) performed one of the few quantitative technique analyses of lineout throwing on a sample of elite players and emphasised the individual nature of throwing technique and the increased involvement of the lower limbs in throws of longer distance. However, there has been little detailed research on the technical variations used by players of different standards to execute accurate throws under varying conditions of both distance and trajectory. Such an analysis would provide important information to coaches and players on technical characteristics to focus on. Therefore, the purpose of this study was to provide a kinematic description of successful lineout throwing and to identify technique differences due to distance, types of throw and playing standard. It was expected that more elite throwers would: demonstrate improved accuracy, particularly at longer distances; exhibit more consistent movement patterns; and exhibit more systematic technique changes when accommodating altered task demands.

METHODS

Participants

Three experienced male rugby players participated in the study. Each participant had a minimum of five years of lineout throwing experience in training and competition settings. Participant A (age = 19 years, mass = 102.1 kg, height = 1.83 m) was Academy / University 1^{st} XV level, Participant B (age = 20 years, mass = 101.8 kg, height = 1.80 m) was an Under-21 International, and Participant C (age = 20 years, mass = 100.9 kg, height = 1.82 m) was a Senior International. All were free from injury and provided written informed consent in accordance with the University Research Ethics Committee procedures.

Procedures

After a self-directed warm-up including practice throws in an indoor environment, participant body mass and height were recorded using standard laboratory procedures. Subsequently, 39 spherical markers of 12.5 mm diameter were attached to specific anatomical landmarks on the participant for use with the Plug-In-Gait model. (Vicon™, Oxford Metrics Ltd., Oxford, UK).

All participants then performed multiple throwing trials using their normal technique and aiming for a static target located at the centre of a basketball back-board. The participants threw from a constant position and the target was moved to the appropriate distance for each trial. For all trials the target was a height of 3.25 m from the ground, the approximate height reached by a 1.95 m tall player jumping with support to catch the ball. Each participant completed 28 trials, with the order being randomised between participants. The distribution was as follows: four ‘flat’ throws to 6 m; four ‘lob’ throws to 6 m; four ‘flat’ throws to 10 m; four ‘lob’ throws to 10 m; four ‘flat’ throws to 12 m; four ‘lob’ throws to 12 m; four ‘flat’ throws to 14 m. In all trials, participants were asked to use their normal technique with the focus on maximum accuracy. Suitable rest breaks were allowed to eliminate effects of fatigue.

Data Collection

Kinematic data from each participant were recorded using an eight-camera Vicon™ 612 motion analysis system (Oxford Metrics Ltd., Oxford, UK), sampling at 120 Hz and calibrated to the manufacturer’s instructions. A digital video camera (Sony, DCR TRV-900E) operating at 50 Hz, and positioned above and behind the thrower, captured video data to record the deviation of the ball from the target (taped cross). The dimensions of the rectangular target board were measured and used to produce four calibration points for use with the affine scaling technique. Two further 50 Hz digital video cameras (Sony, DCR TRV-900E) were placed in front of the participant at angles of approximately 45° to the intended direction of ball travel so that their optical axes intersected at an angle approximating 90°. Sequences from these two cameras were synchronised to within 1 ms by illuminating an array of 20 LEDs (sequentially at 1 ms intervals) in each camera view and used to reconstruct initial ball velocity and trajectory following ball release. The activity volume of the thrower and initial ball trajectory were calibrated using a 25-point 3-D calibration structure (Peak Technologies, Englewood, CO, USA) encompassing a 1.6 m x 2.2 m x 1.9 m volume.

Data Reduction

For each trial, 3D co-ordinates for each of the 39 reflective markers were reconstructed using Workstation software (version 4.5, Oxford Metrics Ltd., Oxford, UK). The marker trajectories were smoothed using a generalized cross-validatory spline (Woltring, 1986), and all subsequent data were processed using custom Matlab code (Matlab 7.0, Mathworks Inc., USA). A 14-segment kinematic model was then created from the calculated joint centre co-ordinates produced from the Plug-In-Gait model, consisting of head, trunk, upper-arm, forearm, hand, thigh, shank and foot segments. Segment inertia parameters (mass, centre of mass location and radius of gyration) were obtained from de Leva (1996) to calculate segment centre of mass (CM) time-histories and subsequently determine the whole body CM trajectory. 3-D joint angle trajectories were provided by the Workstation software from smoothed marker trajectories. First time derivatives (velocities) of joint angles, segment CM, and whole-body CM were obtained by fitting the position data with interpolating quintic splines and outputting the derivative functions (Wood & Jennings, 1979). The X-axis was perpendicular to the intended direction of ball travel, with the positive direction to the right. The positive Y-axis pointed in the intended direction of ball travel, and the Z-axis pointed vertically, with the upwards direction being positive.

Resultant ball velocity was calculated by digitising (Peak Motus, version 8.1, Englewood, CO, USA) the centre of the ball from recordings obtained by the two synchronised video cameras with subsequent 3-D DLT reconstruction (Abdel-Aziz and Karara, 1971). Final resultant velocity was reported as the average of the five fields following ball release. To determine throw accuracy, video images from the rear camera were digitised. An accuracy score was produced by identifying the video field closest to which the ball made contact with the target board and calculating the scaled displacement of the ball centre from the target, with a score of zero indicating perfect accuracy. Ball release was identified as the field of kinematic data following peak right hand velocity (based on Fradet *et al.*, 2004).

RESULTS

Indicators of Performance

All participants were capable of producing very similar ball release characteristics, in terms of release velocity and release angle (Figure 1). Ball release velocity exhibited gradual increases as distance increased for all participants. There was a general increase in release angle as distance increased and also as expected differences between ‘flat’ and ‘lob’ throws to the same distance.

Participant B and C demonstrated good accuracy (less than 0.4 m deviation from target) and exhibited no trend towards decrements in throw accuracy across throws of longer distance and different type (Figure 2). Participant A did exhibit less accurate throws with increasing distance. With approximately 0.8 m mean deviation from the target the performance of participant A could be considered unacceptable in the conditions 12 m-lob and 14 m-flat.

Throws of Different Distance - Whole body CM Variables

All participants generally developed an increased magnitude of vertical CM (CMz) range of motion and peak velocity for throws to longer distance, with the clearest trends for participant C followed by participant A (Figure 3a). Participant B exhibited a much clearer trend for developing additional horizontal CM (CMy) range of motion and velocity in the direction of the throw, which was not as apparent for participant A or C (Figure 3b). Participant B also used a technique which involved a step forward during the throwing action. This meant that in addition to more marked increases above the baseline (6 m-flat) than participant A or C, participant B actually started from a higher baseline CMy peak velocity in the 6 m-flat condition than participant C who used a stationary technique (at 6 m: participant B = 0.51 $m{\cdot}s^{-1}$, participant C = 0.22 $m{\cdot}s^{-1}$; at 14 m: participant B = 0.80 $m{\cdot}s^{-1}$, participant C = 0.26 $m{\cdot}s^{-1}$).

Throws of Different Distance – Magnitude of Joint Angle Variables

Additional velocity could also be developed through increases in the magnitude of joint angle peak velocities at various links in the kinematic chain. Participant C exhibited trends for increases in peak angular velocities in joints more proximal in the chain (knee and hip) whereas participant A demonstrated increases in peak velocities at all joints (Figure 4). Participant B did not exhibit trends for increased joint angle peak velocities as distance increased.

Throws of Different Distance – Timing of Joint Angle Variables

The consistency of the timing (relative to time of ball release) in peak joint angle velocities can provide an indication of the consistency in temporal sequencing of the movement patterns (Table 1). Averaging the standard deviation of the timing of peak joint angle velocities across all joints and all distances shows that participant C showed minimal variability in the timing of the joint actions within conditions (mean = 0.008 s) compared with more variability demonstrated by participant B (mean = 0.020 s) and particularly participant A (mean = 0.028 s).

Throws of Different Types – Changes to Kinematic Variables

The changes to technique made in performing ‘lob’ throws as opposed to ‘flat’ trajectory throws were similar across all participants. These changes involved an increased CMz range of motion (30-120%) and velocity (16-83%), brought about primarily by gains in knee joint range of motion and peak velocity. To ensure overall ball trajectory did not overshoot the target there was a curtailing of shoulder joint range of motion and peak velocity. These changes were most marked for the different types of throws at 6 m and gradually lessened as throw distance increased and the permissible trajectory difference between ‘lob’ and ‘flat’ reduced (Figure 5).

DISCUSSION

The aim of this study was to provide a kinematic description of successful lineout throwing and to identify technique variations between different distances, types of throw and playing standard.

Indicators of Throw Performance

All participants were able to produce ball release characteristics (ball velocity and release angle) sufficient to execute the task demands. Between-participant accuracy differences (Figure 2) indicate that inter-individual variations in skill level existed, and that participants B and C were the more accurate, skilled lineout throwers. The accuracy differences between participants would have practical importance, particularly at the longer distances. Both participant B and C were able to maintain throw accuracy within approximately 0.4 m for all throw distances and types. This is likely to be an acceptable accuracy in practice whereby the jumper (intended recipient) will have sufficient capacity to adjust for the catch within this radius. However, participant A's deviation from the intended target approached a mean of 0.8 m for the longer throw distances. Deviations of this amount would be difficult for the jumper to adjust to and would also increase the likelihood of the opposition jumpers being able to interrupt the ball's trajectory or for the throw to be adjudged "not straight" by the referee, thereby relinquishing possession to the opposition.

Throws of Different Distance – Technique Changes

It is evident that a number of basic throwing techniques can be employed in order to execute successful lineout throwing. The laws of the game do no constrain the technique used and so it is likely that a number of different throwing "models" could be employed. Nevertheless, a number of basic principles have arisen from the present study.

In players who use a stepping movement during the throwing action (e.g. participant B) it seems possible to generate the additional momentum required to throw to longer distances through the actual stepping movement with the increase in whole body CMy velocity this causes. Participant B did not exhibit increased magnitudes of joint angle velocities at any link in the kinematic chain and managed to maintain the timing of these joint actions within moderate limits.

On the other hand, participant C maintained a stationary base of support throughout the throwing action with a tandem (side-by-side) foot configuration. This technique did not allow for increased ball velocity to arise from increased whole body momentum in the direction of the throw. Rather, to throw for longer distances the magnitude of joint angle velocities in the proximal joints of the kinematic chain (the knee and hip) were increased above baseline. These increased magnitudes were accompanied with extremely consistent timings of the joint actions within a given throwing condition. Perhaps importantly, there was little change in the peak magnitudes at the shoulder and elbow joint in this participant throwing to longer distances. Combining the findings of accuracy of this participant (and bearing in mind his international playing level), the minimal change in upper body kinematics, and minimal variability in any joint action timings would suggest that this throwing model fits into a traditional perspective for aiming tasks, where consistent patterns are maintained except for necessary changes in proximal segments away from the end-point to generate the additional ball velocity. The findings of increased involvement of the lower limb with minimal changes to upper body kinematics concur with those of Sayers (2004).

Participant A utilised a throwing technique which began from a semi-tandem position and finished in a tandem foot position via a small step taken during the throwing action. Using this technique this participant had the opportunity to increase CMy velocity through the stepping movement but to a lesser extent than participant B. Results showed that participant A was also required to increase the magnitude of peak joint angle velocities to produce the necessary ball release characteristics, these changes occurring across all joints in the kinematic chain. In this participant, these changes were accompanied by increased variability of joint action timings across all throw distances and types (compared with participant B and C) and a consequent decrement in throw accuracy, particularly at longer distances.

Throws of Different Type – Technique Changes

Despite the differences in basic throwing action exhibited by the participants, there appeared to be similar characteristic technique changes made in order to alter the ball trajectory from 'flat' to 'lob' This essentially involved a transfer to increased vertical body motion, primarily through an increase in knee range of motion and peak knee angular velocity. The increased emphasis on upwards motion led to increases in the ball's release angle between 'flat' and 'lob' of approximately 20° for the 6 m throws, reducing to approximately 10° difference for the 12 m throws. To maintain the desired range to hit the target this meant the ball release speed had to be reduced and this was done in all participants by reducing the excursion and peak velocities developed at the shoulder joint and additionally for participant C by a reduction in peak elbow angular velocities.

Limitations

The number of participants sampled in this study is small, however it is evident from this study and from Sayers (2004) that no “exemplar” lineout throwing technique exists and so attempting any sort of group analysis would prove problematic and likely lead to the masking of important between-player technique differences. The present analysis has focussed on how given individuals manage the altered task demands whilst highlighting how this can differ between individuals. Nevertheless, it would be beneficial to repeat this analysis on additional players from a range of playing standards and using a range of throwing techniques to determine whether the observations accrued from this study can be reinforced. The experimental trials occurred in a lab environment, without the additional pressures of match play which may have an influence on performance and perhaps on the technique used. It would be possible to perform a kinematic analysis of lineout throwing in conditions more similar to match situations (e.g. with live jumpers and opposition, as in Sayers [2004]); however this makes obtaining a robust accuracy score difficult and so this approach was avoided in the present study.

Practical Implications

A number of coaching implications arise from this study. Irrespective of the basic throwing action (with step or stationary), in more successful throwers there is little change made to the kinematics of the upper body (magnitude or timing) when performing throws to longer distances. Therefore, any technique used should encourage stable movement patterns in the upper extremity body segments. Based on the current evidence it seems possible to execute accurate throws to the long distances required in rugby union using a technique with a stationary base (participant C). However, this requires considerable increase in the magnitude of peak joint velocities of the lower body and trunk and so it is speculated that this technique would require players to have considerable strength in the lower limb and trunk muscles. For players with more limited physical capacity successful performance can be equally achieved by using a throwing action where the additional momentum required is generated through a stepping motion with little increase in magnitude of joint actions (participant B). The findings of participant A in this study suggest that in players with a minimal stepping action and perhaps with less “core” strength throws to longer distances require increased joint actions at all links in the kinematic chain and this increases the chances of poor coordination and degradation in accuracy. In this situation, it is recommended that a transition to a stepping action would be beneficial.

In previous studies of lineout throwing technique, a focus has been put on the deception required by the thrower to ensure the opposition do not “read” the intended destination of the throw. This may be an important consideration which has not been fully explored in this study design. However, it is evident that consistent throwing techniques in terms of upper body kinematics perform best in terms of accuracy and these should also be those techniques most difficult to read. Moreover, in actual match situations it is likely that the opposition will be able to decipher more valuable ball destination information from the movements of the jumpers and support players in the line rather than from the body actions of the thrower.

Future Research

In addition to analysing more players in a similar manner to improve the generality of the presented results there are other interesting future directions for this line of research. There is now an established body of literature suggesting that movement variability is a feature of skilled performance (e.g. Bartlett *et al*., 2007), due to the need for adaptability of the system based on environmental constraints and to correct for errors early in the movement cycle. This issue has not been explored in the present study but would certainly be of interest. It may be that the lineout throw is a sufficiently fixed / closed skill that adaptability is not a major consideration, or it may be that more in-depth analyses of the present data would highlight features of variability in the skilled performances.

Conclusion

A number of different basic throwing techniques can be used for effective lineout throwing to different distances and trajectories. Nevertheless, certain basic principles appear necessary for successful performance; that is consistent magnitude and timing of upper limb actions with additional momentum for longer distances being generated only from increased magnitudes of joint actions in the lower limb or a more pronounced stepping movement. Attempting to increase throwing distance via changes to the kinematics at all body joints in the system combined with inconsistent joint action timings leads to inaccurate throws.

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Table 1. Timing variability in peak joint angular velocities across multiple trials of ‘flat’ condition throws.

		SD of Timing of Peak Joint Angular Velocity (s)				
Participant	**Distance**	**Knee**	**Hip**	**Shoulder**	**Elbow**	**MEAN**
A	6_flat	0.017	0.041	0.030	0.030	
	10_flat	0.022	0.031	0.018	0.036	
	12_flat	0.030	0.012	0.046	0.059	
	14_flat	0.014	0.012	0.022	0.007	**0.027**
B	6_flat	0.033	0.031	0.004	0.004	
	10_flat	0.091	0.008	0.004	0.008	
	12_flat	0.022	0.012	0.012	0.008	
	14_flat	0.035	0.020	0.008	0.004	**0.020**
C	6_flat	0.005	0.008	0.005	0.005	
	10_flat	0.011	0.008	0.011	0.005	
	12_flat	0.012	0.006	0.004	0.006	
	14_flat	0.005	0.004	0.019	0.008	**0.008**

List of Figures

Figure 1. (a) Ball release velocity across all throwing conditions; (b) Ball release angle across all throwing conditions.

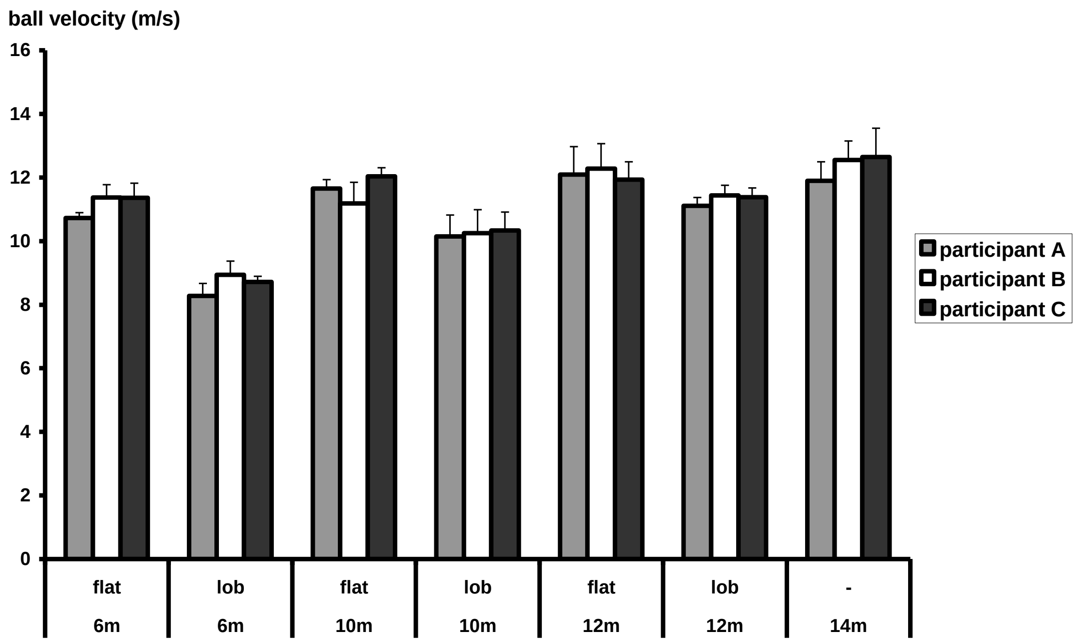
Figure 2. Mean throw accuracy across throwing conditions.

Figure 3. (a) Percentage change (from 6 m_flat condition) in peak CM vertical velocity for all flat throwing conditions; (b) Percentage change (from 6 m_flat condition) in peak CM horizontal velocity for all flat throwing conditions.

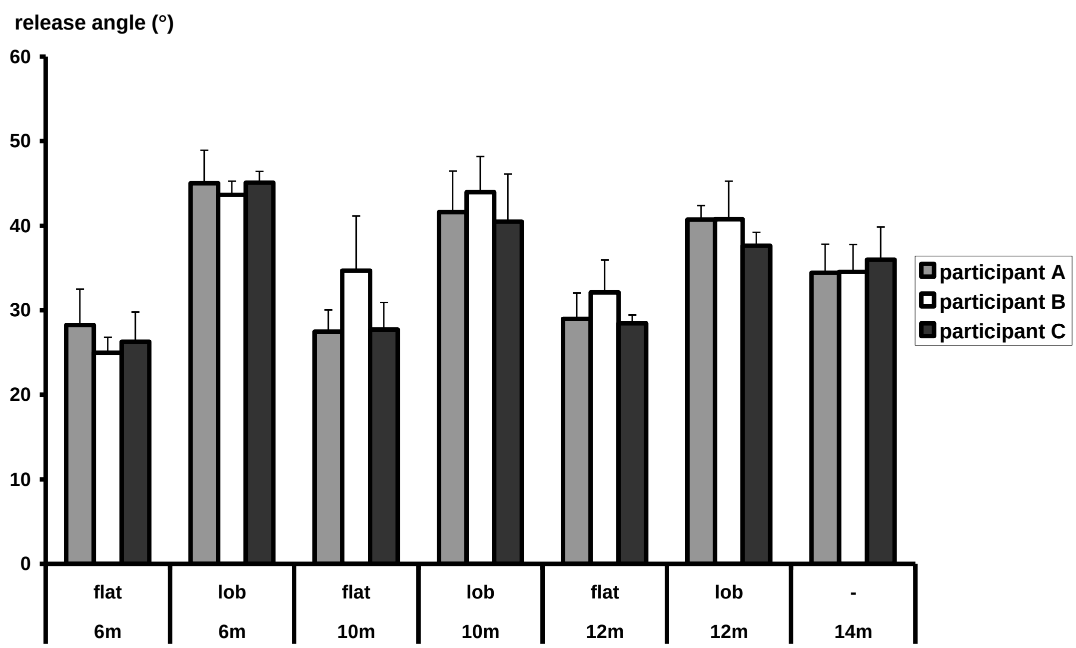
Figure 4. Percentage change (from 6 m_flat condition) in peak joint angular velocities for: a) knee; b) hip; c) shoulder; d) elbow.

Figure 5. Percentage change (from equivalent ‘flat’ condition) for analysed body CM and joint angle kinematic variables for: a) participant A; b) participant B; c) participant C.

(a)



(b)



469 Figure 1

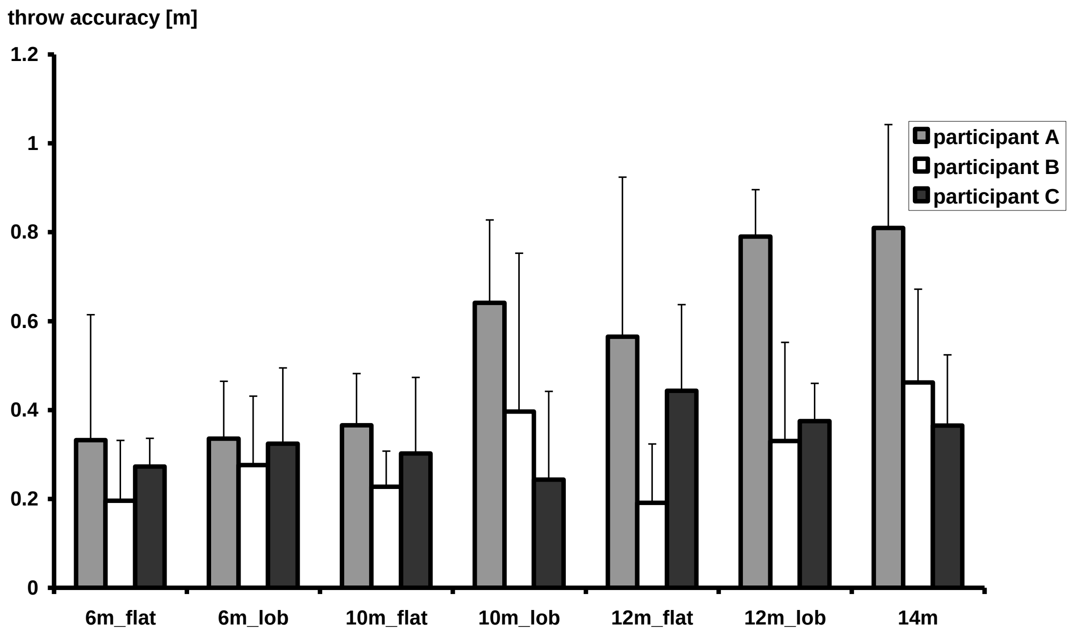
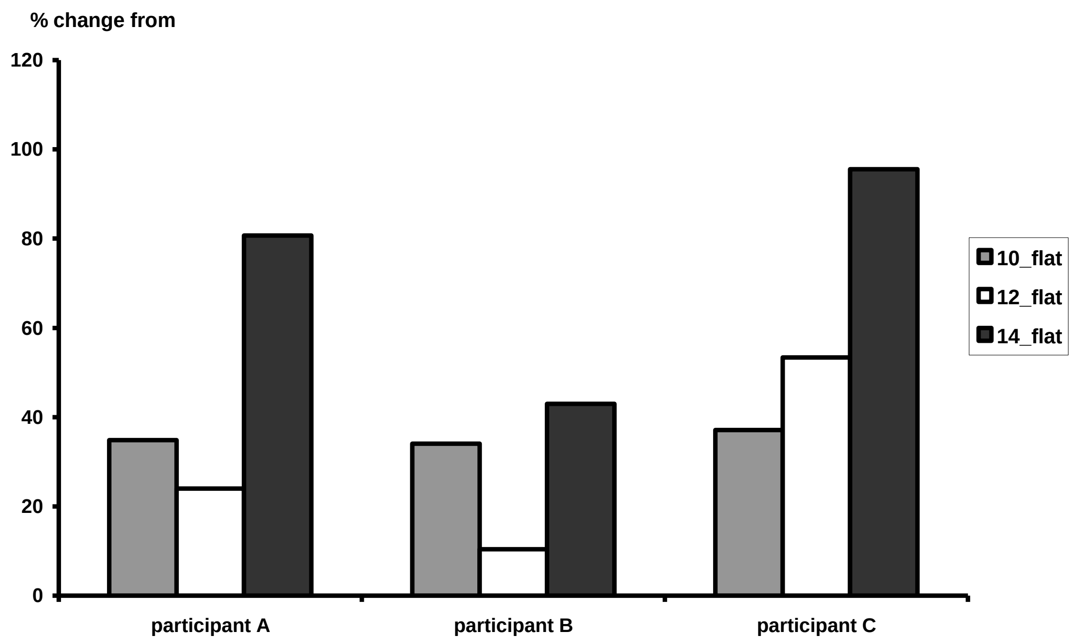

throw accuracy [m]
1.2
1
0.8
0.6
0.4
0.2
0
participant A
participant B
participant C
6m_flat
6m_lob
10m_flat
10m_lob
12m_flat
12m_lob
14m

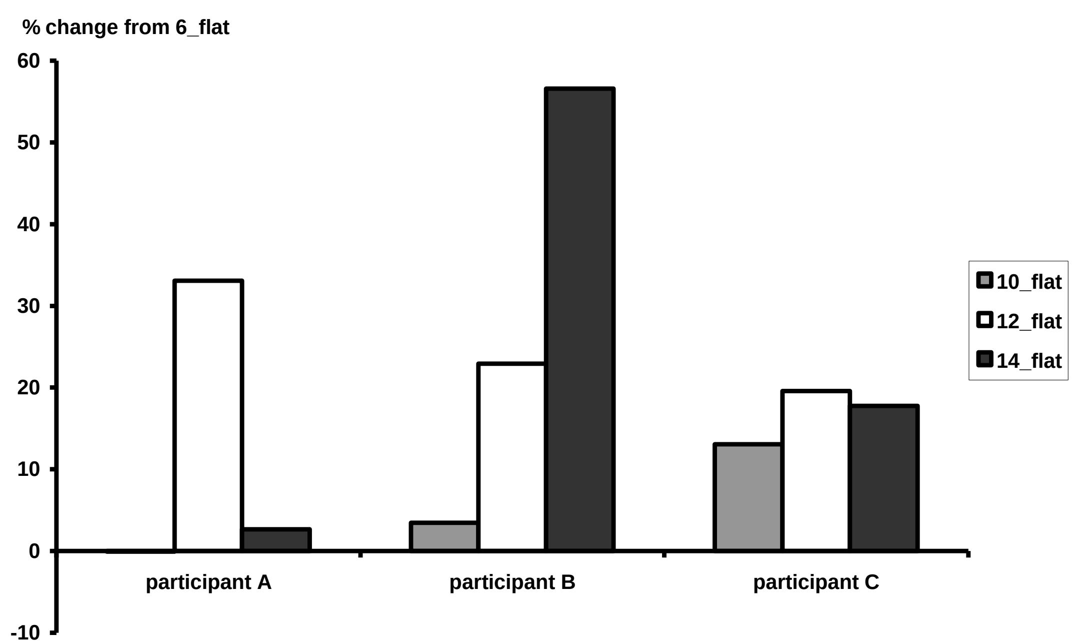
Figure 2

(a)



% change from
120
100
80
60
40
20
0
participant A
participant B
participant C
10_flat
12_flat
14_flat

(b)



% change from 6_flat
60
50
40
30
20
10
0
-10
participant A
participant B
participant C
10_flat
12_flat
14_flat

Figure 3

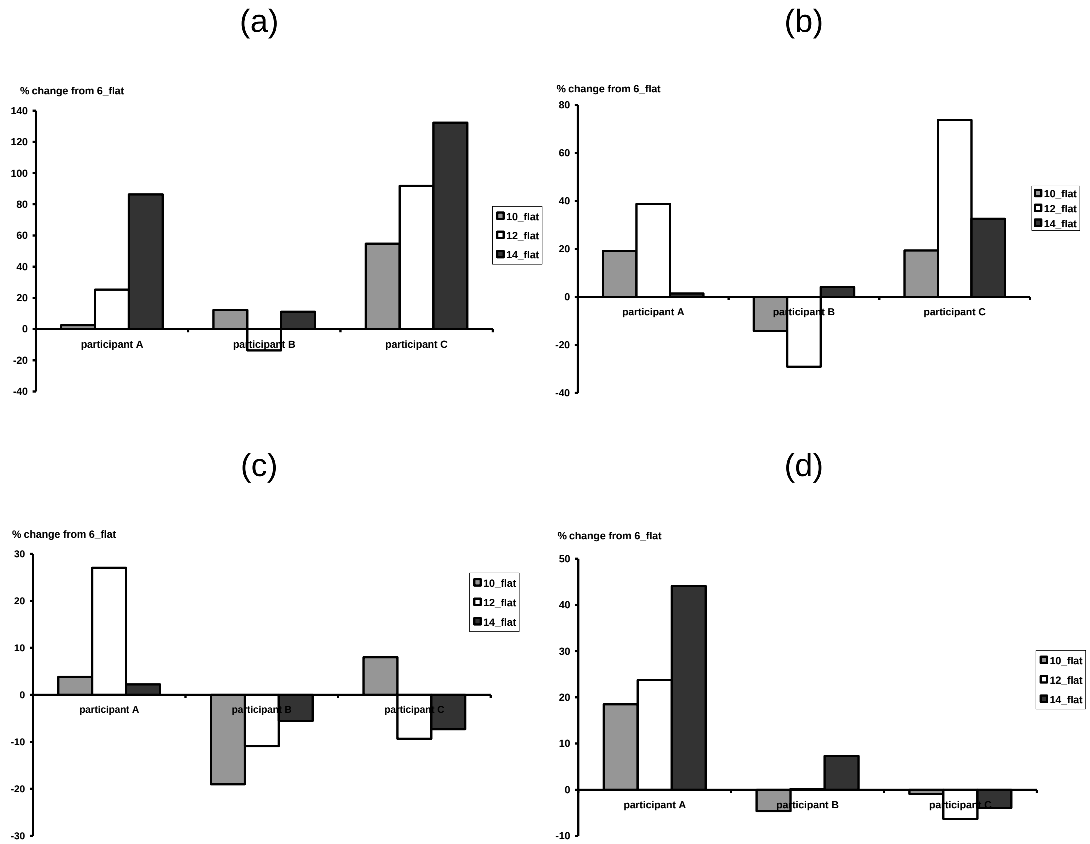

(a)
(b)
(c)
(d)
% change from 6_flat
participant A
participant B
participant C
10_flat
12_flat
14_flat
140
120
100
80
60
40
20
0
-20
-40
50
30
10
-10
-30

Figure 4

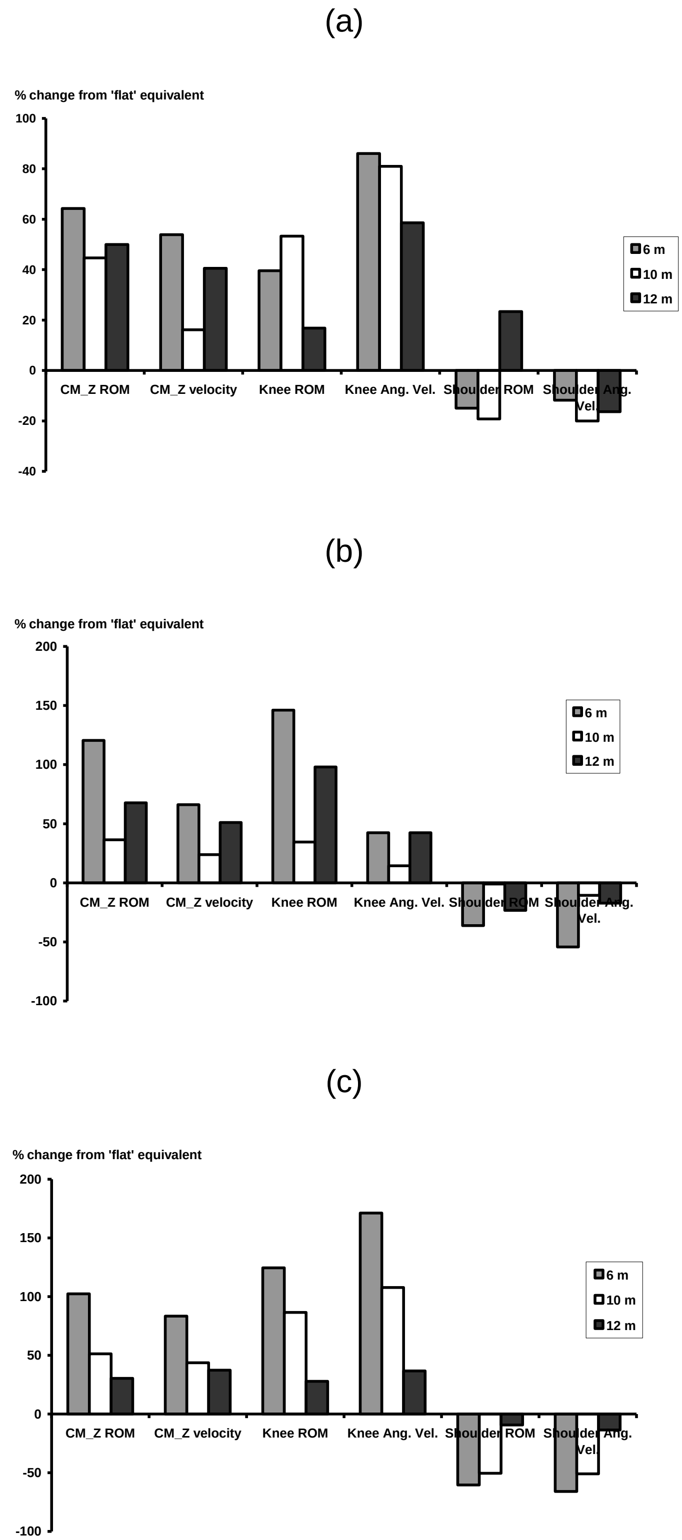

(a)
% change from 'flat' equivalent
100
80
60
40
20
0
-20
-40
CM_Z ROM
CM_Z velocity
Knee ROM
Knee Ang. Vel.
Shoulder ROM
Shoulder Ang. Vel.
6 m
10 m
12 m
(b)
% change from 'flat' equivalent
200
150
100
50
0
-50
-100
CM_Z ROM
CM_Z velocity
Knee ROM
Knee Ang. Vel.
Shoulder ROM
Shoulder Ang. Vel.
6 m
10 m
12 m
(c)
% change from 'flat' equivalent
200
150
100
50
0
-50
-100
CM_Z ROM
CM_Z velocity
Knee ROM
Knee Ang. Vel.
Shoulder ROM
Shoulder Ang. Vel.
6 m
10 m
12 m

Figure 5