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Kinematics of shoulder, trunk, pelvis, and hip while reaching forward to progressively distant targets



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ABSTRACT

Introduction: Information on the normal contribution of various body regions to forward reaching provides a basis for assessing the maneuver. The purpose of this study was to describe the kinematics of the shoulder, trunk, pelvis, and hip of healthy young males while they stood and reached toward a target at arm's length and 5%, 10%, 15%, and 20% of body height beyond.

Method: Twelve healthy adult males were marked with 22 spherical reflective markers. Two trials of unilateral forward reaching were performed towards a target placed at five target distances. Motion was captured via reflective markers and an infrared camera system.

Results: Sagittal and transverse plane motions demonstrated high reliability between trials at each target distance (ICC = 0.716 trunk flexion to 0.977 shoulder flexion). Shoulder flexion and horizontal abduction were major contributors to forward reaching with components of trunk flexion and left trunk rotation at all target distances. Hip flexion, pelvic tilt, left pelvis rotation, and hip external rotation made notable contributions at the furthest targets. All motions became more pronounced as target distance increased ($P \leq .001$).

Conclusion: Kinematic analysis demonstrated that right forward reaching requires composite movements at the shoulder, trunk, pelvis, and hip. The contribution of each body region to forward reaching became more pronounced as the target became more distant. These findings may be helpful when identifying localized movement impairments contributing to limited forward reach in a clinical population, although clinical validation is needed.

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1. Introduction

Reaching is an important activity involving the upper limb (ICF domain d4452) (International Classification of Functioning, Disability, and Health, 2001). The activity has been studied extensively, but most often in the context of the standing “functional reach” test (Bohannon et al., 2017). Reductions in functional reach test performance occur in the presence of neurological disorders such as Parkinson's disease (Smithson et al., 1998) and stroke (Smith et al., 2004), but are also present in healthy aged adults (Norris and Medley, 2011; Monteleone et al., 2008). In addition to balance deficits older adults commonly exhibit reductions in range of motion throughout the body which may contribute to altered

functional reach performance (Holland et al., 2002). The kinematics of the shoulder, trunk, pelvis, and hip during forward reaching have received some attention (Kaminski, 2007; Silfies et al., 2009; Maranesi et al., 2014; Cavanaugh et al., 1999; deWaroquier-Leroy et al., 2014). However, our review of the literature revealed no study examining the simultaneous kinematics of all of these structures while normal adults reached with one upper limb for targets located progressively distant from their bodies.

An awareness of these kinematics in healthy young individuals is essential if aberrations in reaching kinematics present in clinical and older populations are to be properly identified and understood. The purpose of this study, therefore, was to describe, for a sample of healthy adult men, the kinematics of the shoulder, trunk, pelvis, and hip while standing and reaching with the right upper extremity toward a target at arm's length and beyond. Our hypotheses were that reaching to a target at shoulder height would involve angular

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movements at the shoulder, trunk, pelvis and hip and that the movements would increase significantly as the target became progressively more distant.

2. Methods

This study, approved by the Institutional Review Board of Campbell University, enrolled 12 adult male participants between November 2017 and January 2018. Participants were included if they were self-reported as healthy, and between 18 and 35 years of age. This number was deemed adequate based on a power analysis showing that 5 participants would be required to show a significant difference ($\alpha = .05$, power = .80) in trunk rotation during reaching to a target positioned at upper limb length versus a target positioned at upper limb length plus an additional 20% of body height. All participants provided written informed consent.

Throughout data collection each participant was barefoot and wore tight-fitting shorts. We measured participants' height and body mass with a digital scale and stadiometer (Health O Meter, McCook, IL, USA). These measurements as well as body mass index and age are summarized in Table 1.

Participants were marked with 22 spherical reflective markers prior to performing the forward reaching task (Fig. 1). The marker setup was designed by the authors to capture the movements of interest. Single markers were placed in midline at the C7 spinous process, and sacrum between the posterior superior iliac spines. Markers were also placed bilaterally on the superior acromia (midway between the anterior and posterior surfaces), lateral humeral epicondyles (just proximal to radio-humeral joint), dorsal wrists (dorsal radius just proximal to lunata), end of middle fingers (dorsal finger nail), anterior superior iliac spines, medial and lateral femoral condyles (just proximal to tibio-femoral joint line), medial and lateral malleoli, and the base of the fifth metatarsals (dorsal surface). Another marker, which served as a target, was placed on a vertical pole which was mounted on wheels and adjusted to shoulder height for each participant. The position and movement of the markers was captured at 500 Hz by 12 ceiling-mounted infrared cameras (BTS Bioengineering, Brooklyn, NY, USA). The participants were instructed to stand upright with their feet one foot-length apart upon side-by-side force plates and their toes on a line, this served as the starting position for each forward reaching trial.

The baseline position was established by having the participant flex both shoulders with palms together until bilateral upper extremities achieved a position horizontal to the floor (90 degrees of shoulder flexion). The point where the middle fingers of both hands met a marker on the top of the pole served as the starting point for the vertical pole that served as the reach target (Fig. 2). Each participant performed two trials of unilateral forward reaching with the right upper extremity (UE) to each of five progressively distant targets, for a total of ten trials. After two trials at the baseline location the target was moved to distances equal to the baseline location plus 5%, 10%, 15%, and 20% of individual body height respectively. After two trials at each distance, the participant was instructed to step off the force plates while the target was repositioned.

Table 1
Description of 12 male participants in reach study.

Variable	Mean (SD)	Minimum - Maximum
Age	25.7 (3.4)	21–33
Height, cm	176.7 (5.7)	168.0–185.5
Mass, kg	80.7 (4.4)	75.6–89.6
Body mass index, kg/m ²	25.9 (2.0)	23.5–30.9

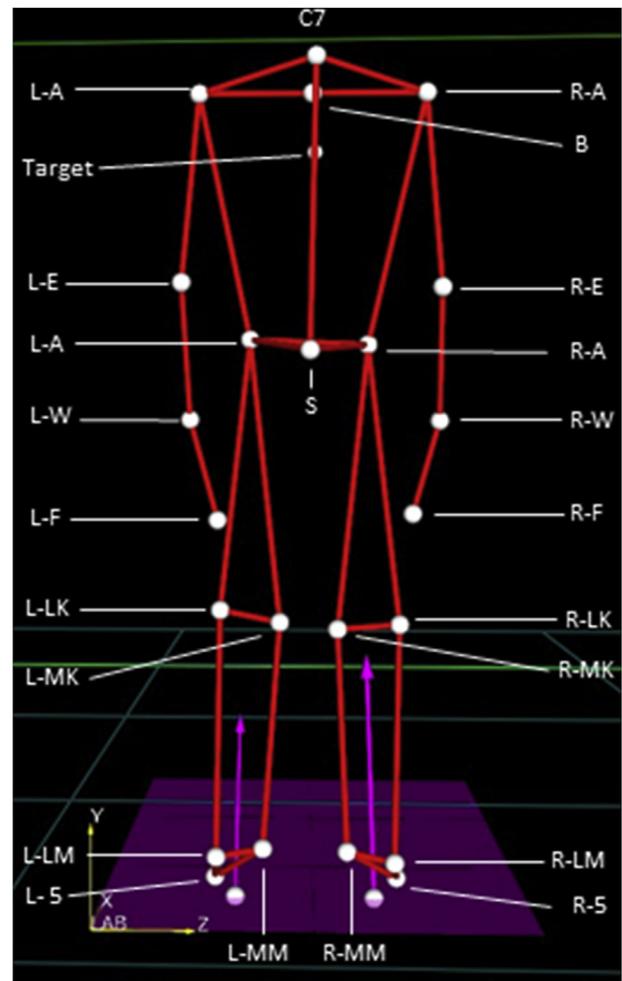


Fig. 1. Posterior view of reflective marker placement within the BTS system. (C7) Spinous process of C7 vertebra, (L-A) left acromion, (R-A) right acromion, (L-E) left lateral elbow, (R-E) right lateral elbow, (L-A) left ASIS, (R-A) right ASIS, (S) sacrum, (L-W) left wrist, (R-W) right wrist, (L-F) left middle finger, (R-F) right middle finger, (L-LK) left lateral knee, (R-LK) right lateral knee, (L-MK) left medial knee, (R-MK) right medial knee, (L-LM) left lateral malleolus, (R-LM) right lateral malleolus, (L-5) left fifth MTP, (R-5) right fifth MTP, (L-MM) left medial malleolus, (R-MM) right medial malleolus, and (B) is a point bisecting the acromia as calculated by BTS system.

The data captured by the infrared cameras was analyzed with BTS Smart Performance (BTS Bioengineering, Brooklyn, NY, USA) software. The placement of the reflective markers allowed the following measurements within the sagittal plane: right shoulder flexion relative to the trunk, forward trunk flexion relative to the pelvis, pelvic tilt relative to the ground, and right hip flexion relative to the pelvis. Transverse plane measurements included: right shoulder horizontal abduction relative to the trunk, trunk rotation relative to the pelvis, pelvic rotation relative to the ground, and right hip rotation relative to the pelvis.

The kinematics of the sagittal and transverse plane motions listed above were plotted and the maximum excursion of each movement determined for each trial at each target distance. The reliability of these repeated excursions was analyzed using intra-class correlation coefficients (ICCs). High mean ICCs (0.716 for trunk flexion to 0.977 for shoulder flexion) allowed mean excursions of the two trials to be used in all further analysis. Repeated measures analysis of variance was used to determine the effect of target distance on reach kinematics with planned post hoc polynomial contrasts to determine trends of the joint movements as target

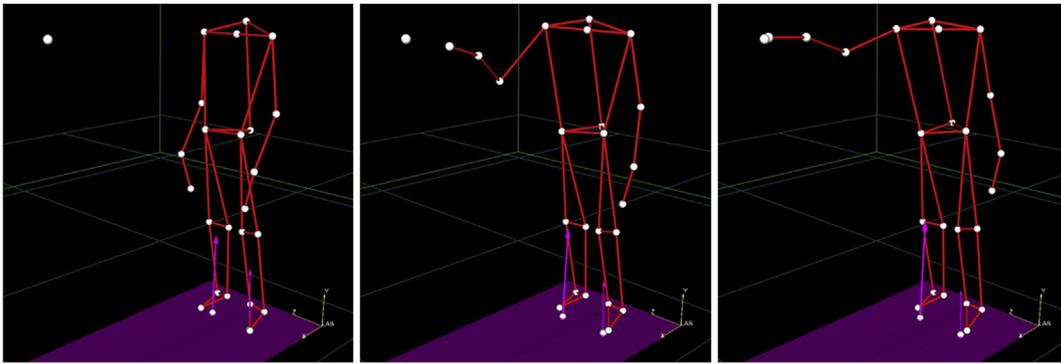


Fig. 2. Oblique view of marker orientation throughout the performance of a standing forward reach to a target 20% of stature beyond baseline. The images (left to right) represent 0%, 50%, and 100% of the forward reach cycle.

distance increased. Planned polynomial contrasts were used to describe the change in movement at each joint as target distance increased and classified as linear, cubic, or quadratic. Data analysis was performed utilizing SPSS version 24 (IBM Corp. Armonk, New York, USA).

3. Results

The sagittal and transverse plane movements during forward reaching are displayed in Fig. 3 (baseline) and Fig. 4 (baseline plus 20% of stature). Right shoulder flexion was the major contributor to reaching the target in the sagittal plane, with trunk flexion also playing a role early during the reaching task. Trunk flexion was more pronounced when participants reached to the furthest target (baseline plus 20% of body height). At this distance, hip flexion and pelvic tilt also made early and sustained contributions. In the transverse plane, right shoulder horizontal abduction was the major contributor to reaching the target, with leftward trunk rotation also beginning early during the reaching task and becoming more pronounced as participants reached to the furthest target. At baseline plus 20% of body height, external rotation of the right hip and leftward pelvic rotation also made notable contributions from the initiation of reaching (see Fig. 4).

Maximum excursion in the sagittal and transverse planes during reaching to progressively distant targets are summarized in Table 2. Analysis of variance showed that all motions increased significantly ($P \leq .001$) as target distance increased. The trend of the increases was significant ($P \leq .001$) and linear for 6 of the motions and significant ($P \leq .001$) and quadratic for 2 of the motions.

4. Discussion

The purpose of this study was to describe the kinematics of the shoulder, trunk, pelvis, and hips of healthy young men as they stood and reached toward a target at arm's length and beyond with their right UE. Our hypothesis was that reaching to a target at shoulder height would involve angular movements at the shoulder, trunk, pelvis and hip and that the movements would increase significantly as the target became progressively more distant.

As expected, based on the findings of previous investigations, we found that reaching involved not just flexion of the shoulder of the reaching right limb, (Bohannon et al., 2017; Fujisawa et al., 2016) but forward flexion and leftward rotation of the trunk (Silfies et al., 2009; Maranesi et al., 2014; Cavanaugh et al., 1999;

deWaroquier-Leroy et al., 2014), and anterior tilting of the pelvis as well (Silfies et al., 2009). We also observed that the right shoulder abducted horizontally relative to the leftward rotating trunk. The pelvis rotated leftward which resulted in right hip external rotation and right hip extension relative to the pelvis as the foot was fixed to the floor.

As anticipated, angular movements increased as the target became increasingly more distant. These increases were largely linear or curvilinear in nature. Previous studies have investigated the kinematics associated with bilateral reaching different distances but did not look at movement of the trunk or pelvis (Kaminski, 2007). Others have examined the kinematics associated with unilateral reaching with participants reaching as far forward as possible (Maranesi et al., 2014; Cavanaugh et al., 1999; deWaroquier-Leroy et al., 2014) precluding the examination of target distance as a determinant of body kinematics.

Our study has several limitations. First, our marker model differed from that used by others. Thus, while allowing us to examine kinematics of interest, the actual degrees of motions are different than those reported by others. Second, for the sake of parsimony we did not examine all of the motions captured by our marker set. For example, left shoulder extension and hip internal rotation were observed but not quantified during right forward reaching. Third, our sample was limited to young males. Age is known to influence the kinematics of reaching (deWaroquier-Leroy et al., 2014) and could reduce the generalizability of our findings. Fourth, all of our participants were right-handed and reached with their right hands. Handedness has been shown to influence reach kinematics (Nelson et al., 2017).

Future investigations should aim to identify alterations within both genders, in reaching kinematics within older individuals and persons experiencing pathology or pain in the shoulders, trunk, pelvis, or hips. If identified these kinematic variations may reasonable targets for clinical intervention in patients exhibiting limitation in standing functional reach.

5. Conclusions

Standing forward reaching with one upper extremity involves motions of the shoulder, trunk, pelvis, and hip. Each component motion increases with further target distances. Knowledge of normal forward reaching kinematics may be useful in identifying abnormalities in movement within clinical populations.

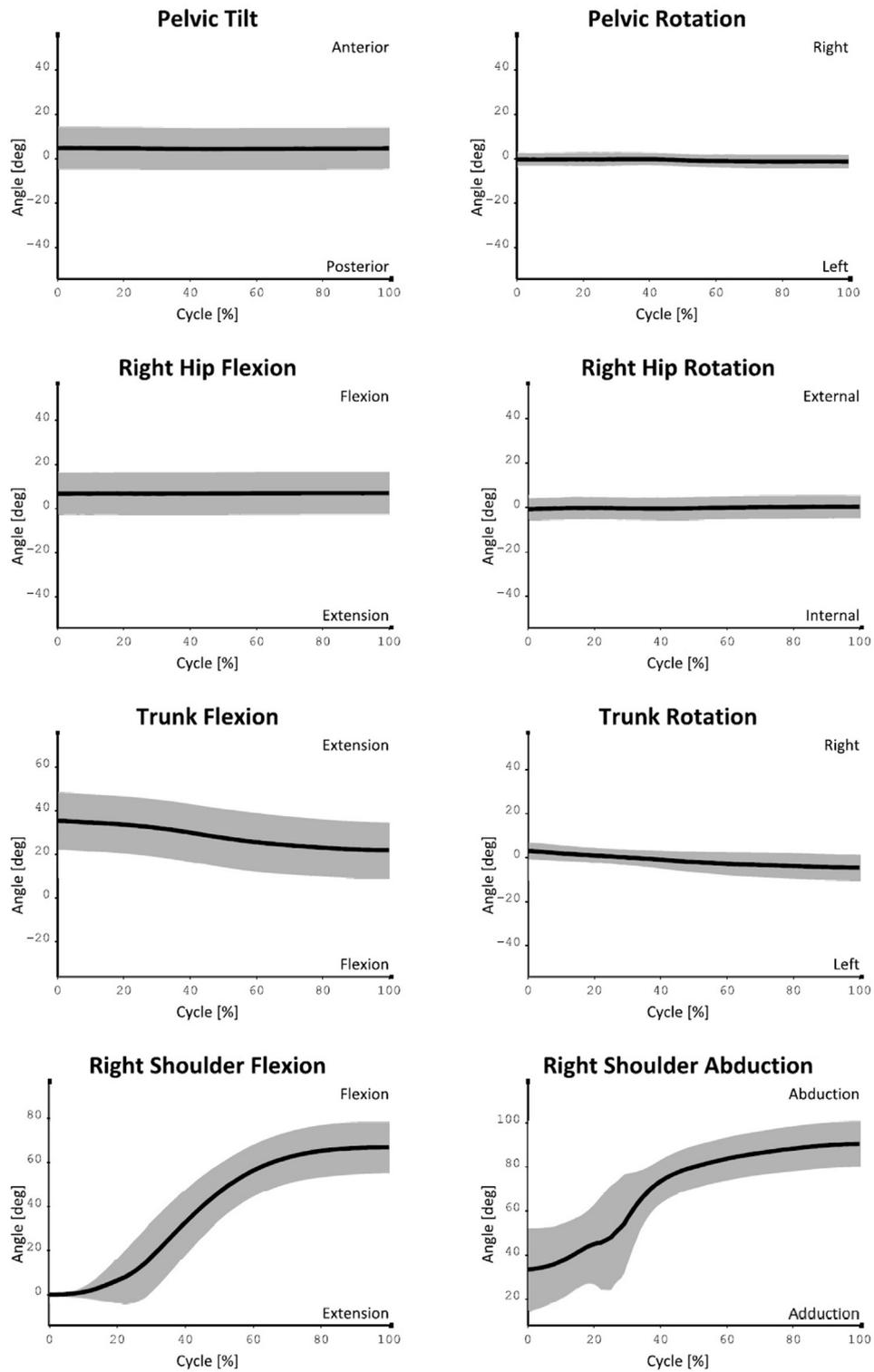


Fig. 3. Plots of 4 sagittal and 4 transverse plane motions during standing forward reach to baseline distance. Forward reach was achieved predominantly by shoulder flexion and abduction with mild trunk flexion and rotation.

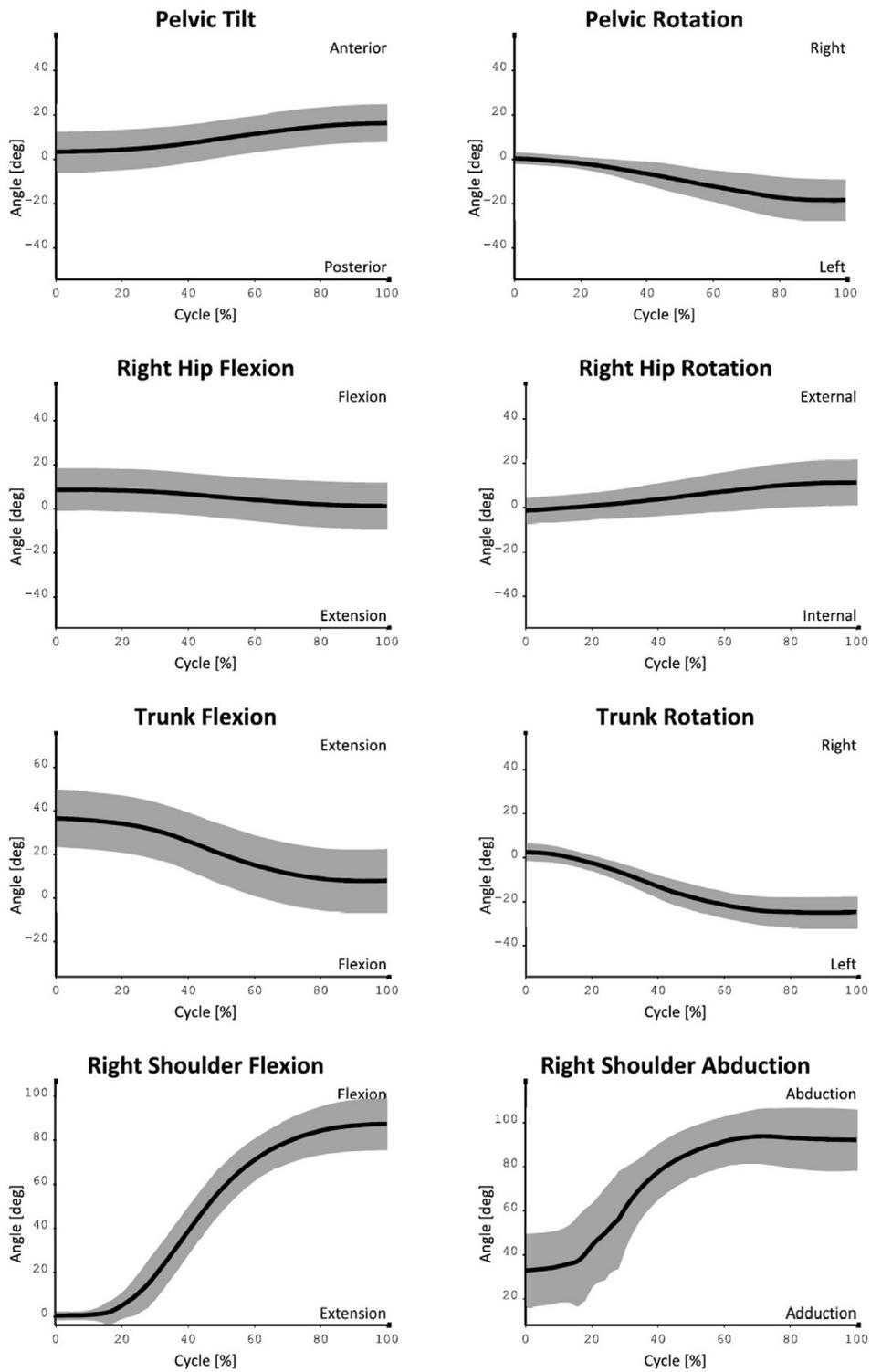


Fig. 4. Plots of 4 sagittal and 4 transverse plane motions during standing forward reach to a distance 20% of stature beyond baseline. Shoulder flexion and abduction remained large contributors, trunk flexion and rotation became more prominent, while pelvic tilt and rotation along with hip extension and rotation began to contribute to forward reach.

Table 2

Maximum motion (degrees) associated with reaching to a target at progressive distances beyond baseline.

Motion	Distance 0%	Distance 5%	Distance 10%	Distance 15%	Distance 20%	Difference F (p)	Trend F (p)
Right shoulder flexion	66.3 (10.9)	70.2 (10.3)	73.9 (10.4)	77.8 (10.6)	87.1 (12.0)	109.1 ($\leq .001$)	152.5 ($\leq .001$)*
Forward trunk flexion	-13.0 (3.3)	-16.5 (3.6)	-20.5 (4.1)	-23.1 (3.9)	-28.5 (5.5)	49.7 ($\leq .001$)	111.0 ($\leq .001$)*
Anterior pelvic tilt	-0.2 (0.6)	0.7 (0.9)	2.9 (1.7)	6.3 (2.5)	12.7 (4.0)	104.8 ($\leq .001$)	114.4 ($\leq .001$)*
Right hip flexion	0.3 (0.5)	0.2 (0.5)	-0.3 (1.1)	-2.3 (2.4)	-7.5 (4.5)	30.2 ($\leq .001$)	46.4 ($\leq .001$)**
Right shoulder horizontal abduction	54.9 (19.1)	61.8 (15.6)	69.2 (18.1)	65.9 (16.5)	59.8 (18.2)	8.3 ($\leq .001$)	73.7 ($\leq .001$)**
Leftward trunk rotation	-6.6 (5.2)	-14.8 (5.4)	-22.7 (6.9)	-26.5 (7.1)	-27.5 (8.1)	72.2 ($\leq .001$)	104.1 ($\leq .001$)*
Leftward pelvic rotation	-0.8 (0.9)	-3.0 (2.9)	-6.9 (6.4)	-12.2 (8.3)	-18.1 (8.4)	38.6 ($\leq .001$)	49.7 ($\leq .001$)*
Right external hip rotation	0.9 (1.1)	2.5 (2.4)	4.9 (4.7)	8.1 (6.7)	12.2 (7.2)	26.4 ($\leq .001$)	31.5 ($\leq .001$)*

Difference F(P) depicts values for repeated measures ANOVA at all target distances. Polynomial contrasts show trend across distances to be primarily Linear (*) or Quadratic (**).

Declaration of competing interest

The authors report no conflict of interest.

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