EXAMINING THE INTRA- AND INTER-DAY RELIABILITY OF THE VALD HUMANTRAK FOR RANGE OF MOTION OF THE SHOULDER IN FIXED- AND FREE-RANGE CONDITIONS

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The purpose of this study was to assess the reliability of a markerless motion capture system, the VALD HumanTrak, for estimating shoulder range of motion. Intra- and inter-day and fixed- and free-range reliability was assessed for shoulder sagittal and frontal plane movements. Results were calculated for three sessions, with 16 general population participants completing the protocol. ICC ranged from good to excellent for abduction (0.753 - 0.959) and flexion (0.868 - 0.975) and poor to good for adduction (0.417 - 0.893) and extension (0.443 - 0.757). The HumanTrak can be a reliable tool to estimate shoulder range of motion within or across days and is a novel measurement tool that has potential use in clinical settings.

KEYWORDS: kinematics, markerless, screening, 3D motion tracking

INTRODUCTION: Athletic, medical, and military populations rely heavily on objective physical performance measurements (Friedl, 2018; Liebermann et al., 2002). Sports technology provides a robust platform to quantitatively capture and analyse biomechanical data, allowing users to monitor and improve physical performance (e.g., range of motion (ROM)) based on the data acquired (Stephenson, McDonough, Murphy, Nugent, & Mair, 2017). VALD's HumanTrak system uses markerless 3D motion tracking to monitor an individual's movements in real-time. This system assesses movement quality, ROM, balance, and stability. HumanTrak shows promise as a tool to estimate shoulder ROM that can be used to highlight improvements, deficits, and changes to injury risk indicators. An earlier version of HumanTrak was reliable, with intra-class correlations above 0.80 in general populations (Beshara et al., 2020). Still, no reliability studies exist using the current model and version, which uses the Azure Kinect camera instead of the Kinect V2. The purpose of this study was to evaluate the reliability of the HumanTrak system within and across days for estimating shoulder ROM in individuals wearing sporting apparel. The following outcome is hypothesised: The HumanTrak ROM data collected will be reliable and give feedback in a non-bias biomechanical form.

METHODS: Sixteen participants were recruited (age 29.9 ± 6.6 years, height 1.72 ± 0.12 m and mass 73.3 ± 15.3 kg) with no history of ROM limitations, acute injuries (≤ 6 months), or medical conditions at the time of testing. Participants completed the Adult Pre-Exercise Screening tool (Exercise Sports Science Australia) and provided written consent approved by the Macquarie University Human Research Ethics Committee (52021988028978). All participants fulfilled the requirement of three testing sessions. Sessions one and two were completed on the same day with a minimum three-hour gap between sessions to assess intra-day reliability. Session three was conducted a minimum of three days after the first day to assess inter-day reliability. All ROM movements were measured and recorded using HumanTrak (VALD, V 2.7.6) at a sample rate of 30 Hz and stored securely via the VALD Hub, a secure cloud-based platform. Participants wore sporting apparel to ensure movement was not unduly restricted. Participants completed one trial of three repetitions for both the left and right side for four shoulder movements (abduction, adduction, flexion, and extension) at a natural speed determined by the participant. All movements were conducted 2.5 to 3 m away from the camera and participants started in anatomical position, facing the camera directly per manufacturers guidelines to be within the calibration zone. All movements were completed with standarised instructions under two conditions: 1) constrained ROM (fixed-range) to a specified target (Dowel, metal frame, or box) and 2) maximal ROM (free-range). For the fixed-range movements, ≈ 130° was imposed for abduction, ≈ 30° for adduction, ≈ 150° for flexion, and ≈ 50° for extension. Data processing was conducted in MATLAB (R2021a, The MathWorks). Average ROM was calculated for each movement in the fixed- and free-range to produce a single ROM value for each session. Intraclass correlation (two-way mixed effects, absolute agreement, single rater/measurement (Koo & Li, 2016), Pearson Correlation (*r*), standard error of measurement (SEM), and 95% confidence intervals (CI) were calculated in Jamovi (Jamovi, v.1.6.23.0) to evaluate HumanTrak's reliability (Weir & Vincent, 2020). ICC values were interpreted as: < 0.5 poor, 0.5 to 0.75 moderate, 0.75 to 0.9 good, and > 0.9 excellent (Koo & Li, 2016). Correlations were defined as follows = 0.3 to 0.5 moderate, 0.5 to 0.7 large, 0.7 to 0.9 very large and > 0.9 nearly perfect (Hopkins, 2000).

RESULTS: Shoulder abduction reliability ranged from good to excellent for each condition, with the lowest ICC in left free-range, intra-day and the highest ICC in the right fixed-range, inter-day. Low SEMs were seen across both free- and fixed-range movements. Shoulder abduction displayed nearly perfect correlations (≥ 0.9) for each condition except the left free-range, intra-day and right free-range, inter-day, which had very large correlations. Intra- and inter-day reliability demonstrated similar results for all but left free-range shoulder abduction intra-day, which showed good reliability (Table 1). Participants achieved a mean average abduction of 125.54° for the fixed-range and a 173.37° for the free-range.
Shoulder adduction ICC values were between 0.417 to 0.893. Right fixed-range, intra- and inter-day and left free-range, intra-day demonstrated good reliability (ICC ≥ 0.778). Poor reliability was found in left fixed-range, inter-day, and moderate reliability was exhibited in all other conditions. All correlations for shoulder adduction movements were large (*r* ≥ 0.61) apart from left fixed-range, inter-day, which displayed a moderate correlation. SEM values were low for all fixed-range movements compared to free-range movements. Intra-day reliability had higher reliability and correlations than inter-day reliability (Table 1). Participants achieved a mean average adduction of 26.86° for the fixed-range and a 48.53° for the free-range.

Table 1. Reliability and correlation analysis of shoulder abduction and adduction

Conditions		Abduction	ICC 95%CI	SEM	*r*	Adduction	ICC 95%CI	SEM	*r*
Left	Free-range	Intra	0.753 (0.42, 0.91)	4.36	0.77**	Intra	0.778 (0.48, 0.92)	8.71	0.77**
		Inter	0.909 (0.76, 0.97)	2.88	0.91**	Inter	0.636 (0.23, 0.86)	11.2	0.65**
	Fixed-range	Intra	0.927 (0.81, 0.97)	2.01	0.93**	Intra	0.689 (0.23, 0.88)	3.51	0.70**
		Inter	0.923 (0.79, 0.96)	2.03	0.92**	Inter	0.417 (-0.06, 0.75)	5.09	0.44
Right	Free-range	Intra	0.897 (0.70, 0.96)	2.48	0.92**	Intra	0.645 (0.24, 0.86)	10.58	0.66**
		Inter	0.852 (0.62, 0.95)	2.93	0.89**	Inter	0.616 (0.18, 0.85)	11.70	0.61*
	Fixed-range	Intra	0.930 (0.82, 0.98)	1.68	0.94**	Intra	0.893 (0.72, 0.96)	2.39	0.90**
		Inter	0.959 (0.89, 0.99)	1.40	0.96**	Inter	0.827 (0.57, 0.94)	3.10	0.84**

Note. *p < 0.05, **p < 0.01, *r* = Pearson Correlation

Shoulder flexion displayed good to excellent reliability, similar to shoulder abduction. SEM was below 6° and nearly perfect correlations were found (Table 2). Participants achieved a mean average flexion of 137.99° for the fixed-range and a 182.81° for the free-range.
Shoulder extension exhibited poor to good reliability; however, good reliability was only observed in the right free-range, intra-day condition. Poor reliability was displayed in left free-range, inter-day, and moderate reliability was seen in all other conditions. SEM values were low for fixed-range movements and high for free-range movements. Correlations for all but two extension movements exhibited were large (*r* ≥ 0.5). Intra-day reliability performed significantly better than inter-day reliability (Table 2). Participants achieved a mean average extension of 39.62° for the fixed-range and a 62.45° for the free-range.

Table 2. Reliability and correlation analysis of shoulder flexion and extension

Conditions		Flexion	ICC 95%CI	SEM	Pearson *r*	Extension	ICC 95%CI	SEM	*r*
Left	Free-range	Intra	0.975(0.93, 0.99)	3.24	0.98**	Intra	0.591(0.10, 0.85)	5.46	0.65*
		Inter	0.891(0.72, 0.96)	5.97	0.90**	Inter	0.443(-0.02, 0.76)	8.05	0.46
	Fixed-range	Intra	0.868(0.67, 0.95)	2.57	0.88**	Intra	0.521(0.06, 0.80)	2.62	0.54*
		Inter	0.907(0.76, 0.86)	2.57	0.92**	Inter	0.566(0.14, 0.81)	2.74	0.57*
Right	Free-range	Intra	0.892(0.72, 0.96)	5.57	0.91**	Intra	0.757(0.4, 0.92)	6.48	0.69**
		Inter	0.962(0.89, 0.99)	2.88	0.96**	Inter	0.534(0.05, 0.82)	9.58	0.54*
	Fixed-range	Intra	0.920 (0.79, 0.97)	2.16	0.95**	Intra	0.639(0.07, 0.87)	2.09	0.80**
		Inter	0.933(0.82, 0.98)	2.32	0.94**	Inter	0.456(-0.01, 0.77)	3.35	0.46

Note. *p < 0.05, **p < 0.01.

DISCUSSION: This study confirmed that HumanTrak is reliable for measuring shoulder flexion and abduction ROM. These results are consistent with previous reliability studies of earlier models of the Kinect camera for abduction and flexion (Beshara et al., 2020; Huber, Seitz, Leeser, & Sternad, 2015). Reliable and precise ROM measurements are integral for injury screening, monitoring, and effectiveness of physical performance programs (Liebermann et al., 2002). The results suggest that the HumanTrak system can be a valuable tool for these activities and show that movements can be measured dynamically due to a natural speed variation used with in this study.

Shoulder flexion and abduction displayed superior results than the other movements for all fixed- and free-range and intra- and inter-day reliability with ICC and correlations generally ≥ 0.852. The results indicate that the HumanTrak has potential clinical use as a tool to measure flexion and abduction (Hopkins, 2002; Koo & Li, 2016). A large ROM value during flexion and abduction was observed relative to the other movements in this study. Large ROM movements reduce error as they are easier to capture; hence, the signal to noise ratio is reduced compared to movements with small ROM values, such as adduction and extension. Furthermore, the arm moves towards the camera (flexion) or in a perpendicular plane (abduction), allowing the arm to be easily tracked in real-time, which improves the camera's ability to detect shoulder orientation without any chance of occlusion at the end range of movement. Potential error in human movement may have caused the outlier in left abduction free-range, intra-day. Therefore, the nature of flexion and abduction seems conducive to the markerless tracking used by the HumanTrak system.

HumanTrak's reliability for measuring adduction is not as good compared to abduction. The adduction movement came out of the perpendicular plane and displayed less ROM than abduction, likely producing a larger variance in individual measurement scores. Despite a low ROM, adduction showed mostly large correlations and acceptable SEMs for fixed-range movements. The ICC scores may not articulate the complete picture of reliability; thus, further investigation is required. In comparison to previous work that used an older Kinect model right, fixed-range reliability (ICC ≥ 0.827) outperformed an ICC value of 0.680 for adduction (Cai, Ma, Xiong, & Zhang, 2019). Left intra-day, fixed-range adduction had equivalent reliability to the Cai study; however, the inter-day reliability is concerning as it demonstrates poor reliability. Similar ICC fluctuations were seen in all free-range shoulder adduction movements. It is difficult to determine whether this poor reliability was a system error or a human movement error. Potential causes of low reliability for adduction could be attributed to the unnatural nature of this task and inconsistencies in the execution of this movement by the participants, such as changes in trunk rotation between sessions.

Overall, shoulder extension had the poorest reliability out of all the movements. A small ROM relative to flexion, the direction of the arm away from the camera, and occlusion of the arm during extension may have been potential causes for low ICC values. Discontinuity when tracking the arm's position due to occlusion may have led to errors in the observed ROM values; this is relevant to this study because peak values for each repetition were calculated. A recent study tested participants' free-range shoulder extension using a previous Kinect model and found an ICC of 0.620 (Çubukçu, Yüzgeç, Zileli, & Zileli, 2020). In the current study, the highest ICC for shoulder extension free-range (0.757) was higher than the Cubukkcu study;

however, the present study's fixed-range and left free-range movements were typically lower. The inconsistencies between conditions and the variable ICC values indicate that more research is required for extension.

Human movement error can influence reliability since free-range ROM effort can be challenging to repeat. Shoulder extension and adduction are not movements typically practised in isolation, nor to their maximal ranges, potentially leading to variability in the results. While the standardised instructions were designed to limit the effects of human movement error, its influence cannot be entirely removed. Consistent equipment set-up also produced a challenge due to the need to change equipment placement, particularly with the inter-day testing scenario (Tziner, Fein, & Oren, 2012). Floor markers were used to mitigate errors in the set-up procedures.

CONCLUSION: VALD's HumanTrak system is a reliable tool to measure shoulder abduction and flexion ROM in fixed- and free-range conditions within and across days while wearing sports aparel. Shoulder adduction and extension reliability ranged from poor to good, with further investigation required. Random system errors and variability in human movement possibly explain these results. VALD's HumanTrak system tended to show superior reliability to previous Kinect camera models. As a non-intrusive ROM evaluation measurement tool, the HumanTrak shows progression towards markerless motion capture systems being used in clinical and human performance testing for shoulder flexion and abduction ROM.

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