Assessment of Shoulder Girdle Elevation Motion using Daid Smart Shirt: A Reliability and Validity Study

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Abstract: Muscle function around the shoulder girdle can be impaired by pain, which leads to abnormal movement *e.g.* elevation. Movement faults should be assessed specifically, therefore individual sport rehabilitation strategies can be implemented. Smart garments are efficient for upper body movement assessment. There is a lack of literature stating that smart textile garments are reliable and valid for shoulder gridle elevation. The purpose of the study was to examine reliability and validity of the DAid smart shirt during shoulder girdle elevation. Twenty-one female volunteers aged 24.3. (SD3.3), body mass index 19.3 (SD 0.5) were recruited. The DAid smart shirt and 2D movement video analysis software Quintic Biomechanics v26, UK were the assessment tools utilized. Cronbach alpha coefficient and Interclass Correlation Coefficient were calculated to assess the within-session test-retest reliability. *Bland – Altman* analysis was applied to determine validity. Results: reliability for the right side measures: Cronbach alpha coefficient $\alpha \geq 0.9$, ICC ≥ 0.9. Reliability for the left side measures: Cronbach alpha coefficient $\alpha \geq 0.9$, ICC ≥ 0.91. *Bland -Altman* analysis presents that DAid smart shirt measures are valid during shoulder girdle elevation. Conclusion: smart shirt measures are reliable and valid during shoulder girdle elevation movements.

1 INTRODUCTION

Shoulder pain affects 22.3% of people, with significant detrimental impact on health-related quality of life and physical functioning (Hill et al, 2010). There is high prevalence of shoulder pain in the populations of overhead athletes, with reports of 12% in amateur golf (McHardy, Pollard and Luo, 2007), 16% in volleyball (Clarsen et al., 2014), 22% to 36%% in elite handball (Myklebust et al., 2011) and 24% in high-level adolescent tennis, which increases to 50% in middle-aged tennis players (Abrams et al, 2012). The prevalence of shoulder pain is even higher in swimmers, ranging between 40% and 91% (Wanivenhaus et al., 2012).

Evidence suggests that muscle function around the shoulder girdle can be impaired by pain and pathology. Altered timing (latency) of electromyographic (EMG) activity has been identified in muscles of the scapula and the glenohumeral joint. Motion analysis studies have identified abnormal movements of the scapula which include elevation, internal rotation of the scapula, and anterior tilt. Alterations in the dynamic control of scapula-thoracic joints are important factors in shoulder pathology. Literature supports the need for a specific assessment of movement faults, so individual rehabilitation strategies can be implemented (Comerford and Mottram, 2012).

There is a wide range of healthcare applications to smart garments, including rehabilitation (Wang et al., 2017), prevention of shoulder injury in overhead sports (Rawashdeh et al., 2016) and enhance physical therapy treatment, e.g., for treating shoulder musculoskeletal disorders and pain (Wang et al, 2017). One of the main parts of smart garments is the sensing system which can include one or several sensing elements for posture and joint motion control and assessment (Wang et al., 2017). The smart garment system is efficient for upper body movement assessment during simple tasks (Wang et al., 2017) and a customized smart shirt can be an objective and convenient device for shoulder motion capture and monitoring during advanced motor tasks such as

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shoulder motor control exercises and ballet training sessions (Semjonova et al., 2018).

However, there is a lack of literature supporting that DAid smart shirts are reliable and valid for the assessment of shoulder girdle elevation motions.

This study aims to examine the reliability and validity of the DAid smart shirt measures during shoulder girdle elevation motions.

2 METHODOLOGY

2.1 Participants

Twenty-one healthy participants of age 24.2 (SD 3.3) were recruited on a voluntary basis. Their Body Mass Index was 19.3 (SD 0.5). Body mass index was (BMI) calculated from self-reported weight (kg) and height (m) according to WHO (World Health Organization) Regional office for Europe guidelines. Participants were excluded if they reported any current neck or shoulder pain, or a history of major trauma to the neck or shoulder (e.g. dislocations, fractures or surgery). Participants gave written informed consent for inclusion before they participated in the study. The study was conducted in accordance with the Declaration of Helsinki, and the study protocol was approved by the Ethics Committee of Riga Stradins University (183/26.01.2017).

2.2 Instrumentation

DAid Smart shirt was used to capture and monitor shoulder girdle motion during a research task for the participants. This smart garment was developed in collaboration between Riga Technical University and Riga Stradins University for posture assessment (Semjonova et al, 2018).

The DAid Smart shirt presents a tight shirt with four embedded highly sensitive knitted strain sensors (Oks et al, 2014). Sensor reactions are transferred via sewn electro conductive pathways to an electronic device acquiring the data and then via Bluetooth to a computer or tablet. The specific placement of the sensor provides independence of the sensors' reactions to patient's shoulder elevation-depression movements. ADC 1 – left side shoulder elevation; ADC 2 – right side shoulder elevation; ADC 3 – right side shoulder protraction; ADC 4 – left side shoulder protraction (Fig.1).

The two camera 2D optical motion capture system Quintix Biomechanics v26 (UK) was used to record the positional data of the reflective markers (diameter: 10 mm) at 100 samples/s. Four reflective

Figure 1: Participant with a smart shirt with sensors and reflective markers for the motion capture system during intervention.

markers were attached to the DAid smart shirt over scapular anatomical landmarks: on the right and left side *angulus acromialis (R_AA, L_AA)*; the right and left side *trigonum spinae scapulae (R_TS, L_TS)* in a neutral standing posture (Fig.1). According to the recommendation of the International Society of Biomechanics (USA) on definitions of joint coordinate systems of various joints for the reporting of human joint motion—Part II: shoulder, elbow, wrist and hand (Wu et al., 2005).

2.3 Intervention

Participants stood with their feet shoulder width apart and arms by their side and performed a standardized familiarization and warm-up procedure of moving their scapula into the end range clavicle movements. Participants were instructed to: 'move the right shoulder girdle as far up as they can' (elevation), 'as far down' (depression). This process was repeated three times (10s rest between repetitions) and one-minute rest between the conditions was given to avoid fatigue (Bet - Or et al., 2017). The metronome was used for counting seconds. The *Metronome Beats* Mobile App in Sony Xperia™ smartphone was set at 60 bpm. Each recording length was 13 seconds.

2.4 Data Statistical Analysis Methods

Descriptive statistical analysis was carried out to describe the study population. The reliability and validity of values of the smart shirt in millivolts (mV) and the angle values of the optical motion capture system in degrees were analysed using IBM SPSS Statistics 22.0 software (IBM Corporation, New York, USA) and Microsoft Excel 2010.

To assess the within-session test-retest reliability for repeated measure units (mV) during the task, Cronbach α coefficient (a Cronbach's $\alpha \geq 0.70$ was considered reliable) and Interclass Correlation Coefficient (ICC) was calculated. Inter-rater reliability was considered poor for ICC values less than 0.40, fair for values between 0.40 and 0.59, good for values between 0.60 and 0.74, and excellent for values between 0.75 and 1.0 (Cicchetti et al., 2006).

To assess the validity within two quantitative methods, Bland Altman analysis was applied. The Bland-Altman analysis plot describes the agreement between the quantitative measurements by constructing limits of agreement. These statistical limits are calculated by using the mean value and the standard deviation and the 95% confidence interval for the limits of the differences between two measurements. To check the assumptions of normality of differences and other characteristics, Bland – Altman system uses a graphical approach (Giavarina, 2015).

3 RESULTS

All data from the DAid smart shirt and optical motion capture system Quintix Biomechanics v26 were imported to the Microsoft Excel 2010 programme. The ACD 1 sensor, ACD 2 sensor and time values where extracted from other unnecessary data. The angular degree and time values of the left and right-side shoulder girdle elevation motions were extracted from the optical motion capture system. The system data were gathered in one common sheet in Microsoft Excel 2010 programme. Visual graphs were made for all the three repeated measures on the left-side (Appendix.Fig.8, Fig.9, Fig.10.) and right-side (Fig.2., Fig.3., Fig.4.), for all 21 participants.

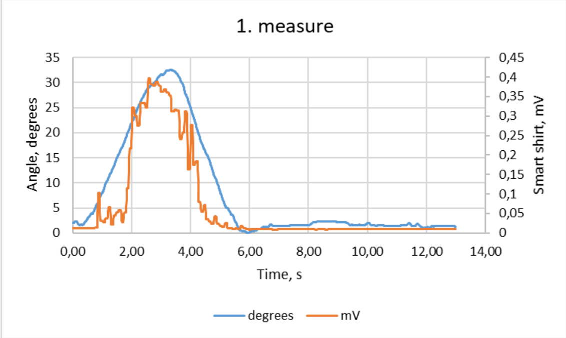

Figure 2: First measure for the right-side shoulder elevation motion.

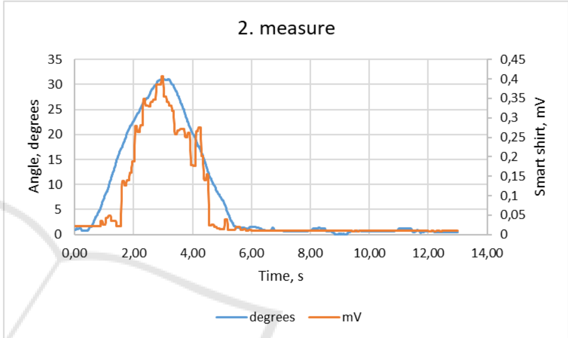

Figure 3: Second measure for the right-side shoulder elevation motion.

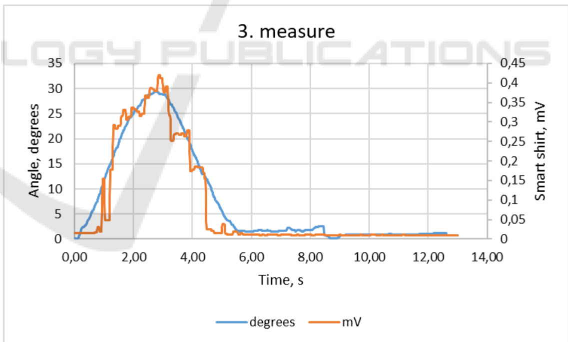

Figure 4: Third measure for the right-side shoulder elevation motion.

Only data from the ACD 1 sensor – left shoulder elevation – and the ACD2 sensor – right shoulder elevation – were analysed. Disadvantages were established in capturing protraction movement with a two-camera 2D optical motion capture system Quintix Biomechanics v26 (UK).

3.1 Reliability

To calculate reliability and validity of the DAid smart shirt as compared with the gold standard of the motion capture system: an optical motion capture system in laboratory environment, data from Microsoft Excel 2010 were imported to IBM SPSS Statistics 22.0 software,

After three repeated measures, the ACD 1 left side results show excellent ICC and Cronbach's α coefficient values. ICC values: 0.91 (95%CI 0.9 - 0.92) – 0.99 (95%CI 0.99 – 0.99) ($p < 0,0001$). Cronbach's α coefficient values: 0.91 – 0.99. The data from ACD 2 – right shoulder elevation shows excellent ICC and Cronbach's α coefficient values. ICC values: 0.91 (95%CI 0.9 - 0.91) – 0.99 (95%CI 0.99 – 0.99) ($p < 0,0001$). Cronbach's α coefficient values: 0.91 – 0.99 during intervention.

3.2 Validity

Bland Altman analysis was applied to assess the validity of the DAid smart shirt measurements and optical motion capture system Quintix Biomechanics v26 as the "gold standard".

The left and right-side 8 s elevation motion duration was divided into 0.5s intervals. Plots of Bland Altman analysis were created for the right and left-side shoulder elevation motion interval of each 0.5s. There were 16 Bland-Altman plots for the right-side shoulder and 16 Bland-Altman plots for the left side shoulder.

First, to compare the values, the amplitude values in millivolts (mV) and the optical motion capture system shoulder elevation angle values in degrees in the DAid smart shirt shoulder elevation motion were normalized.

Second, for the Y axis, the difference between a normalized (N) DAid smart shirt and a normalized (N) Quintix v26 optical motion analysis system values were calculated. For the X axis, the average of these normalized values was calculated. Afterwards, horizontal lines were drawn: the mean difference and the limits of agreement as 95% confidence interval (CI), which are defined as the mean difference plus and minus 1.96 times the standard deviation of the differences (Fig.5.).

Bland Altman recommended that 95% of the data points should lie within limit of agreement (95% confidence interval). There can be no more than 2 data points or outliers out of limit of agreement when comparing the normalized values of the DAid smart shirt and the normalized values of the Quintix optical motion capture system during 0.5s shoulder elevation motion interval.

Regarding the right-side, 100% all data points were in limit of agreement within 16 Blant Altman plots for 0.5s motion interval. Limit of agreement

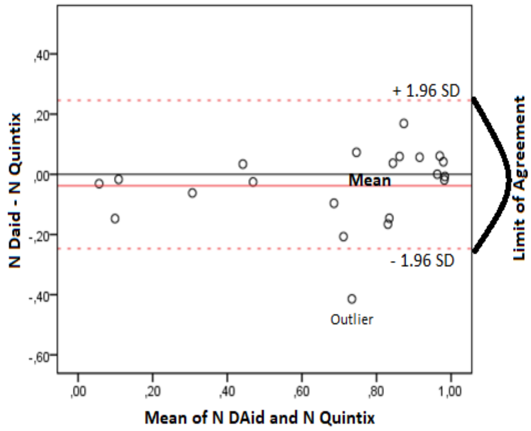

Figure 5: DAid smart shirt method and Quintix method comparison Bland Altman plot.

minimal values for the right-side were within a 0.5s interval of a 7s elevation motion: -0.06: 0.04 (95% CI) (Fig.6). The maximum values of the limit of agreement for the right-side were within a 0.5s interval of a 1.5s elevation motion: -0.34: 0.35 (95% CI).

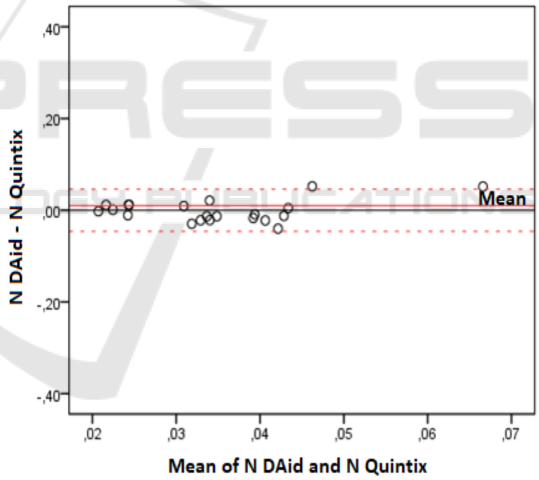

Figure 6: DAid smart shirt and Quintix comparison for right-side shoulder elevation in 7s 0.5s interval.

Left-side 15/16 Bland Altman plots shows, that data points were in limit of agreement. There were 4 outliers from limits of agreement in 1.5s during left shoulder elevation motion in the Bland Altman plot. Limit of agreement minimum values for the left-side were within a 0.5s interval of a 7.5s elevation motion: -0.05: 0.03 (95% CI) (Fig.7). Limit of agreement maximal values for left-side were within a 0.5s interval of a 4.5s elevation motion: -0.25: 0.31(95% CI).

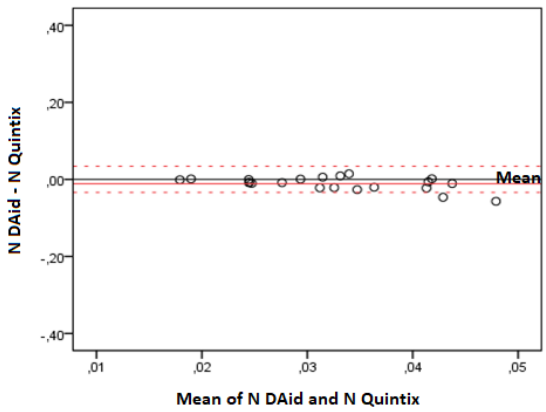

Figure 7: DAid smart shirt and Quintix comparison for left-side shoulder elevation in 7.5s 0.5s interval.

4 DISCUSSION

This study was performed to examine the reliability and validity of the DAid smart shirt measures during shoulder girdle elevation motion.

As significant amount of literature on shoulder motion analysis and optical motion capture systems recording the positional data of the reflective markers identified abnormal movements of the scapula which include elevation (Comerford and Mottram, 2012), a specific assessment of movement faults should be implemented to build individual rehabilitation strategies.

The present study revealed that the DAid smart shirt is reliable and valid to assess shoulder girdle elevation motion on both left and right sides compared with the gold standard optical motion capture system Quintix Biomechanics v26. All DAid smart shirt measures were reliable and valid, however, during the 1.5s left side shoulder motion assessment there were some outliers in the Bland Altman plot. It was also claimed in Cai et al study (Cai et al., 2019), where they tested the concurrent validity and the test-retest reliability of upper limb functional assessment using low-cost marker less motion capture system (Microsoft Kinect V2 Sensor). The system had good accuracy in measuring shoulder angles. However, there were also some deviations both between the Kinect V2 system and the Vicon system (gold standard) and between test sessions (Cai et al., 2019).

Results show that the DAid smart shirt can reliably measure right and left side shoulder elevation motions and measures agree well with the optical motion capture system. In clinical implications it means that DAid smart shirt can be an objective and convenient device for the assessment of abnormal shoulder motions such as elevation.

For both: patient and physiotherapist it can be used as an effective assisting device in addition to conventional physiotherapy for shoulder girdle motion capture and monitoring during shoulder rehabilitation tasks.

The DAid smart shirt motion assessment method is objective, which helps to quantify kinematic parameters and turn data into a knowledge-based data. Also, for a rehabilitation specialist e.g. physiotherapist this is an effective assisting device, because the therapist must not control patient’s shoulder girdle stability during arm movement all the therapy time, as a result therapy process is optimized, but still effective.

Future studies are needed to evaluate these wearable devices over an extended period, and during rehabilitation tasks and within therapy sessions in rehabilitation settings with patients suffering from shoulder pain.

Several limitations apply to this study. First, the DAid smart shirt was a one-sized compression shirt with sewn up textile strain sensors. Second, there were disadvantages in capturing protraction movements with the two-camera 2D optical motion capture system Quintix Biomechanics v26 (UK).

5 CONCLUSIONS

The present study shows that the DAid Smart shirt is reliable and valid for the assessment of the right and left side shoulder girdle elevation motions. The DAid smart shirt has great potential as a low-cost, easily implemented device for assessing abnormal shoulder motions such as shoulder girdle elevation during upper limb rehabilitation tasks. The system is suitable for assessing change in upper limb motions over time, such as disease progression or improvement due to intervention.

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APPENDIX

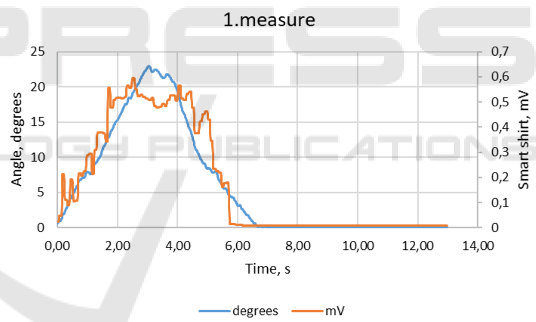

Figure 8: First measure for the left-side shoulder elevation motion.

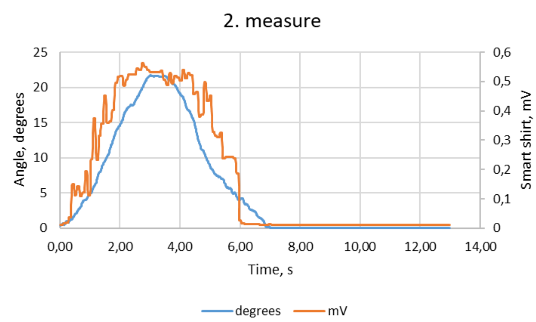

Figure 9: Second measure for the left-side shoulder elevation motion.

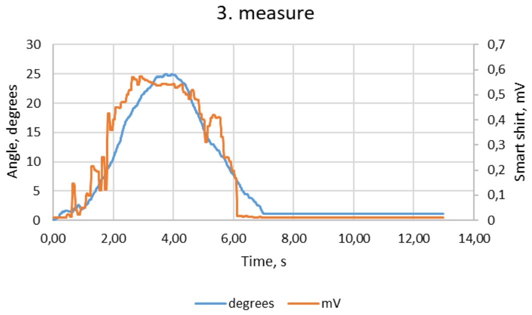

Figure 10: Third measure for the left-side shoulder elevation motion.