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Ageing and joint position sense of the asymptomatic shoulder: An observational study

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ABSTRACT

Purpose: This study aimed to quantify the extent to which age was associated with joint position sense (JPS) of the asymptomatic shoulder as measured by joint position reproduction (JPR) tasks and assess the reproducibility of these tasks.

Methods: 120 Asymptomatic participants aged 18–70 years each performed 10 JPR-tasks. Both contralateral and ipsilateral JPR-tasks were evaluated on accuracy of JPR under active- and passive conditions at two levels within the shoulder forward flexion trajectory. Each task was performed three times. In a subgroup of 40 participants, the reproducibility of JPR-tasks was assessed one week after initial measurement. Reproducibility of JPR-tasks was evaluated by both reliability (intra-class correlation coefficients (ICC's)) and agreement (standard error of measurement (SEM)) measures.

Results: Age was not associated with increased JPR-errors for any of the contralateral or ipsilateral JPR-tasks. ICC's ranged between 0.63 and 0.80 for contralateral JPR-tasks, and from 0.32 to 0.48 for ipsilateral tasks, except for one ipsilateral task where the reliability was similar to contralateral tasks (0.79). The SEM was comparable and small for all JPR-tasks, ranging between 1.1 and 2.1.

Conclusion: No age-related decline in JPS of the asymptomatic shoulder was found, and good agreement between test and re-test measurements for all JPR-tasks as indicated by the small SEM.

1. Introduction

The shoulder, the glenohumeral (GH) joint in particular, contributes to the exceptional mobility of the arm. However, because of its extensive mobility, it is also inherently an unstable joint and, therefore, susceptible to injury (Veeger and van der Helm, 2007). To maintain joint stability during movement and prevent injury, the GH-joint relies heavily on a coordinated interplay between its dynamic (e.g. muscles) and static stabilisers (e.g. labrum, ligaments, and capsule) (Veeger and van der Helm, 2007). A crucial factor for a well-coordinated interplay between these stabilisers is proprioception (Lephart and Jari, 2002). Proprioception is defined as "our perception of joint movement and positioning in space in the absence of visual feedback" (Ager et al., 2017; Sherrington, 1906). It is regulated by i) the cumulative proprioceptive input of mechanoreceptors within muscles, tendons, ligaments, joint capsules and skin, and ii) the central processing of this proprioceptive input in the central nervous system (Han et al., 2016; Ribeiro and Oliveira, 2007). Together, the peripheral mechanoreceptors and central information processing ensure adequate motor responses from shoulder stabilisers and consequently joint stability during movement (Lephart and Jari, 2002).

Proprioception includes several subdomains such as joint positioning sense (JPS), kinaesthesia, sense of change in velocity and sense of force (Ager et al., 2020). Various measurement methods have been developed to test these subdomains specifically, of which JPS is most commonly used to measure proprioception in a clinical setting (Uhl et al., 2002; Vafadar et al., 2016). JPS can be evaluated with various joint position reproduction (JPR) tasks. JPR-tasks can be assessed under active- or passive conditions and may involve either ipsilateral (i.e. the same arm is used for position reproduction) or contralateral (i.e. opposite arm is used for position reproduction) tasks (Han et al., 2016; Zuckerman et al., 1999). The peripheral proprioceptive input and central processing of

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this input depend on the type of JPR-task. For example, muscle spindles and Golgi tendon organs are considered the most important mechanoreceptors for active JPR-tasks, while cutaneous mechanoreceptors (e.g. Pacini and Meisner's corpuscles) play a more dominant role in passive JPR-tasks (Han et al., 2016). Ipsilateral JPR-tasks have a memory component as the same arm is used for both the reference- and reproduction position so that participants must use their memory to accurately reproduce the reference position. Contralateral JPR-tasks require interhemispheric communication as the opposite arm is used for position reproduction (Goble, 2010). Therefore, studies should assess a combination of different JPR-tasks to provide a comprehensive overview of JPS.

In existing literature, it is suggested that JPS declines with age (Adamo et al., 2007; Ferrell et al., 1992), thereby jeopardizing joint stability and increasing the risk of shoulder injury (Lephart and Jari, 2002). Several physiological changes that occur with ageing might affect JPS, such as a decline in the number of mechanoreceptors, decreased mechanoreceptor sensitivity, and degenerative changes of the central nervous system (Aydoğ et al., 2006; Hughes et al., 2015; Miwa et al., 1995; Swash and Fox, 1972). Previous studies that evaluated the effect of age on JPS have, however, reported conflicting results and predominantly focussed on the lower extremities (Adamo et al., 2007; Franco et al., 2015; Kaplan et al., 1985; Pickard et al., 2003; Relph and Herrington, 2016; Schmidt et al., 2013). Only two previous studies evaluated the association between ageing and JPS in the asymptomatic shoulder, both suggesting that JPS declines with age (Echalier et al., 2019; Zuckerman et al., 1999). However, these studies only evaluated a selected subset of active- or passive ipsilateral JPR-tasks, thereby not providing a comprehensive overview of JPS for the ageing shoulder, and also did not assess the reproducibility of JPR-tasks. This study therefore aimed to provide a more comprehensive overview of the extent to which age was associated with JPS of the shoulder in an asymptomatic population. We hypothesised that there would be an age-related decline in JPS. As a secondary aim, we explored the reproducibility of JPR-tasks over time in a subgroup of participants.

2. Methods

2.1. Participants

In this observational study we evaluated JPS of the shoulder in asymptomatic participants between the age of 18 and 70 years. The participants were recruited through advertising in the Leiden University Medical Center (LUMC) public areas and snowballing methods between May 2018 and January 2019 (Fig. 1). To ensure an equal distribution of participants across different age ranges, we recruited 30 participants within each of the following age categories: 18–31, 32–45, 46–58, and 59–70 years old. The exclusion criteria were previous shoulder complaints (i.e. participants who received medical attention for a shoulder complaint or experienced shoulder complaints >1 week), no full range of motion during physical examination, pregnancy, a history of malignancy, previous shoulder fracture, previous shoulder surgery, neurologic or muscle disease, diabetes mellitus, electronic implants, or insufficient Dutch language skills. All measurements were conducted at the laboratory for Kinematics and Neuromechanics (LUMC, the Netherlands). The institutional medical ethical board (METC Leiden-Den Haag-Delft) approved this study (protocol number: P18.028) and written informed consent was obtained from all study participants.

3. Measurement set-up

All measurements were performed using a 3D-electromagnetic motion analysis device (Flock of Birds (FoB); Ascension Technology, Milton, VT, USA). This validated motion device is frequently used to quantify shoulder motion and can accurately (error margin is approximately 2 mm) assess the position of the upper limbs in the 3 dimensional space (Meskers et al., 1998, 1999).

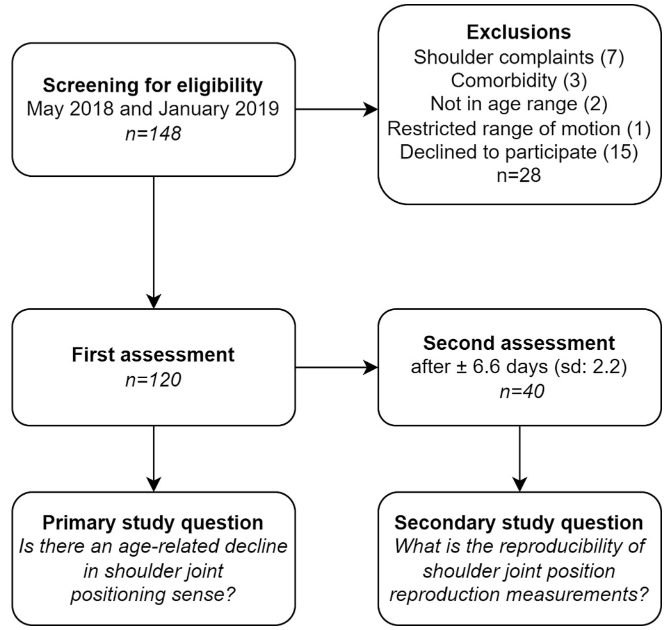

Fig. 1. Flowchart of participant inclusion.

During all measurements, participants were seated in the FoB with their torso upright against the back of a chair. Seven wired sensors were placed on the participant in a standardised way by the investigator using either straps with adhesive tape (manubrium sterni and bilaterally on the flat craniolateral surface of the acromion) or hook-and-loop closures (bilaterally posteriorly on the distal part of the humerus and bilaterally on the dorsal side of the distal forearm). One additional sensor was attached to a stylus to digitise twenty-four-bony landmarks identified by palpation and create a 3D bone model specific for each participant (de Groot, 1997; Meskers et al., 1999).

3.1. Experiment design

JPS was assessed using multiple JPR-tasks in the trajectory of shoulder forward flexion. JPR is widely accepted and one of the most commonly used methods for measuring proprioception through the accuracy of position reproduction (JPR-error, i.e. the difference between a predetermined reference position and the reproduction of this position) in the absence of visual feedback(Ager et al., 2017; Dover and Powers, 2003). In the present study, the position of the wrist (i.e. the projection of the centre of the processus styloideus radii and the processuss styloideus ulnae) was used to estimate JPR-error. JPR-error was defined as the absolute difference in height (in centimetres (cm)) between the wrist's reference- and reproduction position on the y-axis of the FoB system.

A combination of ipsilateral and contralateral JPR-tasks were conducted because of the difference in central processing for these tasks as described above (Han et al., 2016). For ipsilateral JPR-tasks, the arm of a blindfolded participant is brought (either actively by the participant or passively by the investigator) to a predefined reference position for at least three seconds and the participant is asked to remember this position. Then, the arm is returned to the starting position. Subsequently, the investigator requests the participant to reproduce the predefined position (again either actively or passively) with the same arm. For contralateral JPR-tasks, the arm of a blindfolded participant is brought to a predefined reference position (again either actively or passively) and the arm stays in this position. Thereafter, the investigator requests the participant to reproduce the predefined position with the contralateral arm.

As it has been shown that JPR-error varies with the level of shoulder forward flexion (Anderson and Wee, 2011), we tested JPS at two different levels of shoulder forward flexion: i) a low position (i.e. approximately 50 degrees of shoulder forward flexion) and ii) a high position (i.e. approximately 90 degrees of shoulder forward flexion). For each position, participants had to perform five different types of JPR-tasks as the peripheral proprioceptive input differs for active- and passive JPR-tasks (Goble, 2010): i) contralateral active-active reproduction, ii) contralateral passive-active reproduction, iii) ipsilateral active-active reproduction, iv) ipsilateral passive-passive reproduction, and v) ipsilateral passive-active reproduction. Each JPR-task was performed three times, so each participant performed 30 JPR-tasks in total.

During all measurements the participants were blindfolded and did not wear clothes covering the shoulder to avoid proprioceptive input of the skin. The participants were instructed to keep their elbows straight during all JPR-tasks. All measurements were conducted by four investigators, who had received extensive training before study start. To minimise the effect of arm dominance, the arm to be tested was determined using computer-generated block randomisation in blocks of two. Furthermore, to reduce learning effects, the participants did not receive feedback regarding their JPR accuracy and the sequence of tasks was randomised to minimise the impact of muscle fatigue (Carpenter et al., 1998).

When evaluating the association between age and JPS, it is essential that the outcome measure is reproducible. Therefore, we also assessed whether JPR-tasks could be reproduced over time. For a subgroup of participants, JPR-tasks were assessed twice by the same investigator, one week after the first assessment (see sample size justification below). We assumed that one week was short enough to avoid any significant changes within the participants and/or investigator affecting study measurements.

All data were analysed using custom-made software in MATLAB (2021b release, The Mathworks Inc. Natick, Massachusetts, USA).

3.2. Statistical analysis

Before our study, a power analysis using G*power Version 3.0.10 (Faul et al., 2009) was conducted to estimate the sample size needed. Based on an alpha of 0.05 and a power of 0.80 it was estimated that 111 participants were required for an effect size of 0.3 with regression analysis. Accounting for approximately 10% loss of data, 120 participants were recruited. For reproducibility analysis, it is advised to recruit at least 30 participants (Koo and Li, 2016). We increased the sample size for reproducibility analysis to 40 participants to account for potential loss of data.

All statistical analyses were performed using the statistical package SPSS version 25.0 (IBM, Armonk, NY, USA). Parametric continuous data were described using means, standard deviation (SD) and 95% confidence intervals (CI) and nonparametric data were expressed in medians and interquartile ranges (IQR). Numbers and percentages were presented for categorical data.

For each of the 10 JPR-tasks, a linear mixed model analysis was used to evaluate the association between JPR-error and age (in years) to account for the three repeated task measurements. We modelled covariance with an unstructured covariance structure. Repetition (repetition 1, 2, and 3) was included as the repeated factor, and we adjusted for sex (male/female), BMI (kg/m^2) and sports hours per week which were included as fixed factors. Measurements in which the reference position deviated >20 degrees from the actual target value were excluded from the analysis. A Bonferroni correction was applied to correct for multiple testing (Armstrong, 2014) which set the P-value to indicate statistical significance on less than 0.005 ($\alpha = 0.05/10$).

To estimate the reproducibility of JPR-tasks, both reliability (intraclass correlation coefficients (ICC)) and agreement (standard error of measurement (SEM)) measures were calculated (de Vet et al., 2006). The mean JPR-error of the initial- and re-test measurements in the subgroup of participants was used to determine JPR-task reliability over time, and quantified by the ICC from a two-way mixed model with absolute agreement (Weir, 2005). The following classification was used to interpret ICC values: 0.0–0.5, poor reliability; 0.5–0.75 moderate reliability; 0.75–0.9, good reliability; 0.9–1.0 excellent reliability (Koo and Li, 2016). A well-known disadvantage of ICC is that a lack of variability among the sampled participants may result in misleadingly low ICC values (Koo and Li, 2016). Therefore, the ICC was supplemented by the SEM, calculated for each JPR-task using the following formula: $SEM = SD \times \sqrt{(1 - ICC)}$ (de Vet et al., 2006). Here, SD reflects the pooled standard deviation from the initial and re-test measurements.

4. Results

In total, 120 participants participated in the study with a mean age of 44 years (SD: 14.9). The majority were female (56%) and right-hand dominant (92%). Other baseline characteristics can be found in Table 1.

Table 2 shows the association of age with JPR-error in each of the contralateral and ipsilateral reproduction tasks. Age was not significantly associated with JPR-errors for any of the contralateral JPR-tasks ($p > 0.005$). Similar results were found for the ipsilateral JPR-tasks, with only one of the ipsilateral JPR-tasks approaching statistical significance (task: Passive-Active; Low, estimate: 0.066 (95%CI: (0.020–0.112), $p = 0.005$).

A subgroup of 40 (33%) participants had their JPR-tasks re-assessed by the same assessor, after a mean of seven days (SD: 2.2). These participants had a mean age of 44 years (SD: 15.4), 23 (58%) were male and 38 (95%) were right-hand dominant. For contralateral reproduction tasks, the ICC's ranged between 0.63 (task: Active-Active; Low) and 0.80 (task: Passive-Active; Low) (Table 3). For ipsilateral reproduction tasks, the ICC's were considerably lower (ranging between 0.32 and 0.48), except for the passive-active task in low position (0.79). The SEM was comparable for all JPR-tasks, ranging from 1.1 to 2.1 (Table 3).

Table 1
Participant characteristics.

	Asymptomatic participants n = 120
Age, years (mean, sd)	44 (14.9)
Female (n, %)	67 (56)
Right side dominance (n, %)	110 (92)
Dominant side assessed (n, %)	60 (50)
BMI (mean, sd)	24 (3.7)
Profession (n, %)	
Unemployed (n, %)	12 (10)
With upper limb activity below shoulder level (n, %)	99 (82.5)
With upper limb activity above shoulder level (n, %)	9 (7.5)
Sports	
No sports (n, %)	15 (12.5)
Sports with upper limb activity below shoulder level (n, %)	53 (44.2)
Sports with upper limb activity above shoulder level(n, %)	52 (43.3)
Hours/ week	3.8 (2.8)
Self-reported general health	
Excellent (n, %)	31 (25.8)
Very good (n,%)	49 (40.8)
Good (n,%)	39 (32.5)
Fair (n,%)	1 (0.8)
Bad (n,%)	0 (0)
Constant Shoulder score dominant arm (median, IQR)	96 (93, 100)
Constant Shoulder score non-dominant arm (median, IQR)	95 (92, 100)
VAS for pain at rest 0–100 (median, IQR)	0 (0, 3)
VAS for pain during movement 0–100 (median, IQR)	1 (0, 3)
VAS for daily functioning 0–100 (median, IQR)	0 (0, 3

Table 2
Association of age and other independent variables with JPR-error for all contralateral and ipsilateral JPR-tasks.

Contralateral JPR-tasks

Task & Position	*Active-Active, High*		*Active-Active, Low*		*Passive-Active, High*		*Passive-Active, Low*	
	Estimate (95CI)	P-value	Estimate (95CI)	P-value	Estimate (95CI)	P-value	Estimate (95CI)	P-value
Intercept	0.593 (−1.953–3.139)	0.645	0.085 (−3.763–3.933)	0.965	2.419 (−2.066–6.904)	0.287	4.189 (−1.211–9.590)	0.127
Age (years)	0.014 (−0.011–0.040)	0.271	0.010 (−0.027–0.046)	0.595	0.015 (−0.030–0.060)	0.512	−0.013 (−0.066–0.041)	0.644
Sex*	−0.457 (−1.172–0.258)	0.208	−0.141 (−1.159–0.877)	0.785	−0.618 (−1.862–0.626)	0.327	−0.090 (−1.563–1.382)	0.903
BMI (kg/m^2)	0.078 (−0.025–0.180)	0.136	0.128 (−0.030–0.287)	0.112	0.081 (−0.104–0.266)	0.389	0.133 (−0.090–0.356)	0.240
Sports (hours/week)	−0.008 (−0.136–0.120)	0.900	−0.044 (−0.219–0.130)	0.614	0.026 (−0.199–0.251)	0.817	0.009 (−0.255–0.273)	0.946

Ipsilateral JPR-tasks

Task & Position	*Active-Active, High*		*Active-Active, Low*		*Passive-Passive, High*		*Passive-Passive, Low*		*Passive-Active, High*		*Passive-Active, Low*	
	Estimate (95CI)	P-value	Estimate (95CI)	P-value	Estimate (95CI)	P-value	Estimate (95CI)	P-value	Estimate (95CI)	P-value	Estimate (95CI)	P-value
Intercept	3.348 (1.367–5.330)	0.001	4.747 (1.445–8.048)	0.005	5.402 (2.803–8.002)	<0.001	3.195 (0.933–5.457)	0.006	0.434 (−2.708–3.576)	0.785	4.694 (0.066–9.322)	0.047
Age (years)	0.002 (−0.018–0.022)	0.842	0.018 (−0.014–0.051)	0.264	−0.026 (−0.052−0.000)	0.048	0.024 (0.001–0.046)	0.040	0.000 (−0.031–0.032)	0.978	0.066 (0.020–0.112)	0.005
Sex*	−0.194 (−0.739–0.351)	0.483	−0.430 (−1.336–0.475)	0.347	−0.049 (−0.769–0.672)	0.894	−0.248 (−0.874–0.378)	0.434	−0.258 (−1.138–0.623)	0.563	−0.690 (−1.966–0.585)	0.286
BMI (kg/m^2)	−0.028 (−0.106–0.050)	0.480	−0.093 (−0.228–0.042)	0.176	−0.026 (−0.131–0.078)	0.615	−0.038 (−0.130–0.055)	0.421	0.168 (0.043–0.294)	0.009	−0.092 (−0.279–0.094)	0.329
Sports (hours/week)	−0.081 (−0.182–0.020)	0.115	0.022 (−0.142–0.187)	0.787	−0.081 (−0.209–0.047)	0.213	−0.055 (−0.166–0.056)	0.330	0.032 (−0.126–0.190)	0.692	0.091 (−0.139–0.321)	0.433

Results of linear mixed model analysis: A p-value < 0.005 was considered statistically significant.

* Male is reference. Estimates in 10^{-2} m.
Abbreviations: JPR = Joint Position Reproduction, CI = Confidence Interval

Table 3
Reproducibility of contralateral and ipsilateral JPR-tasks.

Contralateral JPR-tasks

Task & Position	*Active-Active, High*	*Active-Active, Low*	*Passive-Active, High*	*Passive-Active, Low*
Reliability (ICC)	0.716	0.632	0.752	0.804
95% CI	0.451–0.853	0.245–0.821	0.514–0.873	0.612–0.901
Agreement (SEM)	1.1	1.5	1.5	1.7

Ipsilateral JPR-tasks

Task & Position	*Active-Active, High*	*Active-Active, Low*	*Passive-Passive, High*	*Passive-Passive, Low*	*Passive-Active, High*	*Passive-Active, Low*
Reliability (ICC)	0.400	0.389	0.419	0.480	0.316	0.794
95% CI	−0.143–0.684	−0.229–0.694	−0.119–0.698	0.039–0.723	−0.284–0.637	0.606–0.892
Agreement (SEM)	1.4	1.9	1.4	1.2	2.1	2.1

Abbreviations: JPR = Joint Position Reproduction; ICC = Intra-Class Correlation Coefficient; CI = Confidence Interval; SEM = Standard Error of Measurement (in centimetres)

5. Discussion

The present study showed that higher age was not associated with a decline in JPS of the shoulder, contrary to our initial hypothesis. The ICC's suggested moderate-to-good reliability over time for contralateral JPR-tasks but lower (poor) reliability for ipsilateral JPR-tasks, except for the passive-active task in low position which had similar good reliability. However, the SEM was comparable and low for all JPR-tasks, indicating good agreement between test and re-test measurements.

Two previous studies evaluated the association between age and JPS in the asymptomatic shoulder (Echalier et al., 2019; Zuckerman et al., 1999). Both studies suggested there was an age-related decline in JPS, but the reported differences in JPR-error between younger and older participants were small (range: 1–4 degrees of shoulder forward flexion) and the clinical relevance of these differences can be questioned (Relph and Herrington, 2016). Additionally, the results of these studies must be interpreted with caution since they had several methodological limitations and were limited to a relatively small number of participants (40 and 44 participants respectively). For instance, Zuckerman et al. only performed one measurement for every JPR-task, which is considered insufficient for JPR (Zuckerman et al., 1999). Echalier et al. did perform multiple measurements for each JPR-task, using the mean value across measurements for analysis. However, an overall mean value does not adequately convey proprioceptive information since the variance of JPR measurements is lost when using only a mean value (Han et al., 2016). Importantly, both studies only evaluated a selected subset of JPR-tasks, thereby not providing a complete overview of JPS for the ageing shoulder.

Several other factors could explain why we did not find an age-related decline in JPS. First, it is possible that JPS is not primarily affected by ageing itself. Instead, it may reflect age-related changes in cognitive functions (Schmidt et al., 2013) (e.g. deficits in memory) or is the consequence of reduced physical activity with ageing (Pickard et al., 2003; Relph and Herrington, 2016). Rikli et al. previously suggested that physical activity level is more important for maintaining proprioception than age (Rikli and Busch, 1986) which might explain our findings as the participants in our study were relatively active (mean duration of sports activities was 4 h per week). Secondly, a decline in JPS could be present only in individuals older than 70 years of age. Yang et al. showed that a decline in proprioceptive acuity of the ankle joint was most prominent beyond the age of 75 (Yang et al., 2019) whereas the participants in our study were considerably younger. Third, an age-related decline may not be present in the shoulder forward flexion trajectory. Contrary to shoulder abduction or rotation, shoulder forward flexion is almost completely within the visual field and the participants may be more skilled and experienced with such tasks as most daily activity movements are performed in front of the body (Galloway and Koshland, 2002; Goble, 2010). Lastly, an age-related decline in proprioception may be absent in JPS, but could be present in other subdomains of proprioception (e.g. kinaesthesia).

The pathophysiology of shoulder disorders is considered multifactorial (Raz et al., 2015). A decline in proprioception could contribute to the development of shoulder pathology as it leads to instability of the shoulder joint (Lephart and Jari, 2002). Previous studies have demonstrated that there is an association between proprioceptive deficits and shoulder disorders, such as rotator cuff disease, shoulder instability, frozen shoulder and subacromial pain syndrome (Ager et al., 2017; Fabis et al., 2016; Gumina et al., 2019; Overbeek et al., 2022; Smith and Brunolli, 1989). It is unknown whether proprioceptive deficits are the cause or the result of shoulder pathology (Lephart and Jari, 2002). Recent evidence shows that deficits in proprioception have a negative influence on rehabilitation processes and may predict poor surgical outcomes, thereby showing its clinical importance (Lephart et al., 1994). For that matter, proprioception may be targeted to treat shoulder pathology which highlights the need for future studies to further investigate the role of shoulder proprioception. To further explore the role of proprioception in shoulder pathology, it is first necessary to understand its natural course in healthy individuals. The present study therefore adds to existing literature that there seems to be no age-related decline of JPS in healthy individuals, thereby providing reference for future research.

With regard to reproducibility of JPR tasks we found substantially lower ICC's for most ipsilateral JPR-tasks, but comparable and low SEM. The lower ICC's for ipsilateral JPR-tasks in comparison to contralateral JPR-tasks can be understood by the fact that ipsilateral JPR-tasks result in smaller JPR-errors, which may be explained by the lack of need for interhemispheric communication (i.e. ipsilateral JPR tasks do not require interhemispheric communication as the same arm is used for both the reference and reproduction position) that might reduce the accuracy of a JPR-task (Goble, 2010). Ipsilateral JPR-tasks may lead to lower ICC's as the intra-individual variability is relatively high compared to a low population variability (participants generally accurately reproduced the reference position, i.e. had good JPS), even when the intra-individual variability is very small (see Appendix A for test–retest plots). Rather than telling something about reproducibility, the low ICC's for ipsilateral JPR-tasks may merely indicate that JPR is not able to discriminate between individuals in such a homogenous population (i.e. asymptomatic participants). The latter illustrates the necessity to evaluate the reproducibility of outcome measures with both reliability (ICC) and agreement (SEM) measures (de Vet et al., 2006).

The strengths of the present study are its large sample size and the application of a variety of JPR-tasks and thus its extensive evaluation of JPS in the shoulder. While most studies only assess JPS by one specific JPR-task, we measured both contralateral and ipsilateral JPR-tasks under both active and passive conditions, thereby providing a more comprehensive overview of shoulder JPS in the asymptomatic population. However, some limitations should be noted. First, we only measured JPS in the shoulder forward flexion trajectory. Therefore, we cannot conclude whether our results are generalizable to other movement trajectories of the shoulder (e.g. abduction and/or rotation movements). Second, it is also possible to perform contralateral JPR tasks with a memory component (i.e. contralateral remembered matching), where the reference arm is returned to the starting position before position reproduction with the opposite arm. However, we did not perform contralateral remembered matching tasks within the present study. Thirdly, we cannot rule out the presence of selection bias due to the fact that participants were recruited via advertisements, which may result in a selected group of participants (e.g. a relatively active group with special interest in shoulder functioning) so that the results do not necessarily apply to the general healthy adult population. Furthermore, we included participants based on clinical assessment and did not rule out asymptomatic pathologies through radiological examination. Hence, participants with asymptomatic shoulder pathology may have been included in the present study. Lastly, we did not include participants beyond the age of 70 and it is possible that a proprioceptive decline mainly occurs above the age of 70 years.

6. Conclusion

Using a 3D-electromagnetic motion analysis device for measuring JPS in the shoulder flexion trajectory, we found no age-related decline in JPS for the asymptomatic shoulder. Furthermore, the comparably low SEM for all JPR tasks indicated good agreement between test and re-test measurements. Future studies are needed to confirm our findings and further explore the role of proprioception in shoulder pathology.

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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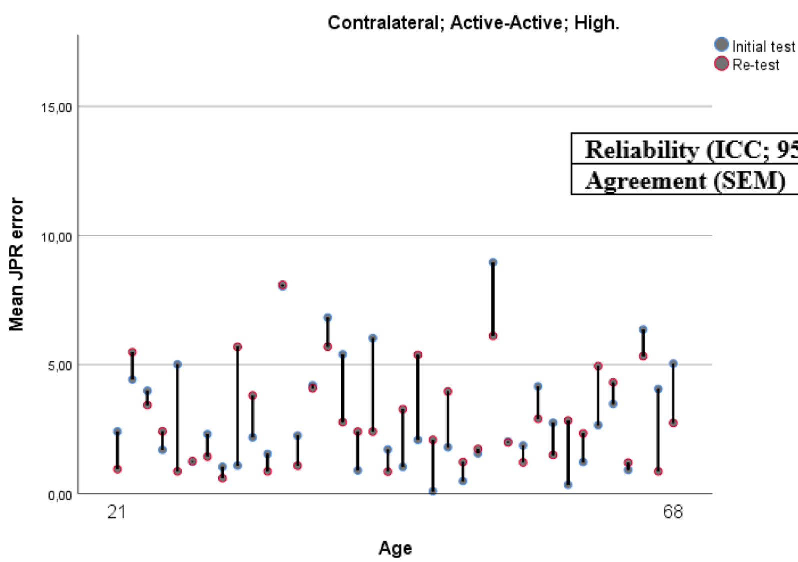
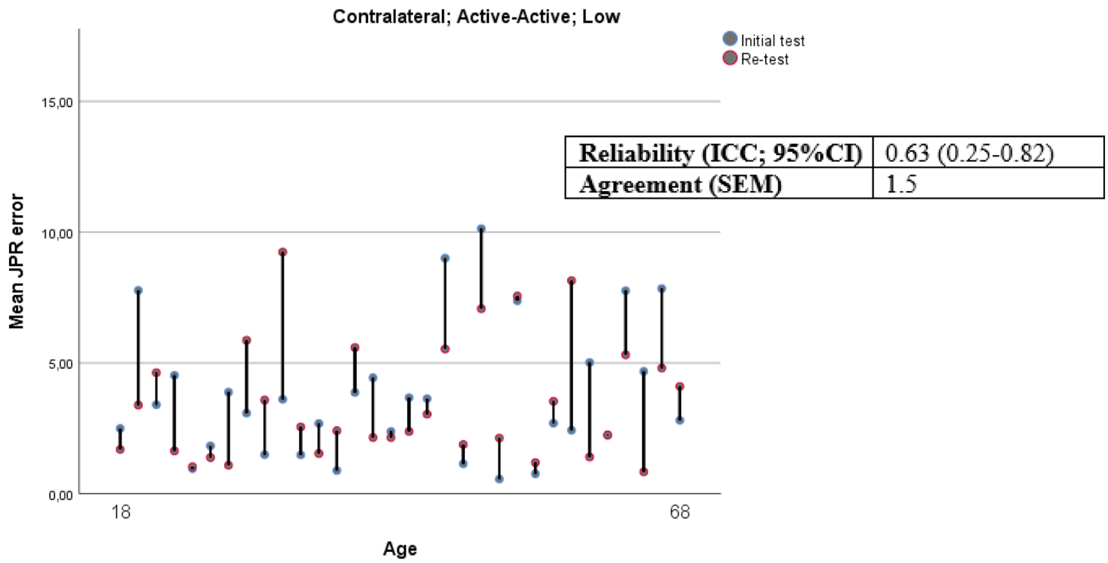
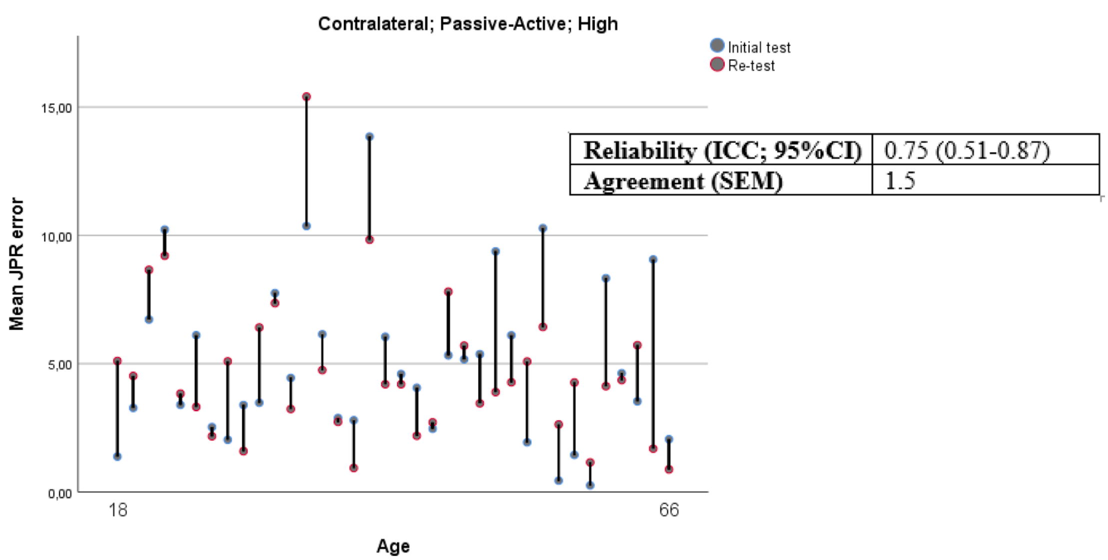
Appendix A. Test re-test plot and corresponding ICC and SEM for all JPR tasks

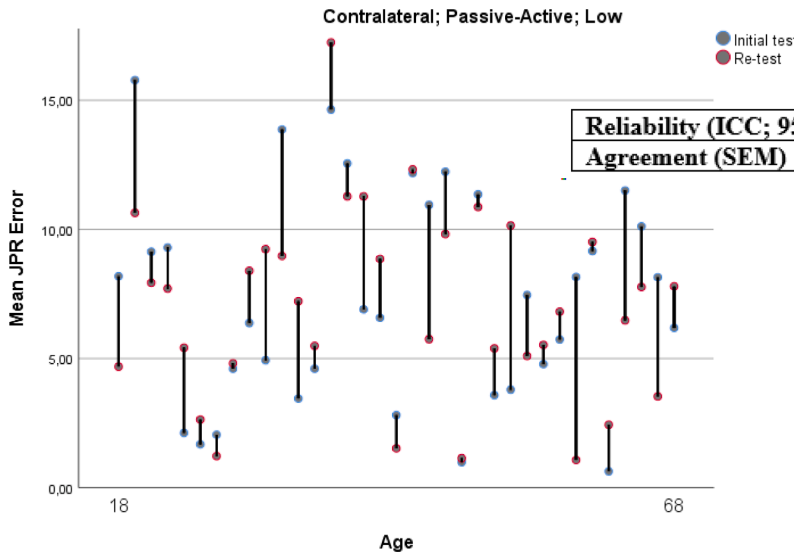
Mean JPR error of the initial test and re-test of all participants in the subgroup analysis. Each vertical line corresponds to a participant. The blue disks indicate the mean JPR error of the initial test and the red disks represent the mean JPR error of the re-test. The black line shows the difference in mean JPR error between the initial test and re-test.



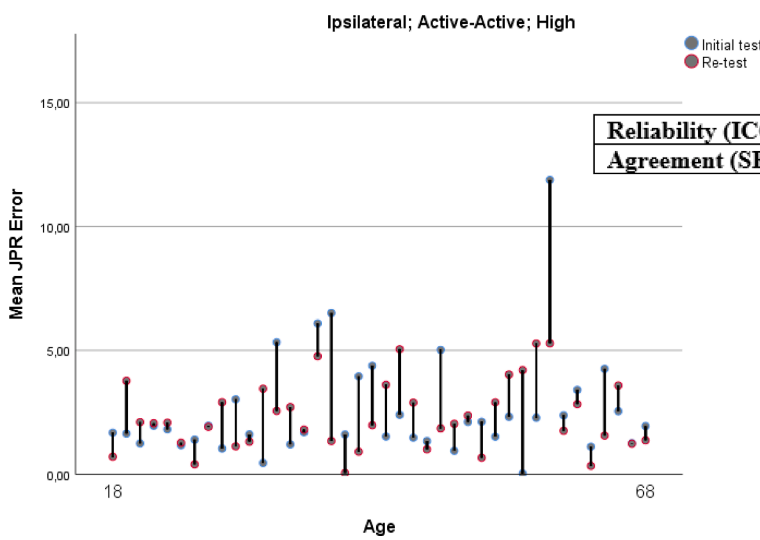
Reliability (ICC; 95%CI)	0.72 (0.45-0.85)
Agreement (SEM)	1.1


Contralateral; Active-Active; Low
Initial test
Re-test
Reliability (ICC; 95%CI) 0.63 (0.25-0.82)
Agreement (SEM) 1.5
Mean JPR error
15,00
10,00
5,00
0,00
18
68
Age

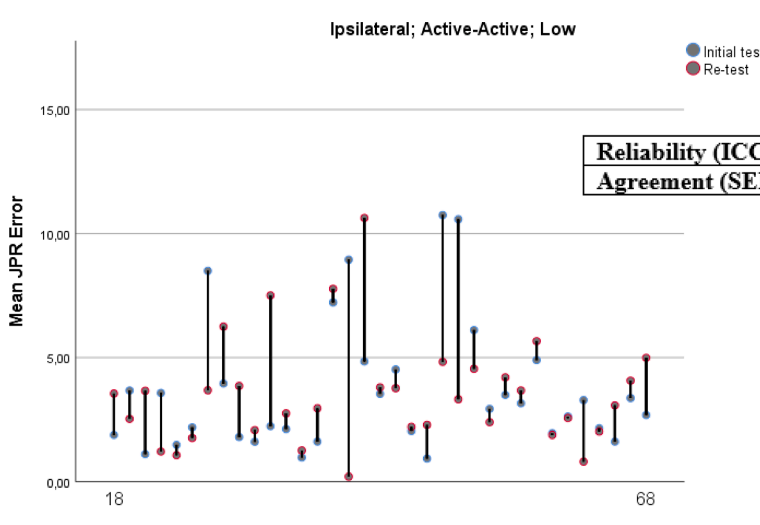

Contralateral; Passive-Active; High
Initial test
Re-test
Reliability (ICC; 95%CI) 0.75 (0.51-0.87)
Agreement (SEM) 1.5
Mean JPR error
15,00
10,00
5,00
0,00
18
66
Age



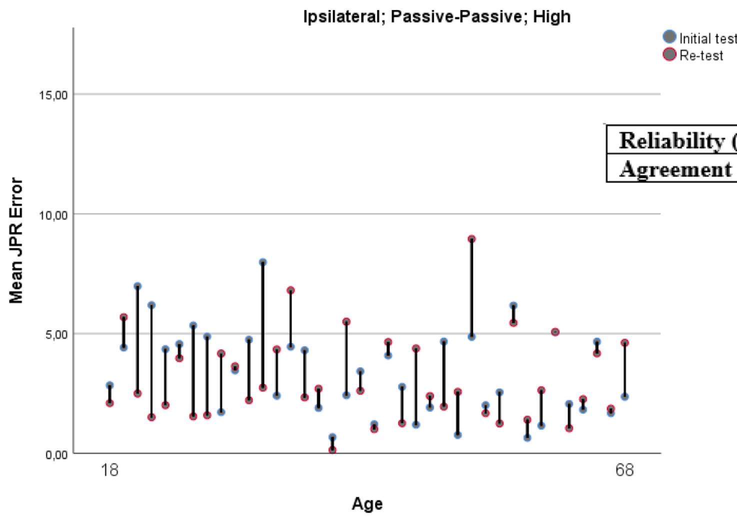
Reliability (ICC; 95%CI)	0.80 (0.61-0.90)
Agreement (SEM)	1.7



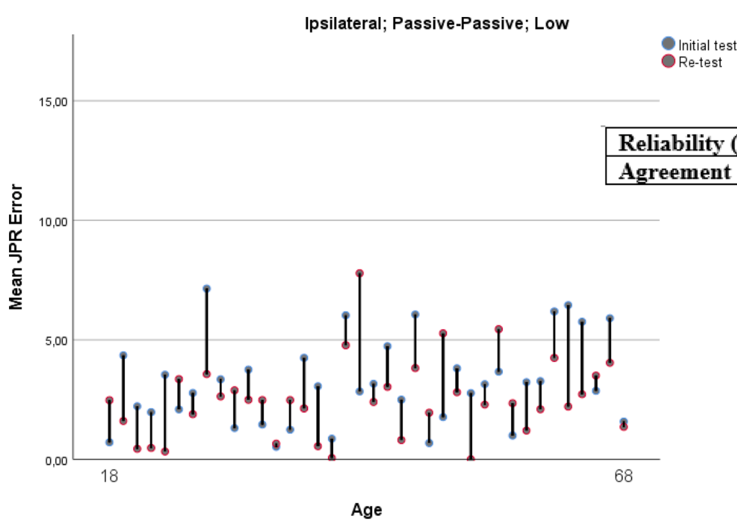
Reliability (ICC; 95%CI)	0.40 (-0.14-0.68)
Agreement (SEM)	1.4



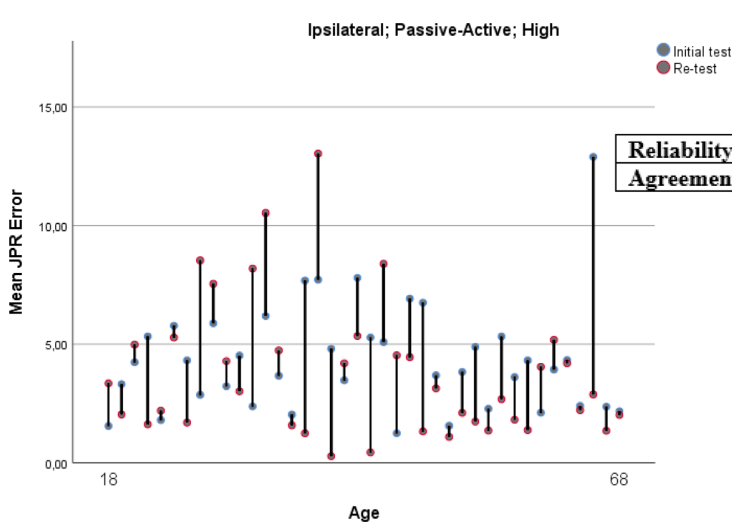
Reliability (ICC; 95%CI)	0.39 (-0.23-0.69)
Agreement (SEM)	1.9



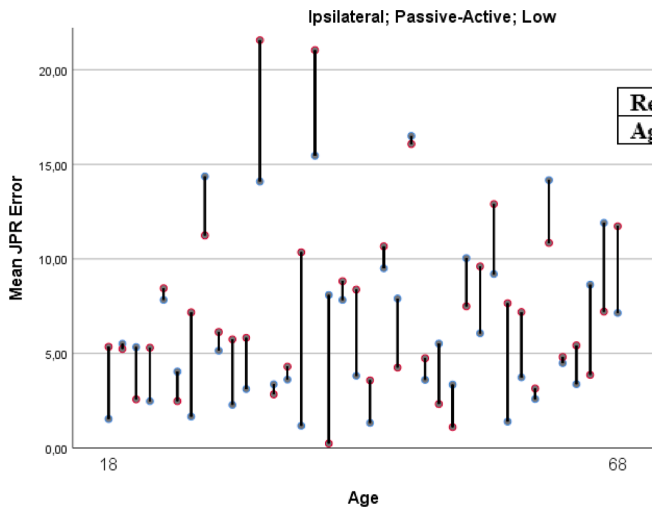
Reliability (ICC; 95%CI)	0.42 (-0.12-0.70)
Agreement (SEM)	1.4



Reliability (ICC; 95%CI)	0.48 (0.04-0.72)
Agreement (SEM)	1.2



Reliability (ICC; 95%CI)	0.32 (-0.28-0.64)
Agreement (SEM)	2.1



Reliability (ICC; 95%CI)	0.79 (0.61-0.89)
Agreement (SEM)	2.1

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