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ORIGINAL ARTICLE

Assessment of proprioceptive and kinesthetic memory in shoulder joint using KEMTAI software system

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Abstract

Proprioception and kinesthesia refer to the sense of joint position and movement, assessable through joint position sense (JPS). We evaluated the potential of the KEMTAI software system in tracking and quantifying shoulder movement by examining 40 subjects (ages 22-68) divided into three age groups. Subjects, blindfolded, performed shoulder flexion, stopped on voice command and by their own at predefined angles measured by the software. Our findings indicated no significant differences in JPS accuracy across age groups, although precision improved with external cues, and a decline in JPS memory over short intervals was observed, suggesting further exploration is needed.

Keywords: AI · receptors · proprioception · motion tracking software · KEMTAI method

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Introduction

We define proprioception and kinesthesia as the feeling of joint position and movement, and one way to assess it is through joint position sense (JPS), which is the possibility to inform the body about the speed and direction of movement without visual control (Proske & Gandevia, 2012). This is enabled by receptors that recognize information from the skin, tendons, muscles, and joints, and send it to the central nervous system. Some of the receptors that contribute to the sense of movement and position are the muscle spindle and Golgy's tendon organ, which are activated in response to muscle length and tendon force, respectively, and are more present in the proximal joints. Therefore, proprioception and kinesthesia are a set of a large number of information that affects motor control and the general physical condition of a person (Lephart et al.,1997; Héroux et al., 2022).

Kinesthetic memory, or muscle memory, enables the performance of physical movements through repetition without conscious effort (Yang et al., 2021). This memory type is essential for athletes, musicians, and patients in rehabilitation to refine their skills, relying on brain structures like the cerebellum and basal ganglia (Lam, 2020). Therefore, proprioceptive acuity to accurately perceive the taught kinesthetics and short-term memory to store the perceived information are two critical functions for reproducing the taught movement (Chiyohara et al., 2023).

The shoulder is a very mobile joint, with the possibility of developing different types of instability. Shoulder stability is ensured by active and passive structures together with information from the receptors (proprioceptors) located in them (Ager, 2017). Many daily activities that involve the shoulder joint take place below the level of the joint (in standing or sitting) where the ligaments and joint capsule are slacked, so movements are primarily constrained by coordinated muscle contraction and reflex reactions (Glendon & Hood, 2016).

Proprioceptive precision can be measured in several ways, and up to now, laser pointers, inclinometers, and standard goniometers have been used (Balke et al., 2011; Dover & Powers, 2003; Vafadar et al., 2016).

Upon reviewing the literature, we concluded that the number of reliable methods for assessing joint position sense remains limited. Our research aimed to investigate kinesthetic memory within the inner and middle ranges of the shoulder joint during upper arm flexion. Moreover, we sought to evaluate the potential of a system that maps specific anatomical landmarks to track and quantify the extent of movement, including joint positioning. For this purpose, we utilized the KEMTAI software system.

Method

Participants

In this cross-sectional study, the examined sample consisted of 40 subjects of both sexes (ages from 22 to 68 years old) divided into three groups (<30, 31-50, and >51 years) based on our assumption that we could find differences in kinesthetic memory. Participants were excluded from the study if they reported any pain in the shoulder, no full range of motion, previous injury in the upper extremity/neck, and if they routinely did overhead activities daily that could lead to better JPS. All participants were recruited through personal networking and gave their informed consent before the experiment by signing forms approved by the ethics board of the Academy of Applied Studies Belgrade, College of Health Sciences (approval number 01-264/4).

Experimental protocol

According to the protocol, standing subjects were instructed to actively reproduce shoulder joint flexion movements at two different target ranges: a low range of 55° and a midrange of 90°. The subjects were required to reproduce a specific angle within approximately 10 degrees of these target angles. After the first attempt, during which we stopped the subject and the movement, subjects were asked to repeat the movement two more times, stopping themselves at the previously memorized position (within 10 degrees of the predefined angle).

Throughout the procedure, subjects stood with their arms at their sides and were blindfolded (Figure 1). On our voice command, the subject began shoulder flexion at a physiological speed and stopped at the command "stop" when the predefined angle was reached. After a few seconds, during which the software measured the angle, the subject returned their hand to the initial position. The subject then repeated the memorized position twice more, indicating to the examiner when they were confident, they had reached the given position. An iPhone 12 mini, equipped with KEMTAI software, was used to record the movement and was placed on a tripod 2 meters away. To minimize the influence of the learning effect, participants were not provided with feedback on their memorized position and accuracy (Carpenter et al., 1998). The level of statistical significance used in the analysis was $p<0.01$.

KEMTAI is an advanced software application designed for motion analysis using computer vision and artificial intelligence. Released in 2021 and now in version 4, KEMTAI tracks anatomical landmarks to analyze movement patterns in real time. It calculates angles between body segments, providing detailed feedback on exercises to help improve form and technique (Jovanovic et al., 2024).

Figure 1. Measuring range of motion using KEMTAI software

Statistical analysis

In the analysis of our data, we employed non-parametric statistical methods due to the non-normal distribution of the outcome variables. Specifically, to compare the medians across multiple independent groups, we utilized the Kruskal-Wallis test. This choice was informed by the test's robustness in handling ordinal data or continuous data that do not meet the normality assumption, which was the case in our dataset. Upon finding significant differences with the Kruskal-Wallis test, we proceeded to identify which groups differed from each other through post-hoc analysis using the Mann-Whitney test. To check if there are differences in deviation from the memorized position after two repetitions, we applied the Friedman test. This test was particularly suited to our repeated measures design, where each subject was exposed to multiple conditions. Significant outcomes identified by the Friedman test were further explored using pairwise Wilcoxon signed-rank tests to pinpoint the specific conditions between which the differences occurred. This stepwise approach allowed for a comprehensive analysis of our data while carefully controlling for type I errors, especially in the context of multiple comparisons.

Results

Tables 1 and 2 indicate that there were no significant differences among the three groups in terms of the degree of error when subjects stopped their arms.

Table 1. Arm movement deviation across age groups for angle 55°

Variable	Groups			
	< 30 years	31-50 years	51-70 years	p-value
Deviation from the angle of 55 °	4 (0-9)	3.5 (0-8)	3 (0-8)	0.951
Deviation from the memorized position – the first repetition	5 (1-14)	6.5 (0-21)	4 (0-19)	0.429
Deviation from the memorized position – the second repetition	5 (1-13)	8 (1-22)	6 (1-22)	0.745

Table 2. Arm movement deviation across age groups for angle 90 °

Variable	Groups			
	< 30 years	31-50 years	51-70 years	p-value
Deviation from the angle of 55 °	2 (0-6)	4 (0-10)	3 (1-8)	0.766
Deviation from the memorized position – the first repetition	1.5 (1-4)	2 (0-11)	2 (0-17)	0.524
Deviation from the memorized position – the second repetition	3 (1-7)	2 (0-21)	2.5 (0-23)	0.723

Tables 3 and 4 compare the deviation in degrees when subjects stopped their arms at a specific angle (55° or 90°) versus when they stopped at a remembered position. Overall, subjects exhibited statistically lower accuracy when repeating the stop at 55° compared to stopping at 55° on command. For the age group 31-50 years, the results mirrored the overall findings, showing lower accuracy when repeating the stop at 55°. However, for the other age groups, there were no significant differences in accuracy. When stopping the arms at 90°, there were no differences in movement accuracy across all age groups.

Table 3. Deviation in arm movement accuracy between commanded and remembered position at 55 ° across age groups

Variable	Groups			
	All	< 30 years	31-50 years	51-70 years
Deviation from the angle of 55 °	4 (0-9)	4 (0-9)	4 (0-9)	3 (0-8)
Deviation from the memorized position – the first repetition	5.5 (0-21)**	5 (1-14)	7 (0-21)**	8 (1-22)
Deviation from the memorized position – the second repetition	6.5 (1-22)**	5 (1-13)	4 (0-19)**	6 (1-22)
p-value	0.002	0.562	0.003	0.442

** $p < 0.01$ vs. memorized position at 55 °

Table 4. Deviation in arm movement accuracy between commanded and remembered position at 90 ° across age groups

Variable	Groups			
	All	< 30 years	31-50 years	51-70 years
Deviation from the angle of 90 °	3 (0-10)	2 (0-6)	4 (0-10)	3 (1-8)
Deviation from the memorized position – the first repetition	2 (0-17)	1.5 (1-4)	2 (0-11)	2 (0-17)
Deviation from the memorized position – the second repetition	3 (0-23)	3 (1-7)	2 (0-21)	2.5 (0-23)
p-value	0.394	0.674	0.982	0.218

Discussion

The aim of our study was to investigate kinesthetic memory within the inner and middle ranges of the shoulder joint during upper arm flexion The results of our research show that there were no differences between the three compared age groups in the accuracy of memorizing the position to stop the movement of the upper arm at angles of 55^{0} and 90^{0}. Some previous studies indicate that in the case of an asymptomatic shoulder, with upper arm flexion and angles of 55⁰, 90⁰ and 120⁰, there is a very small decrease with age in JPS in amounts to 1-4⁰ (Echalier et al., 2019) and that older age did not lead to a decrease in JPS of the shoulder (Geurkink et al., 2023). The authors give several possible explanations for this. Firstly, older participants may be more skilled and experienced when performing shoulder flexion because it is within their visual field and corresponds with frequent daily activities (Goble, 2010). Secondly, JPS is not primarily affected by aging itself, but by changes in cognitive functions, or is the consequence of reduced physical activity with aging (Relph & Herrington, 2016). In addition, a more serious decline in JPS likely occurs only after the age of 70 (Yang et al., 2019). In the population included in our study, we only had four respondents over the age of 65, while not a single respondent reached the age of 70.

Lower precision when repeating movements at an angle of 55 degrees can be explained by the fact that receptors in muscles and joints are less active at this angle than at an angle of 90 degrees. Namely, there is an increased activity of capsulo-ligamentary and muscle-tendon receptors during the stretching of the capsule and ligaments, which is certainly greater when the upper arm is positioned at an angle of 90 degrees, which is also concluded by other authors (Suprak et al., 2006). Also, there is a fact that certain mechanoreceptors are activated in certain joint positions (Lephart, 1993). Accordingly, it is known that muscle-tendon receptors are especially active when muscle activity is more pronounced. In this scenario, when the upper arm is positioned at a 90-degree angle in the shoulder joint, gravity's effect is maximized (at the most advantageous angle when standing), resulting in increased muscle contraction. This heightened contraction further activates the muscle-tendon receptors, leading to a more precise perception of muscle-tendon feedback. Some authors state that the contribution of muscle-tendon sensors is greater than capsulo-ligamentary sensors, which also favors more precise perception at an angle of 90 degrees (Vafadar et al., 2016). When stopping the movement on an auditory command, antagonistic muscle groups are activated to produce a braking force that opposes inertia, which additionally contributes to the activation of muscle-tendon receptors and has a positive effect on JPS and kinesthetic memory at the position of the upper arm at 90 degrees in the shoulder joint.

In addition to the above, statistically less accuracy was obtained in all subjects when repeating stops at 55° on their own than when stopping at 55° on a sign. The fact that all subjects showed significantly greater precision when stopping at 55 degrees at the examiner's signal than when they had to repeat the movement according to their assessment seems logical because in the second case, they rely on their reference system, which could not be always precise (Ribeiro & Oliveira, 2007).

Additionally, in our subjects, we observe a greater deviation during the second repetition of the movement to the memorized position of 55 degrees, which we explain by the weakening of the JPS memory with the flow of even short time intervals (Butler et al., 2008).

Our study has certain limitations. We assessed JPS exclusively in the forward flexion trajectory of the shoulder, limiting the generalizability of our findings to other movements such as abduction or rotation. Additionally, we did not include contralateral remembered matching tasks, which could have offered valuable insights into proprioceptive abilities. Lastly, our study did not include participants over the age of 70, potentially overlooking age-related proprioceptive decline that may be more pronounced in this age group.

Conclusion

In summary, our research indicates that there were no significant differences in the accuracy of memorizing upper arm movement positions at 55⁰ and 90⁰ angles among the three studied age groups. Contrary to some prior studies, which suggested minor age-related decreases in JPS, our findings highlight the stability of JPS across these angles and age groups. Several factors, including participants' familiarity with shoulder flexion due to daily activities, changes in cognitive functions, and muscle-tendon receptor activation, might have contributed to these results. Moreover, participants exhibited greater precision when stopping at 55 degrees upon the examiner's signal, emphasizing the importance of external cues in enhancing accuracy. However, a decline in JPS memory over short time intervals was observed, indicating the need for further exploration of the complex interplay between sensory input and kinesthetic perception in motor tasks.

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