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AN ATTEMPT TO OPTIMISE THE ACTIVE KNEE ANGLE TRACKING TEST WHILE USING A CYCLIC MOVEMENT PATTERN

POSKUS OPTIMIZACIJE TESTA AKTIVNEGA SLEDENJA POLOŽAJA V KOLENSKEM SKLEPU Z UPORABO PONAVLJAJOČEGA CIKLIČNEGA VZORCA GIBANJA

ABSTRACT

Voluntary angle tracking methods are used as training and diagnostic procedures for improving or analysing the performance of the sensory-motor system. Despite their wide application, only a few existing studies examine the repeatability of active tracking methods. Our study tested intra- and inter-visit repeatability and the sensitivity of parameters. We carried out measurements on 30 subjects on three non-subsequent days. At the first visit, we examined intra-visit repeatability and reliability by measuring different forms of reference signals (sine, triangle and trapezoid). During the remaining two visits, the subjects only carried out one instance of the test to check for inter-visit repeatability. The results indicate a poorer inter-visit ($ICC<0.8$) and medium-high intra-visit repeatability ($ICC>0.8$). Differences between various forms of the reference signal statistically differ significantly among themselves ($p<0.05$). Active tracking methods have been shown to have medium intra-visit repeatability and poor inter-visit repeatability. In the future, it would be beneficial to examine the protocols to improve the inter-visit repeatability.

Keywords: motor control, diagnostics, repeatability, joint angle, tracking, feedback

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Izvleček

Metode aktivnega sledenja se uporabljajo tako pri vadbi kot postopkih vrednotenja z namenom izboljšanja ter analize funkcije senzorično-motoričnega sistema. Kljub širokemu področju uporabe, je le malo študij preverjalo njihovo ponovljivost. V predstavljeni študiji smo preverili znotraj- ter med- obiskovno ponovljivost ter občutljivost najpogosteje uporabljenih parametrov. Meritve so bile izvedene na vzorcu 30-ih merjencev, v treh različnih dneh. Na prvem obisku so bile opravljene meritve namenjene proučevanju znotraj-obiskovne ponovljivost ter občutljivosti s pomočjo merjenja aktivnega sledenja položaja v kolenu pri čemer so bile uporabljene tri fazlične oblike referenčnega signala (sinusoidna, trikotna in trapezasta oblika). V preostalih dveh dneh so merjenci opravili aktivno sledenje položaja kolenskega sklepa sinusoidnega referenčnega signala pri isti frekvenci, s čimer smo preverili med-obiskovno ponovljivost. Rezultati nakazujejo na nizko med- obiskovno ($ICC < 0,8$) in srednje visoko znotraj-obiskovno ponovljivost ($ICC > 0,8$). V natančnosti aktivnega sledenja različnim oblikam referenčnega signala so bile statično pomembne razlike ($p < 0,05$). V prihodnje bi bilo potrebno preveriti ali lahko s spreminjanjem merilnega protokola izboljšamo med-obiskovno ponovljivost in zmanjšamo učinek učljivosti med zaporednimi ponovitvami testa.

Ključne besede: Gibalni nadzor, vrednotenje, ponovljivost, sklepni položaj, aktivno sledenje, povratna informacija

INTRODUCTION

Evaluating the sensory and motor functions, espcially the correlation between the two, allows us to see how healthy people move (Bartlett, Wheat, & Robins, 2007; Maffiulettii, Bizzini, Schatt, & Munzinger, 2005; McCloskey 1978; Proske, 2006; Whitacre & Shea, 2000), and uncover the deficiencies caused by various injuries and defects (Bonfim, Paccola, & Barela, 2003; Chung, Cho, & Lee, 2006; Heroux & Tremblay, 2006; Johansson, Sjölander, & Sojka, 1991; Krogsgaard, Dyhre-Poulsen, & Fischer-Rasmussen, 2002; Kurillo, Zupan, & Bajd, 2004; McCormick, Zalucki, Hudson, & Moseley, 2007). The sensory-motor system consists of the central and peripheral nervous systems, the musculotendinous and skeletal systems and the joints, all of which can be studied with various analytical diagnostic tools (neurophysiological, biomechanical, histological etc.).

The sensory-motor function can also be evaluated at the level of complex, integral and concurrent performance of all of its constituent parts in certain circumstances, as opposed to selective electrophysiological methods (Enoka, 2004; Morton & Bastian, 2003). Examples of such tests include measurements of body balance during static or dynamic conditions (Guskiewicz, 2003; Wikstrom, Tillman, Chmielewski, & Borsa, 2006), the ability to detect motion in an individual joint, passive or active angle reproduction in a joint (Patten, Kothari, Whitney, Lexell, & Lum, 2003) and several other clinical tests (Desrosiers, Rochette, & Corriveau, 2005).

In order to monitor the accuracy of shooting and later mainly to evaluate the sensory-motor function of people with nervous system injuries or diseases, active grip force tracking or static contraction methods were used (Carrey, Patterson, & Hollenstein, 1988). These methods use a a compression or tension force sensor (Kurillo, Gregoric, Goljar, & Bajd, 2005; Kurillo et al., 2004), while the subject carries out static muscle activity with no joint movement. The active tracking method can be similarly used in several other circumstances that involve dynamic movement (Chung et al., 2006; Maffiulettii et al., 2005), such as movements of an individual limb or joint by using a suitable position sensor.

All the methods used in both clinical and research practice have to meet measuring power criteria to make the test useful for observing and evaluating the ability to be measured. Apart from validity and objectivity, it is necessary to guarantee adequate repeatability and sensitivity. Our research was carried out with the aim of studying the reliability of the measurement method for the voluntary angle tracking task (ATT) in the knee. We were interested in the reliability during the same ATT and sensitivity to detect differences among different tasks by using a calculated general quantitative parameter. We also wanted to know how the parameters will react to changes in speed and shape of a preset signal used to determine the required motion. The purpose of the study was to optimise the measurement procedure, so as to have potential for scientific theoretical and applied value in sport and rehabilitation science.

METHOD

Participants

The study was carried out on 30 young adult volunteers (21 males and 9 females; M = 22 years, SD = 2.45 years) with no previous history of injuries to the neuro-muscular and/or skeleto-articular systems that could impact measurement results. The procedure, which was approved by the

National Medical Ethics Committee, was explained to all subjects prior to the test; they also signed a statement of voluntary participation.

Instruments and procedure

Motor task and measurement protocol

After describing the motor task, the subject was placed into a measurement brace as shown on Figure 1. The signal from the electronic sensor that displays the angle between the fixed and movable arm was recorded by a computer and displayed on screen in real time. The subject tried to follow the pre-programmed reference signal waveform (RS), displayed on a computer screen 1.5 metres away and did not see his or her moving leg. The subject's attempt was shown as a superimposed actual signal waveform (AS). The first, pre-programmed, RS waveform was set by the measurer by inputting parameters on the cycle's amplitude, shape and duration. The other waveform was simultaneously displayed on the screen as the current brace sensor signal value (AS). The subject was told to alternately extend and flex the knee joint in such a way as to follow the first waveform as closely as possible. As extreme positions can lead to errors, we used between 10% and 90% of the total movement amplitude.

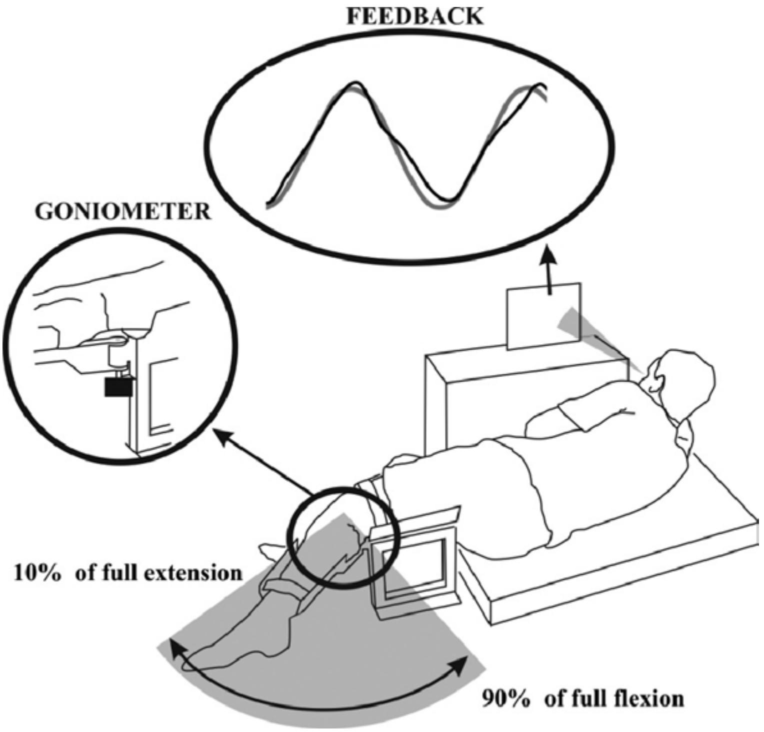

Figure 1: Measurement brace for knee joint ATT is composed of a movable arm to support the subject's calf and the static arm to support the thigh. The movable part only moves horizontally. The rotation axis between the movable and static arm includes an electronic goniometer, linked to a computer. The brace allows for changes to the length of the calf arm to adjust to the subject's longitudinal dimensions.

Measurements were conducted during three separate visits with at least a three-day break between each of them. The subjects first carried out several shorter 20-second trial runs to familiarise themselves with the task. This was followed by the main measurement. During the first visit, the subjects carried out nine variations of the motor task (each lasting 60 seconds), which included various RS forms (sine (SIN), triangle (TRI), trapezoid (TRA) – all at 4- second cycle durations). During SIN, the subjects executed five different variations that differed in dinamics (cycle duration: 1, 2, 4, 8, and 16 seconds). To measure intra-visit repeatability, the subjects repeated the SIN-4s task three times. To avoid systematic fatigue and learning effects, there was at least a two-minute break between individual instances of the test, and the sequence was chosen at random. On the second and third visit, the subjects only carried out one SIN-4s task to test inter-visit repeatability.

Data analysis

Specially developed software (Wise Technologies, Slovenia) was used to process the acquired (sampling frequency 1,000 Hz) signal. The root mean square (RMS) was computed for the difference between RS and AS. By expressing RMS relative to RS's amplitude and time, the normalized amplitude (NA) was computed, enabling a comparison between different subjects (see Equation 1). Only 50 seconds of the signal were processed, disregarding first 8 and last 2 seconds.

$$NA = \left[\sqrt{\sum (F1 - F2)^2} / aF1 \right] / t$$

Equation 1: Equation used to calculate NA. RMS was computed by summing all differences between RS (F1) and AS (F2) values. RMS was then divided by RS amplitude (aF1) and duration of acquired signal (t).

Measurement data was abnormally distributed, as a result of which we used non-parametric tests in its analysis. The analysis was carried out with the use of Friedman ANOVA method, a nonparametric test for checking differences during repeated measurements. The results were statistically significant if the alpha error was lower than 5% ($p<0.05$), while considering the necessary correction for multiple comparisons. Post-hoc tests to discover the differences between individual variables were carried out by means of the Wilcoxon test.

We used two different/complementary approaches to measure intra- and inter-visit repeatability. The first was the intra-class correlation coefficient (ICC), which has been widely used for repeatability assessment (McGraw & Wong, 1996). This method is based on an analysis of variance and compares changes in variability of pre- and post-measured data of the same observed construct. We used SPSS (SPSS Inc., Rainbow Technologies) to calculate the two-way ICC random consistency model. Since an important insight into changes to the mean of sets of measured data is lost in the ICC (McGraw & Wong; 1996), we used an additional approach, proposed by Hopkins (2000), which can help to compensate for methodological deficiencies and show measurement changes for the mean (CM) and typical (TE) measurement error.

RESULTS

The results of the analysis of differences among various ATT requirements regarding the RS dynamics and form are shown in Table 1. The comparison of NA values at different RS speeds showed statistically significant differences (Friedman; p<0.05), which appeared among practically all compared pairs (corrected Wilcoxon; p<0.05/10 = p<0.005). The comparison of different RS forms at the same speed (4-second cycle duration) showed statistically significant differences (Friedman; p<0.05), which appeared between the SIN and TRA forms of the RS (corrected Wilcoxon; p<0.05/3 = p<0.017), while the SIN, TRI and TRI, TRA pairs did not show any statistically significant differences (p<0.05).

Table 1: Results of analysis of differences between various conditions of RS form and speed. Statistical significance * marks p<0.05 and ** p<0.001, for which correction for multiple comparisons was added to the Wilcoxon test.

Test condition		mean	s.d.	p (Friedman)	p (Wilcoxon)				
					1 s	**2 s**	**4 s**	**8 s**	**16 s**
Cycle Duration	**1 s**	7.24	3.42	0.000**	-	0.000**	0.000**	0.000**	0.000**
	2 s	3.09	0.86			-	0.000**	0.000**	0.000**
	4 s	2.65	0.69				-	0.000**	0.000**
	8 s	2.00	0.55					-	0.002**
	16 s	1.94	2.50						-
					SIN		**TRI**		TRA
Shape	**SIN**	2.65	0.69	0.000**	-		0,111		**0,009***
	TRI	2.93	0.93				-		0,349
	TRA	3.09	0.87						-

The repeatability analyses for SIN-4s RS are shown in Table 2. ICC values point to a reasonably good intra-visit repeatability (ICC 0.81) and low to medium inter-visit repeatability (ICC 0.58). Intra- and inter-visit average TE values were both at approximately 15%. CM values dropped for intra-visit as well as inter-visit observations, hence, from 25.2% to 14.5% and from 6.9% to 0.6%, respectively.

Table 2: Statistical repeatability tests` results for RS SIN-4s.

	Visit	Repetition	Mean	s.d.	ICC
Intra-visit	1st	1st	2.65	0.69	0.813
	1st	2nd	2.27	0.45	
	1st	3rd	2.13	0.49	
Inter-visit	1st		2.65	0.69	0.579
	2nd		2.14	0.60	
	3rd		1.85	0.37	

DISCUSSION

The aim of the study was to evaluate (i) the sensitivity of the knee ATT to changes in input RS parameters (speed and shape) and (ii) the repeatability of the knee ATT measurement method. We employed the RS waveform with the same regularly repeating cycles. The study has proven that the knee ATT accuracy statistically significantly changes in regards to the speed of joint movement at which the RS required the subject to operate. Differences were also present among various RS forms, although to a lesser extent. The repeatability analysis further proved that the knee ATT test has medium-high reliability if RS with a SIN form and 4-second cycle duration is used.

Based on the results, we can also confirm that motion accuracy and speed are in an inverse relationship, meaning that activities at higher speeds resulted in less accurate tracking. This was first observed by Woodworth (1899), whose claims were some 50 years later scientifically corroborated by Fitts (1954), who discovered that accuracy and speed are in a logarithmic relationship. The inverse relationship between speed and motion accuracy can be explained by theories of feedforward and feedback control.

Several authors, including Nielsen (2004), oppose rigid separation between feedforward and feedback control as they showed that all natural motions contain elements of both principles. The feedforward mechanism also appears in long-lasting motion, while the feedback mechanism appears during rapid motion (Schmidt & Lee, 1999). It was further shown that tracking tasks include movement adjustments according to the feedback control principle. This does not hold true for shorter cycle durations and consequently higher speeds, as information needs a certain amount of time to travel from the sensors to the control centre, to be evaluated and to trigger a suitable response. Cyclic movements also cause the appearance of anticipation, i.e. an individual's ability to predict future motion.

Both information from peripheral proprioceptors and visual information is important for the movement that we used in this study. Their processing requires a certain amount of time (Schmidt & Lee, 1999), which is why movement probably follows the feedforward control principle (where previous experience is very important) in shorter cycle durations (1 and 2 s). Shorter cycle durations are therefore inappropriate for sensory-motor function evaluation with the use of feedback control, as in such a case the CNS cannot adjust motor commands on the basis of information from peripheral receptors.

We should ask ourselves here whether the movement speed at which we are the most accurate is also the most suitable speed for measuring the knee joint sensory-motor function. Our results have, similarly to Fitts (1954), shown that the most accurate tracking appears at the slowest motion speed (16-second cycle duration). This, however, does not mean that this speed best represents the functioning of the musculo-nervous system during the most common movements. This is why our results do not allow us to conclude which of the slower motion waveforms (4-, 8- or 16-second cycle durations) would be the most appropriate for evaluating the knee's sensory-motor functions.

Tracking various RS forms indicates differences in motion control. This is shown in the mechanism to achieve the goal (in our case accurate movement of a body part), when the agonistic and antagonistic muscles flex simultaneously, an event known as co-contraction (Enoka, 2002). Concurrent activation of agonists and antagonists gradually slows down the motion and allows for smooth transitions between extending and flexing. This control mechanism is favourably represented by the sine waveform, while the trapezoid and triangle ones are (due to their shape) probably farther removed from natural motion. This is why we would expect to encounter significant differences during measurements utilizing different waveform shapes; however, statistically significant differences only appeared between the sine and trapezoid waveform in active knee angle tracking.

The reliability of active force and angle tracking in the knee joint was medium high in our testing. The majority of studies (Carrey et al., 1988; Carrey et al., 2004; Maffiulettii et al., 2005; Patten et al., 2003) only tested the reliability with the use of ICC, which has shown the method to have high reliability. Contrary to our study, the majority of other studies also measured tracking accuracy on distal parts of upper extremities, which are known for high levels of cortical innervation that results in high motion accuracy. Despite medium-high reliability, our study proved that tracking test results improved during repeats at later visits.

Until recently, the tracking method was only used for monitoring and evaluating motion control in healthy people and people with neurological defects. However, it has become increasingly popular as a therapeutic aid, especially in the treatment of neurological cases (Carrey, Kimberley, Lewis, Auerbach, Dorsey, Rundquist, & Ugurbil, 2002; Cho et al., 2007; Chung et al., 2006). They discovered that practice involving tracking methods also improves the kinaesthetic feeling in individual joints (Kriz, Hermsdörfer, Marquardt, & Mai, 1995). Based on the above, we can see that there is a indicate future development of methods for active tracking of preset motion, both in research (studies of motor control, motor learning etc.) and in practical activities in sports and rehabilitation (evaluating effects of training and other interventions, kinesthetics and coordination practice, joint control re-education in post-traumatic and post-surgery states etc.).

The results found in literature and examined by our study prove that the knee joint ATT needs to be examined further to discover the most suitable protocols for it. Our study allowed us to conclude that the method is sensitive to changes in RS movement speed and form. Due to learning effects of the test and the possibility of anticipational activity during cyclic and repeatable motor tasks, we can forecast that higher inter-visit accuracy, sensitivity and reliability can be achieved by standardising the appropriate accommodation protocol before the measurement and by using a random waveform shape for movement. By continuing our research activities, we are already aiming at reaching these goals.

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