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The sense of position and movement in the knee joint during voluntary movements

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The aim of the paper was to assess body position reproduction as well as jump height during an intended movement, together with an assessment of the influence of factors that disturb this process. Factors disturbing the jump were related to with the reproduction of different knee joint angles (90° or 120°); different muscle activity in performed jumps: SJ with no countermovement and CMJ with countermovement; as well as with and without visual (VC) of control movement (nVC) – eyes covered. Nineteen subjects aged twenty-one years participated in the experiment. Jump height (*h*) was calculated on the basis of a reaction force (R) of the base, as registered with a tensometric platform. Two-dimensional cinematographic analysis was used to assess the reproduction of angular position in the knee joint. A significant factor determining the level of position reproduction during voluntary movements was the imposed angle as well as the character of muscle activity. The biggest difficulty of developing maximum heights occurred during jumps with disturbed visual control (eyes shut).

Key words: *proprioreceptors, sense position, voluntary movements*

1. Introduction

Goodwin [1] made the first discoveries concerning the role of muscle receptors (proprioceptors) in kinesthesia. The author proved on the basis of sensory effects under vibration that muscle spindles take part in the conscious experience of the sense of movement. At present, it is thought that when there is no visual feedback, position and movement sense take place via main endings of muscle spindles [2]. Primary spindle endings respond to the change of muscle length and to the speed of this change, whereas secondary endings are not significantly sensitive to the change in position and movement, but signal only the change in length [3]. The sense of muscle tension is provided by the Golgi tendon organs. Also, in some body parts, especially distant ones, additional information is provided through the skin and peripheral nerves in the joints [2].

According to the newest research, muscle spindle reactions allow joint position to be sensed during midrange movements, whereas capsuloligamentous mechanoreceptors, i.e., Ruffini endings, Pacinian corpuscles, and Golgi endings remain relatively dormant during that time [4]. They are stimulated more when stem tissue is being stretched. Consequently, these receptors can constitute detectors of movement limitations [3].

Smith et al. [5] showed the influence of muscle fatigue on the sense of limb position. In the conducted experiment, during isometric contractions of varied intensity, greater position matching error occurred with higher contraction intensity This proves the significant impact muscle fatigue has on proprioceptive sense, which was also confirmed by Allen and Proske [6]. After conducting exercises that decreased maximum voluntary contraction (MCV) by 30%, the researchers proved considerable error in position sense, but not in the range of movement. Other researchers believed that this might suggest a separate, centre

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interpretation of information coming from the position and movement sense [3]. Many authors regard the sense of effort as the sense of muscle fatigue caused by exercises that lead to errors in body position matching. According to research conducted by Walsh et al. [2] and Allen et al. [7], if muscle spindles influence position sense, then an additional impulse comes from increased muscle tension that is indispensable for keeping position. It has a crucial meaning for maintaining body balance. Gandevia et al. [8] conducted an experiment utilizing a pressure cuff to block conduction in hand movement and supply spindles. Subjects intending to move an anaesthetized hand sensed change of about 20° in palm position. It means that if afferent signals are not available, then information about position comes from the sense of muscle tension. Smith et al. [5] also made an important observation, as they discovered that subjects could sense a change of 6°–7° in hand position after making isometric contractions of extensor and flexor muscles in an elbow joint. Additionally, it proves that during voluntary movements, fatigue signals are always available and can coexist in position sense [3].

In sports, the sense of muscular tension with simultaneous assessment of body position has crucial meaning for shaping and teaching, as well as correcting, habits of movement. That's why, if we assume on the basis of the current study that muscle spindles play an important role in position and movement sense, then their ability to signal such changes seems essential for trained dynamic movements in which changeable muscle activity occurs. The aim of the paper was to assess body position reproduction as well as jump height during an intended movement, together with an assessment of the influence of factors that disturb this process. The most accurate and simplest movement to be performed to meet the paper's goal was a counter movement jump (CMJ) and a squat jump (SJ), commonly used in sports for training diagnosis. Factors disturbing the jump were related to with the reproduction of different knee joint angles (90° or 120°); different muscle activity in performed jumps: SJ with no countermovement and CMJ with countermovement; as well as with and without visual (VC) of control movement (nVC) – eyes covered.

2. Materials and methods

2.1. Research material

Nineteen subjects aged twenty-one years participated in the experiment. Mean body mass amounted to 82.5 ± 5.53 kg and body height equalled 183.5 ± 9.08 cm. The criterion for selection to groups was acquired motor habit of vertical jump. The subjects were to perform 12 jumps on a tensometric platform. The experiment was divided into three stages. Each stage was preceded by a warm-up, and each stage of the experiment took place at the same time each day. Figure 1 presents a diagram of the conducted research.

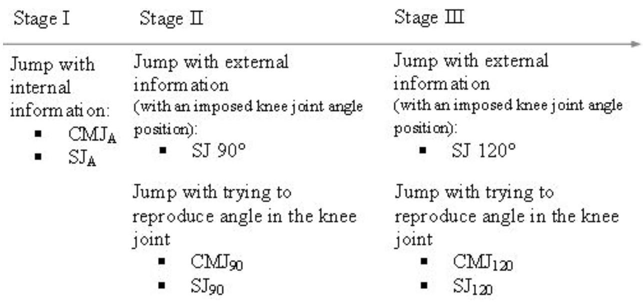

Fig. 1. A diagram of the research conducted

In stage I, subjects performed jumps with internal information from a squat position (SJ_A) and with a counter movement jump (CMJ_A) – in order to both achieve maximum jump height (h) and to define the assumed angle in a knee joint (α) while performing countermovement (CMJ_A) and in the initial position in SJ_A attempt. When measurements from the squat position (SJ_A) were taken, an attempt in which the subject did not lower centre of gravity at the start of the push-off phase was analysed. Also, in order to achieve trial repetitiveness, the subjects performed two jumps of each kind.

During stage II, the subject performed jumps with external information from the semi-squat position (SJ) with an imposed knee joint angular position of 90° in static phase.

Next, the subjects were trying to reproduce the memorised angle in the knee joint (α) and reach maximum jump height during a counter movement jump (CMJ) and a squat jump (SJ) conditioned by visual control or its absence (eyes covered). For this purpose, a 150 cm × 70 cm mirror was placed perpendicular to the coronal axis, and within 120 cm of the axis.

During stage III, the same kinds of jumps were performed along with an attempt to reproduce the position of 120° between shin and thigh. When measurements were taken from squat position (SJ), an attempt of the subject starting the push-off phase without the initial lowering of the centre of gravity was analysed.

2.2. Research methods

Jump height (*h*) was calculated on the basis of a reaction force (R) of the base, as registered with a tensometric platform.

Two-dimensional cinematographic analysis was used to assess the reproduction of the angular position in a knee joint. Images were recorded with a frequency of 60 Hz, a shutter speed about 1/120 second, and in a NTSC system by a JVC GR-DVL 9800 digital camcorder. The camera was set perpendicular to subject's sagittal axis. The APAS 2000 (Ariel Performance Analysis System) programme was used to calculate the angle.

Figure 2 shows an example of the reaction force record and camera position during measurements.

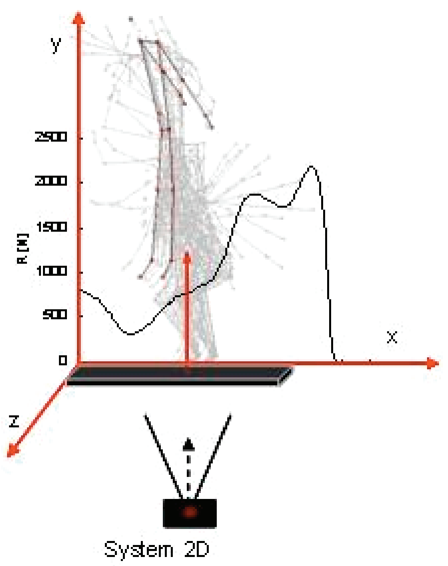

Fig. 2. An example of the reaction force record and camera position during measurements

The body position in jumps with external information (during $SJ_{90,\ 120}$) with an imposed knee joint angle (attempt I – 90°; attempt II – 120°) was defined by means of a goniometer to an accuracy of 0.5° (assuming that the full range of extension for joints amounts to 180°).

The rotation axis of a goniometer in the sagittal plane was located near the head of the calf bone in accordance with the joint horizontal axis. The upper arm – immobile – was positioned along the longitudinal axis towards the greater trochanter of the thigh bone. The lower arm – mobile – was positioned along the shin at the height of the malleolus of a fibula. The result cinematographic analysis was factored into consideration in order to assess the reproduction of the imposed angle. Both methods are commonly used to assess body position sense, especially during analysis in the standing position [9].

2.3. Methods of statistical analysis

Statistical analysis was divided into several stages. The first analysis compared subjects' results during attempts at voluntary (SJA, CMJA) and controlled movements (SJ). Analysis of variance (ANOVA) for repetitive measures was conducted and followed by post-hoc Newman–Keuls test. The angle position in knee joint (α) and jump height (*h*) reached in individual attempts were compared.

The purpose of the second analysis was to assess the influence of the imposed factors and interactions between them during the attempts of body position reproduction. ANOVA was also used for repetitive attempts. In this case, the results obtained in voluntary and controlled movement attempts were not taken into consideration.

The third and final analysis aimed at assessing the errors in the reproduction of angles between thigh and shin in each of the SJ and CMJ jumps, in comparison with the results of control samples. The analysis also aimed at assessing the errors of achieved values of the jump height that were obtained during attempts of reproduction, in comparison to results achieved during the voluntary movements. Paired Student's t-test was used for this purpose.

Additionally, relative errors for the reached position were calculated in relation to control samples as well as the jump heights reached in relation to voluntary movement attempts. The level of $p < 0.05$ was considered significant.

3. Results

The first table shows all mean values of jump height reached during trials as well as of the knee joint angle reached.

Statistical analysis showed that jump height was considerably ($F_{(3.45)} = 21.3$; $p < .001$) different between individual samples. A detailed analysis proved that the subjects reached a significantly lower height in a control jump SJ-120° in comparison with the values reached in other samples ($p < .001$). Yet in the second sample, with an imposed knee joint angle (90°), the subjects were characterized by a level very similar to a voluntary jump with no countermovement (SJ_A). It was also observed that body position adopted by the subjects during the preparatory phase (static) in the jump with internal information SJ_A was very similar to those adopted in a control jumps, which can be proved by a lack of differences between the reached angles. On the other hand, during the jump CMJ_A, the knee joint position suggested that in a countermovement phase the subjects lowered the centre of gravity much more when compared to other samples ($p < .001$).

Table 1. Mean values of maximum jump height (*h*) and angle knee joint (α)

	h (m)	α (°)
Jump with internal information (voluntary jump)		
SJ_A	0.369 ± 0.032	95.9 ± 8.4
CMJ_A	0.406 ± 0.036	72.1 ± 11.4
Jump with external information – SJ (control jump)		
90°	0.364 ± 0.031	92.2 ± 4.6
120°	0.319 ± 0.056	115.0 ± 4.9

SJ_A – squat jump, CMJ_A – counter movement jump, VC – visual of the control movement, nVC – without visual of the control movement.

Table 2. Mean values of maximum jump height (*h*) and angle knee joint (α)

			h (m)	α (°)
Jump with trying to reproducer angle in the knee joint				
90°	VC	SJ	0.366 ± 0.026	87.9 ± 5.3
		CMJ	0.398 ± 0.034	75.2 ± 10.6
	nVC	SJ	0.352 ± 0.047	92.6 ± 5.2
		CMJ	0.375 ± 0.042	77.0 ± 6.8
120°	VC	SJ	0.322 ± 0.054	115.0 ± 4.9
		CMJ	0.347 ± 0.054	112.6 ± 9.1
	nVC	SJ	0.288 ± 0.046	95.0 ± 7.8
		CMJ	0.330 ± 0.046	118.4 ± 6.6

In the second and third stage of the experiment, the subjects were to reproduce the angular knee joint position during CMJ and SJ attempts with and without visual control (nVC). Table 2 shows the mean values of jump height and the reached angle attained during those attempts.

When conducting the analysis of variance for the reached angle, no interaction between the three considered factors was observed (visual control, imposed angle, and jump type). Figure 3 shows the result of this analysis.

Significant interactions occurred between the imposed angle (90°, 120°) and jump type (CMJ, SJ) $F_{(1.14)} = 5.54$; $p < .05$. The factor of visual control or the lack there of had little influence on the ability to reproduce angle in knee joint. It should be noted, however, that values reached in jumps with eyes shut (despite lack of gravity) were closer to the imposed angle in a knee joint than in attempts performed with VC (visual control).

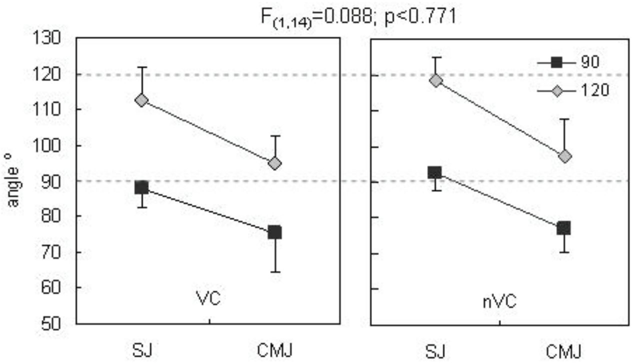

Fig. 3. Mean values of the knee joint angle (α) in jumps with trying to reproduce 90 and 120 degrees

When calculating the relative error of angular position reproduction in individual attempts, it was observed that subjects were characterized by lower levels of angular position sense in the knee joint when performing dynamic CMJ attempts, which is proven by the biggest and most significant differences in both reproduction cases, 90° and 120° (Fig. 4).

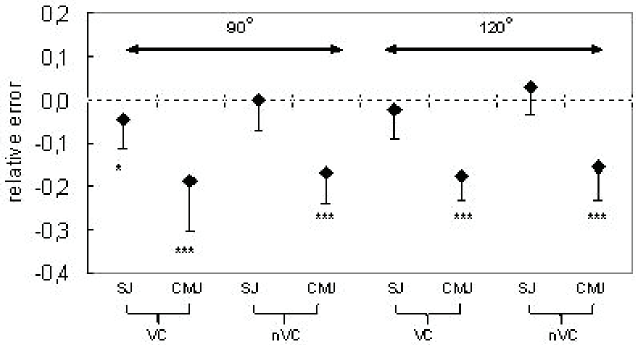

Fig. 4. Mean values of relative error of the knee joint angle (α) in jumps with trying to reproduce 90 and 120 degrees

In the attempts of body position reproduction, when the subjects could preliminarily position their body before performing a jump, the values of errors were smaller. The only difference observed was between SJ jump performed with visual control (90°), which was on the level of $p < .05$.

Another parameter that was analysed was jump height that subjects reached during successive attempts. This parameter reflects subjects' volitional engagement in the task performed. Volitional engagement impacts the activity of corticospinal cells, which are continuously controlled and modified by impulses coming from the cerebellum. It was also connected with the appropriate activation of muscle spindles. Thus, jump heights were compared; the results in the form of relative errors in relation to the voluntary movement attempts are shown in Fig. 5.

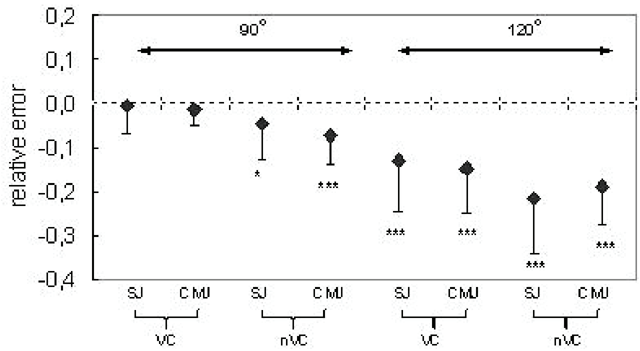

Fig. 5. Mean values of relative error of the jumps height (*h*) in relation to jumps with internal information

On the basis of the analysis conducted, it was concluded that jump height reproduction was considerably more difficult than body position reproduction. Characteristic differences occurred in attempts when the subjects simultaneously reproduced the 120° position. Typical errors were also observed in attempts to reach 90° with no visual control, during both a SJ and CMJ jump. Moreover, it was observed that the factor disturbing visual control indeed determined whether maximum heights were reached during both stages II and III.

4. Discussion

More and more scientific reports indicate that what constitutes the basis of a high level of proprioceptive sense are neurological feedback mechanisms, which originate from joint and musculotendinous structures [9]–[11]. In the case of jump with internal information, when conscious muscle contractions are being generated, joint receptors as well as muscle receptors are activated [3], [11]. The analysed position reproduction, with a simultaneous reaching of maximum jump height, has proven to be a very complex issue. Thus, the abilities to reproduce the position and jump height were therefore analysed separately.

A significant factor determining the level of position reproduction during voluntary movements was the imposed angle as well as the character of muscle activity. When reproducing both the 90° and 120° angles, subjects reached a greater error of position reproduction in dynamic attempts (CMJ) than in SJ. During SJ jumps, the reproduction of the imposed angle was performed with adopting an initial position using slow movement; in this case subjects were characterized by a high level of the imposed position reproduction. The high level of body position sense when performing SJ jump attempts confirmed research by Clarks et al. [12], as well as by Taylor and McCloskey [13]. On the basis of their research, it was proven that in cases of movements performed more and more slowly, what appeared initially to be a sensation of movement changes into sensation of position change.

When performing CMJ jumps, there should be more discharge from proprioceptors that provide more detailed information about limb position [2]. Also, Suprak [14], on the basis of his research, stated that position sense was more accurate when muscle contractions were more intensive, explaining this phenomenon by an increase in impulses sent by muscle spindles. Studied subjects were asked to reach maximum jump values. This requirement intensified the participation of muscle receptors in this study. Also, the range of movement utilized in the present studies (reaching the 90° and 120° angles) confirms the activity of muscle spindle receptors [1], [4], [7]. However, the results of the present paper suggested that position sense is more complicated in conditions of the dynamics of muscle function.

An explanation of the results of the present work, which suggest a lower level of kinaesthetic sense during CMJ jump, could be the fact that the intensified activity of spindles was caused with sudden muscle extension when antagonistic muscles were simultaneously activated and their contraction blocked (quadriceps femoris muscle) due to impulses from tendon organs. The Golgi tendon organs as “muscle force” sensors prevent the muscle from developing too much strength and simultaneously protect the muscle-tendon complex from damage [15]. The result observed can be a proof of positive reaction to the muscle-tendon level. At present, plyometric exercises [16], [17] based on muscle activity in a loading-contraction cycle are used in sports aiming at to increase muscle stiffness (strength) at the same muscle length [15]. Such exercises are often drop jumps from various heights. However, many researchers suggest that using training to lower the suppressing effect of an impulse from a spindle can be one of the reasons for injuries that an athlete experiences when developing or overcoming large external forces [18]. Enriching this kind of training with proprioceptive exercises will potentially influence the increase in tolerance to stretching load that causes increased muscle activity,

[0]reduce the negative influence of an impulse from tendon organs during voluntary movements, and positively influence the resilience of the muscle-tendon complex.

In the present study, another factor taken into consideration was the conditioning of the control of limb position reproduction through performing jumps with eyes closed. Taking this factor into consideration, no interaction between the aforementioned two factors was observed. An error in the 90° and 120° position reproduction during SJ and CMJ attempts was at the same level when there was visual control and when eyes were shut. Such a result can confirm the hypothesis that, when there is no access to visual information, the position and movement sense of the limbs is mainly provided by the muscle spindle endings [2].

The level of proprioception can also be considerably affected by memory of movement patterns created during the life of an individual. Information stored in a memory bank, i.e., cerebellum is automatically used during voluntary movements [19]. Also, smooth movement performance, which allows for optimal realization of movement task, is connected with the greatest level of body position sense and body movement sense [14]. In the presented study, the subjects' task was to reproduce lower limb position, simultaneously reaching maximum jump height during voluntary movement attempts. The reproduction of maximum heights, which proved much more difficult than position reproduction, was connected with reaching appropriate muscle tension. During a CMJ jump, muscles were functioning in a loading-contraction cycle. On the basis of literature, it has been shown that such muscle activity allows greater force and force developing speed to be reached, significantly affecting jumping ability [15]. It is connected with the use of resilient properties of muscle-tendon complex when returning to the initial shape after mechanical tension that causes strain is gone [17]. Another mechanism, the so-called central one, which influences this effect, uses stretching impulses from muscle spindles as well as reactions of the Golgi tendon organs [15]. These theories find their confirmation in the results of the reproduction of jump heights with the simultaneous reaching of 120° position. The observed differences in all types of jumps (SJ, CMJ) and with different control were typical. This probably resulted from the lack of appropriate conditions of muscle activity.

According to conducted research, maximum jump heights are significantly influenced by the countermovement depth [20], i.e., in this case it was adopting the imposed knee joint angle. It may be confirmed by similar results of jump height during 90° angle reproduction attempts. Also, on the basis of an initial comparative analysis it was observed that during voluntary movement attempts, subjects reached a knee joint angle close to 90°, which suggests that muscle conditioning connected with its stretching was similar. The biggest difficulty of developing maximum heights occurred during jumps with disturbed visual control (eyes shut). Significant differences were noticed during these attempts. Additionally, it was observed that the factor of visual control considerably influenced the possibility to reproduce maximal values of jump heights including the attempt of achieving the angle of 120°; this result is contrary to what was observed in the case of analysis of the attempts to reproduce body position.

It is impossible to explicitly state, on the basis of the research conducted, whether errors in the reproduction of maximum heights are affected by movement habits or maybe they are related to higher degree more with initial muscle conditioning, i.e., initial muscle stretching. Research should be conducted in which an angle, the value of which should be somewhere between the ones given in the present study, is reproduced. The studies are to be continued to answer the question: To what extent are people capable of changing the formed movement model, using proprioceptive sense, and simultaneously improve the results? Another reason for further studies of the presented issues is that by using only formed movement habits and due to lack of sensory stimulation, people are not accustomed to sensing the body. This leads to more frequent body injuries, increased staggering, risk of falling, and changes in walking structure [21]. Styczyński et al. [19] claimed that primarily low proprioceptive sensitivity that is not supported by a proper training during the life of an individual might be the reason for predisposition to various motor system diseases.

Acknowledgements

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