

KINEMATIC ANALYSIS OF POSTURAL CHANGES IN BIPEDAL STANCE AT APPLICATION OF STIMULUS FROM EXTERNAL ENVIRONMENT AND MODIFICATION OF VISUAL SCENE IN PATIENTS WITH ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION

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Tears and rupture of the anterior cruciate ligament (ACL), which has an important function in knee joint stability, are very common and more so in sports. ACL injury can be managed in two ways. One alternative pertains to conservative therapy whereas the second variant is surgical intervention (reconstruction). The number of ACL reconstructions has risen recently. The purpose of this study was to analyze the postural changes in bipedal stance at application of a stimulus from external environment and the resultant modification in the visual scene in patients with ACL reconstruction. The examined group consisted of 25 subjects – 11 patients with ACL reconstruction and 14 healthy adults. The external stimulus was realized by striking a flying ball; the modification of visual scene was obtained using special glasses. The 3D videography method was applied to evaluate postural changes. The most differences during three various monitored measurements were found for kinematic parameters of the lower limbs and the trunk in each group (both patients and healthy subjects). Statistically significant differences between the group of patients and healthy subjects (between both groups) were obtained for comparison of measurements with an unmodified visual scene and measurements with a modified visual scene, especially for the elbow and shoulder joints.

Keywords: Anterior cruciate ligament (ACL), proprioception, visual modified scene, 3D videography.

INTRODUCTION

The anterior cruciate ligament (ACL) plays a key role in assuring stability of the knee joint. Afferent information from ACL mechanoreceptors significantly participates in facilitating dynamic stability of the knee joint. This somatosensory information, as well as information from the visual and vestibular receptors, contributes to the maintenance and control of bipedal stance, posture and balance in a particular position during movement. A considerable modification of the sensory information, disturbance of the functional stability of the knee and impairment of postural control can occur due to traumatic ACL injury or ACL reconstruction (Harrison et al., 1994; Hoffman et al., 1999; Bonfirm et al., 2003; Liu-Ambrose et al., 2003). Impaired postural control measured by balance in the case of single limb stance has been reported after acute and chronic ACL injuries, as well as after ACL reconstructions (Lysholm et al., 1998; Hoffman et al., 1999; Denti et al., 2000; Henriksson et al., 2001).

Vision is particularly important in stabilizing posture under more challenging conditions or if the proprioceptive information from the lower limbs is reduced (ankle, knee injuries, amputees, etc.) (Lord & Menz, 2000).

Okuda et al. (2005) investigated the type of role played by vision in patients with LCA insufficiency during maintenance of postural stability. Notably, there was no significant difference between the injured and uninjured legs regarding postural sway during one leg standing with the eyes open, but the amount of postural sway increased significantly with the eyes closed. Pursuant to these results it can be inferred that vision appears to be dominant in compensating for reduced and/or compromised contribution by the injured (or reconstructed) ACL especially under more challenging conditions.

Modification of the visual scene and contemporary application of stimulus from an external environment can culminate in higher demands on balancing ability, especially as regards the lower limbs and the trunk. Our interest was focused on the question of whether the potential deficit in proprioception is manifested by postural changes under simple motor test conditions (hitting of a ball on arms raised forward) and how the visual system reacts in order to compensate for this deficit.

The purpose of this study was to analyze, by means of kinematic analysis, the postural changes in the bipedal stance at the application of a stimulus from the external environment and the resultant modification of the visual scene in patients with ACL reconstruction.

SUBJECTS

A total of 25 individuals agreed to participate in this study. Fourteen healthy individuals who reported no history of significant orthopaedic knee injury or balance related disorders served as the control group. The control group comprised 7 females and 7 males (age 24.9 ± 3.5 years, body weight 70.6 ± 9.4 kg, height 174.4 ± 10.3 cm). For the ACL reconstructed group, the mean age was 25.4 ± 6.9 years, weight was 70.5 ± 10.7 kg and the height was 174.2 ± 9.5 cm. The 4 females and 7 males had undergone reconstruction of the ACL with patellar tendon graft (7 patients) or hamstring tendon graft (4 patients). The average post surgery period was 51 days.

METHODS

Special hardware Olympus Eye trek FMD-700 (Fig. 1) was applied to modify the visual scene in our research. This optic system has OSR (Optical Super Resolution) for high quality on screen display equivalent to 720 000 pixels. The advantage of this special optical lens system is the possibility of connecting to various external devices (for example connection with a personal computer, television, DVD player, etc.). Connection to the video camera was also incorporated during our measurement.

Fig. 1

Special hardware Olympus Eye trek FMD-700



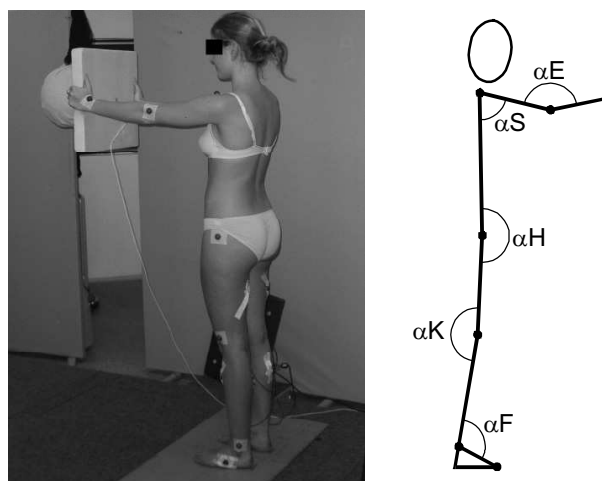
The experiment used two different visual conditions (scenes) with respect to the form of visual perception. The first part of the measurement took place with full visual control, without any restriction as to special hardware and with real visual perception. This was followed by the next phase where we modified visual perception by using special optical glasses, Eye trek FMD-700.

Stimulus from the external environment was applied by reason of major “dynamization” of the situation (by reason of creating a more complicated situation). The impulse was applied by a basketball of variable weight depending on the weight of the subject and from different heights. The weight of the ball was set up so that its momentum at the moment of striking the board conformed to 7% of the weight of the subject. To determine the solid weight (ball + weight) for the given proband we applied the law of conservation of mechanical energy. In the event of zero level potential energy at the bump site applies $m_l gh = \frac{1}{2} m_l l^2 \omega^2$, where m_l is the weight of the hanging body/sphere, $g = 9.81 \text{ m} \cdot \text{s}^{-2}$, h determines the sphere height before activation with respect to the sphere height after the bump, ω its angular speed and a l is the suspension length. If $v = \omega l = \sqrt{2gh}$ applies, then the conditions for the dynamic of the solid at the moment of the bump is $m_p v = 0.07 m_p$ (where m_p is the proband's weight) we gain for $h = 0.5 \text{ m}$ the relation $m_l = 0.0220 m_p$.

The main task of each subject was to cushion the striking ball with the aid of a light board made of laminated polystyrene, which was held by the subject's raised arms (Fig. 2). A total of 7 attempts were made. The first three measurements were without any visual modification. The other four measurements were conducted with special glasses, whereas the flying ball was caught by the experimenter near the impact site (already out of the visual field of the subject) during third trials with simulated stimulus.

Fig. 2

An illustration of measurement without modification to the visual scene and the evaluated angle parameters



The 3D videographic method was used to evaluate the basic kinematic parameters. Special marks indicating projection of the specific anatomic structures on the body were assigned on the left side of the body of

each subject. These eight structures comprised: the tragus, the acromion, the lateral humerus epicondyl, the capitatum, the major femoral trochanter, the lateral femoral epicondyle, the lateral malleolus, and the capitulum ossis metatarsi quinti. Each subject was filmed by two video cameras, followed by processing of the video record, resulting in kinematic parameters of 3D movement evaluation.

The changes in angle magnitude in the sagittal plane at intervals 0–1600 ms were analyzed. The time 0 ms was characterized as the moment when the experimenter let go of the ball and 600 ms as the impact of the ball on the board. Later, we evaluated the interval 1000 ms following impact. We noted the time run of changes of these angles: metatarsus – shank, shank – thigh, thigh – trunk, trunk – arm, and arm – forearm (Fig. 2).

STATISTICAL ANALYSIS

Data obtained by kinematic analysis were statistically processed by the programme Statistica, version 6.0.

The non parametric unpaired test (Mann-Whitney) was used for comparing the two different groups (patients and healthy subjects). Specification of differences between the angles in a single group during various measurements was performed by using the non parametric sign test.

RESULTS AND DISCUSSION

Comparison of the kinematic parameters of a single group of healthy subjects

Significant differences in single kinematic parameters (excepting the angle shank – thigh of healthy subjects) when comparing measurement results with an unmodified visual scene and measurements taken at a modified visual scene with real stimulus were not found for healthy subjects not even after ACL reconstruction (TABLE 1).

TABLE 1

Comparison of kinematic parameters on the lower limbs of the group of healthy subjects

	Aver N		Aver I		Aver II		Comparison of differences		
Metatarsus – shank α_F	AV	SD	AV	SD	AV	SD	N × I	N × II	I × II
Max. (°)	138.50	1.78	138.01	1.73	137.82	1.72	6/8	8/6	9/5
Min. (°)	136.68	1.81	135.62	1.73	134.14	1.74	9/5	13/1 **	12/2 *
Dif. (°)	1.83	0.15	2.39	0.22	3.69	0.25	3/11	1/13 **	1/13 **
Time max. (ms)	0.36	0.11	0.18	0.14	0.38	0.12	7/7	8/6	6/8
Time min. (ms)	0.03	0.09	0.15	0.10	0.36	0.11	4/10	3/11	4/10
Aver 1 (°)	137.40	1.80	136.91	1.76	135.92	1.71	9/5	11/3	11/2 *
Aver 2 (°)	137.64	1.79	136.94	1.72	135.81	1.74	8/6	11/3	12/1 **
Shank – thigh α_K	AV	SD	AV	SD	AV	SD	N × I	N × II	I × II
Max. (°)	171.24	1.34	170.91	1.35	172.47	1.34	7/7	4/10	0/14 **
Min. (°)	168.73	1.28	166.87	1.37	170.13	1.34	13/1 **	3/11	0/14 **
Dif. (°)	2.52	0.35	4.04	0.34	2.34	0.23	2/12 *	6/8	13/1 **
Time max. (ms)	-0.12	0.12	-0.06	0.10	0.45	0.07	6/8	1/12 **	3/11
Time min. (ms)	0.28	0.05	0.30	0.03	0.00	0.13	2/10 *	11/3	11/3
Aver 1 (°)	170.88	1.33	170.62	1.36	170.68	1.35	6/8	6/8	6/7
Aver 2 (°)	169.85	1.30	168.91	1.37	171.56	1.34	11/3	2/12 *	0/13 **

Legend to TABLE 1, 2, 3 and Fig. 3, 4, 5

AV = average * = $p < 0.05$

SD = standard deviation ** = $p < 0.01$

N = measurements without any modification of the visual scene (non-modification)

I = measurements with modification of the visual scene with a real stimulus

II = measurements with modification of the visual scene with a simulated stimulus

Max. = maximal amplitude of angle in time period 0–1600 ms

Min. = minimal amplitude of angle in time period 0–1600 ms

Dif. = difference between maximal and minimal amplitude of angle in time period 0–1600 ms

Time max. = time of achievement of maximal amplitude of angle in time period 0–1600 ms

Time min. = time of achievement of minimal amplitude of angle in time period 0–1600 ms

Aver 1 = average magnitude of angle in time period 0–600 ms (before the stroke of a ball)

Aver 2 = average magnitude of angle in time period 600–1600 ms (after the stroke of a ball)

Aver N = average magnitude of angle of three measurements without any modification to the visual scene

Aver I = average magnitude of angle of three measurements with modification to visual scene with real stimulus

Aver II = average magnitude of angle during modified visual scene with simulated stimulus

The number of significant differences increased when a simulated stimulus was applied. Perhaps the best illustration of these changes is provided by the difference between the maximum and minimum degrees of angle. Most of the differences were ascertained for

kinematic parameters of the lower limbs and trunk at particular measurements (Fig. 3, TABLE 2). On the other hand, minimum differences for a single angle were obtained for the upper limbs.

Fig. 3

Graphic comparison of the difference between the maximal and minimal degrees of the metatarsus-shank angle (α_F) at single measurements (modification)

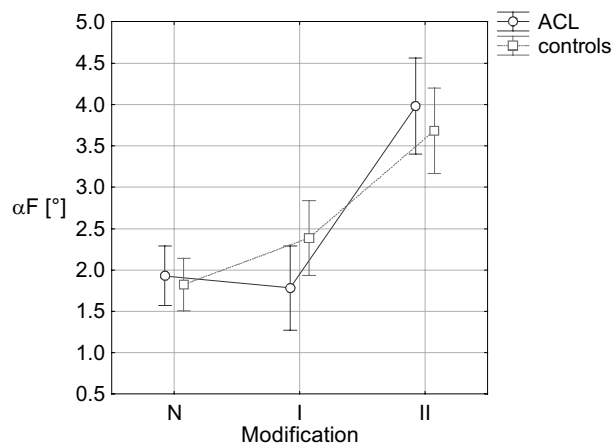


Fig. 4

Graphic comparison of the time of achievement of the maximal value of the arm – forearm angle (α_E) in single measurements (time of stroke – 0 ms on Y-axis)

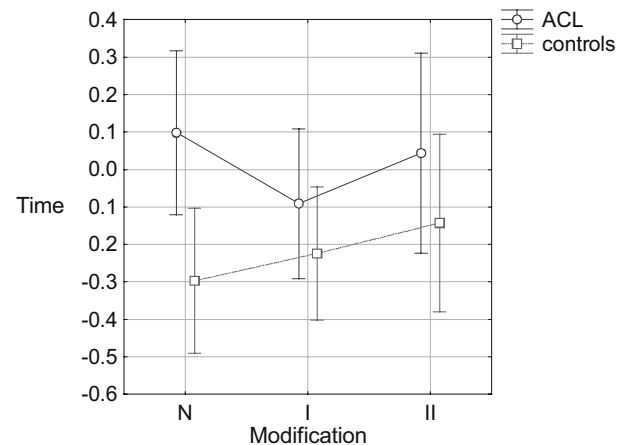


TABLE 2

Comparison of kinematic parameters on the lower limbs of the group of patients

Metatarsus – shank α_F	Aver N		Aver I		Aver II		Comparison of differences		
	AV	SD	AV	SD	AV	SD	N × I	N × II	I × II
Max. (°)	138.83	2.01	138.82	1.95	138.36	1.94	7/4	6/5	9/2
Min. (°)	136.90	2.04	137.04	1.95	134.38	1.96	4/7	10/1 *	11/0 **
Dif. (°)	1.93	0.17	1.78	0.25	3.98	0.28	5/6	0/11 **	0/11 **
Time max. (ms)	0.34	0.13	0.37	0.16	0.27	0.13	4/7	6/5	4/6
Time min. (ms)	-0.02	0.10	0.15	0.12	0.29	0.13	5/6	5/6	4/7
Aver 1 (°)	137.68	2.03	137.20	1.98	136.55	1.93	4/7	10/1 *	10/1 *
Aver 2 (°)	138.03	2.02	137.10	1.94	136.28	1.97	7/4	10/1 *	9/2
Shank – thigh α_K	AV	SD	AV	SD	AV	SD	N × I	N × II	I × II
	AV	SD	AV	SD	AV	SD	N × I	N × II	I × II
Max. (°)	172.57	1.51	173.30	1.52	174.80	1.51	3/8	0/11 **	0/11 **
Min. (°)	170.55	1.44	169.67	1.55	172.91	1.52	9/2	0/11 **	0/11 **
Dif. (°)	2.02	0.39	3.63	0.38	1.88	0.26	2/9	6/5	10/1 *
Time max. (ms)	0.10	0.13	-0.20	0.11	0.53	0.08	7/4	2/9	0/11 **
Time min. (ms)	0.22	0.05	0.27	0.03	0.17	0.15	2/8	7/4	7/4
Aver 1 (°)	172.16	1.50	173.08	1.53	173.42	1.52	1/10 *	1/10 *	3/8
Aver 2 (°)	171.63	1.47	171.52	1.55	173.97	1.51	7/4	0/11 **	0/11 **

TABLE 3

The values of test standards for kinematic parameters of the upper limbs during comparison between healthy subjects and patients

ANGLE	Attemp	Max.	Min.	Dif.	Time max.	Time min.	Aver 1	Aver 2
Trunk – arm α_s	N	0.602	0.985	0.164	0.712	0.137	0.876	0.766
Arm – forearm α_e	N	1.478	1.916	-1.642	2.600 **	-0.082	1.369	2.026 *
Trunk – arm	I	1.095	1.204	-0.493	1.724	-2.546 *	0.931	1.040
Arm – forearm	I	2.245 *	2.573 **	-1.752	0.684	-1.177	2.190 *	2.464 *
Trunk – arm	II	1.916	2.245 *	-1.040	1.013	-0.438	1.861	2.245 *
Arm – forearm	II	1.861	2.464 *	-1.150	0.164	-1.177	2.080 *	2.683 **

Comparison of kinematic parameters and measurements between both groups

a) Measurements without modification to visual scene

Statistically significant differences were found at the only angle (arm – forearm) during measurement without any modification to the visual scene between patients and healthy subjects (TABLE 3). The time of achievement of maximal magnitude of the arm – forearm angle and the average magnitude of this angle in the time period 600–1600 ms (after the stroke of a ball) were mentioned as observed parameters. As is illustrated in Fig. 4, it can be inferred that the value of the maximum angle at the elbow is achieved in patients after striking the ball, whereas in healthy subjects this is seen before such a hit. The value of the angle at the elbow in time period 600–1600 ms is greater in the group of patients.

b) Measurements with modification to the visual scene with a real stimulus

More statistically significant differences were found during measurement with a modified visual scene and at the application of a real stimulus in comparison to measurements without special glasses. A possible interpretation thus could be that maintaining postural stability is rather more difficult when the visual scene is changed. Additionally, altered visual function means higher demands on proprioception and vestibular information. More marked differences were evidenced with the arm – forearm angle. Differences at the level of statistically significant $p < 0.05$ were shown for the minimal magnitude of the shank – thigh angle and the time of achievement of the minimal magnitude of the trunk – arm angle.

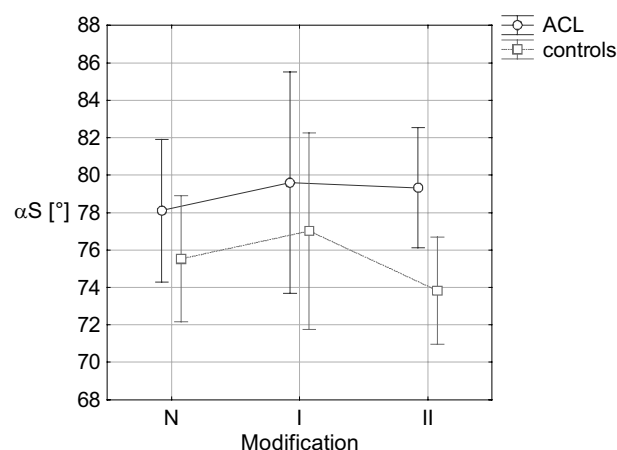
c) Measurements during a modified visual scene with a simulated stimulus

Measurements carried out during a modified visual scene and a simulated stimulus represented an unexpected situation for each subject. In comparison with the other two measurements mentioned above, where

the arm – forearm angle manifested itself as a significant difference, the trunk – arm angle parameters (Fig. 5) showed similar significance. The reaction of subjects to simulated stimuli was more complex (global) as far as the particular segments of body and their connections are concerned, and also more individual – from the strategical aspect.

Fig. 5

Graphic comparison of the minimal magnitude of the trunk – arm angle (α_s) at single measurements (modification)



According to the results mentioned above it is evident that applying special glasses did not have a strong influence on the motor task. Major differences occurred during changes between real and expected situations. It should then be generally true that measurements without any modification to the visual scene be regarded as “posturally simplest” rather than “more challenging” following modification of a visual scene with a real stimulus, and the attempt with a simulated stimulus was relatively specific.

The higher average values of most angles were registered for patients in contrast to healthy subjects. However, the question is how we can interpret and judge

these findings with regard to postural stability. Greater tendencies to extension in almost the majority of the tested joints demonstrated a higher value of the magnitude of particular joints in patients. Many of the joints (knee, elbow) are locked in extension. The stability of the knee joint is highest at full extension (Kapandji, 1991). Therefore, it is rather easier to stabilize the joints only in these extension positions and total proprioception control is thus not indicated. It also manifests itself in the form of smaller demands being made on muscle coordination.

It is, however, possible that proprioceptive changes following ACL injury can occur without affecting any control of standing balance, as suggested by Birmingham et al. (2001) – possibly through compensation by means of visual, vestibular and somatosensory input from receptors in other structures and joints. Corrections of postural sway rendered at the hip and trunk can play a compensatory role intended for maintaining balance, too (Allum et al., 1998).

We supposed that disturbed interpretation as well as the processing of proprioceptive information will be shown in patients with ACL reconstruction, which will manifest in postural changes. Our hypothesis was proven to be true only partially.

One of the reasons here can be the fact that a small group of 25 subjects was investigated. The applied external stimulus could be insufficient and neither was the power of stroke strong. Therefore, the subjects were able to cushion the strike of the ball at the upper part of the body, eventually balancing some postural sways by using ankle strategy. The tested task was not as demanding since not only healthy subjects but also the patients were able to compensate their potential proprioceptive deficit very well. Alternation of knee joint proprioception wasn't manifested and didn't influence essentially the postural control of the lower limbs.

Generally, good health, muscle power and motor abilities could play a substantial role in patients as well. However, the possibility of minimal proprioceptive deficit cannot be excluded in instances such as in cases of its measurement following optimally selected rehabilitation.

CONCLUSIONS

From the stated results it follows that postural demands in a given situation change with modification to the visual scene. Similar tendencies of (in) postural changes were noted in both groups. The most statistically significant differences between both groups (between the group of patients and healthy subjects) were obtained for comparison of measurements with the modified visual scenes, especially for the elbow and shoulder

joints. It is not so apparent that the changes observed by us are related to a potential proprioception deficit at the knee joint. The supposed varied postural strategies were not confirmed for the lower limbs.

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**KINEMATICKÁ ANALÝZA POSTURÁLNÍCH
ZMĚN V BIPEDÁLNÍM STOJI PŘI APLIKACI
PODNĚTU ZE ZEVNÍHO PROSTŘEDÍ
A MODIFIKACI VIZUÁLNÍ SCÉNY U PACIENTŮ
PO PLASTICE PŘEDNÍHO ZKŘÍŽENÉHO VAZU**
(Souhrn anglického textu)

Tato studie se zabývá změnami postury při modifikované zrakové scéně a při aplikaci podnětu ze zevního prostředí u zdravých jedinců a u pacientů po plastice předního zkříženého vazů (LCA) za nezměněné a modi-

fikované vizuální scény. Do vyšetřovaného souboru bylo zahrnuto 11 pacientů po plastice LCA a 14 zdravých jedinců. Modifikace vizuální scény bylo dosaženo prostřednictvím speciálního optického systému Olympus – Eye trek FMD-700. Zevní podnět byl realizován pomocí nárazu letícího míče. K hodnocení posturálních změn jsme využili kinematickou analýzu. U pacientů po rekonstrukci LCA i u zdravých jedinců jsme nejvíce diferencí v jednotlivých způsobech provedení našli pro kinematické parametry na dolních končetinách a trupu. U obou skupin probandů jsme zaznamenali podobné tendence k posturálním změnám. Při porovnávání kinematických parametrů mezi skupinou pacientů a zdravých jedinců jsme našli rozdíly v poloze horních končetin. Pro dolní končetiny a trup (s výjimkou minimální velikosti úhlu bérce – stehno při modifikované scéně s reálným podnětem) nejsou rozdíly mezi oběma skupinami statisticky významné.

Klíčová slova: přední zkřížený vaz (LCA), propiocepce, modifikace vizuální scény, 3D videografická metoda.

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