Gait & Posture 60 (2018) 251–257

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Effect of cognitive challenge on the postural control of patients with ACL reconstruction under visual and surface perturbations

Alexis Lion[a,*], Paul Gette[a], Christophe Meyer[a], Romain Seil[a,b], Daniel Theisen[a]

[a] *Sports Medicine Research Laboratory, Luxembourg Institute of Health, Luxembourg, Luxembourg*
[b] *Department of Orthopaedic Surgery, Centre Hospitalier de Luxembourg - Clinique d'Eich, Luxembourg, Luxembourg*

ARTICLE INFO

Keywords:
Knee injuries
ACL
Balance
Body sway
Proprioception
Cognition

ABSTRACT

Our study aimed to evaluate the effect of cognitive challenge on double-leg postural control under visual and surface perturbations of patients with anterior cruciate ligament reconstruction (ACLR) cleared to return to sport.

Double-leg stance postural control of 19 rehabilitated patients with ACLR (age: 24.8 ± 6.7 years, time since surgery: 9.2 ± 1.6 months) and 21 controls (age: 24.9 ± 3.7 years) was evaluated in eight randomized situations combining two cognitive (with and without silent backward counting in steps of seven), two visual (eyes open, eyes closed) and two surface (stable support, foam support) conditions. Sway area and sway path of the centre of foot pressure were measured during three 20-s recordings for each situation. Higher values indicated poorer postural control.

Generally, postural control of patients with ACLR and controls was similar for sway area and sway path ($p > 0.05$). The lack of visual anchorage and the disturbance of the plantar input by the foam support increased sway area and sway path ($p < 0.001$) similarly in both groups. The addition of the cognitive task decreased sway area and sway path ($p < 0.001$) similarly in both groups.

Patients with ACLR who recently completed their rehabilitation have normalized postural control during double-leg stance tests. The use of a dual task paradigm under increased task complexity modified postural control, but in a similar way in patients with ACLR than in healthy controls. Double-leg stance tests, even under challenging conditions, are not sensitive enough to reveal postural control differences between rehabilitated patients with ACLR and controls.

1. Introduction

The anterior cruciate ligament (ACL) has not only a mechanical constraint function to stabilize the knee, but also a somatosensory function to provide, via the mechanoreceptors, proprioceptive information to the central nervous system regarding joint position [1]. This sensory information is processed simultaneously with neural input from the visual and vestibular system to stabilise body posture according to a planned motor task within a specific environment [2]. Therefore, it is not surprising to observe that an injury to the ACL can induce postural control deficits, e.g. increased body sways [3–5].

Most patients with ACL injuries undergo reconstructive surgery with the aim of returning to normal daily activities and, especially, sport participation. However, while ACL reconstruction (ACLR) procedures are generally followed by good recovery of knee function [6], postural control deficits have been reported during double-leg stance at the conventional time of return to sport (≈7 months after ACLR) [7]. Double leg-stance represents a standardized and reliable postural position to assess static balance and has been recommended to monitor progress during rehabilitation programs following ACLR [8]. Double-leg stance can be challenged by altering visual or proprioceptive information, a paradigm which can help to reveal more easily postural disorders. These sensory alterations are often observed during sport and could be involved in the sport-related ACL injury mechanism. Moreover, ACL injury occurs often during sport when the athlete has to manage simultaneously a motor response and an attentional process to detect, select and treat the relevant information in a highly uncontrolled environment. Swanik and colleagues showed that patients with ACL injury have decreased motor response times and visual-spatial disorientation [9], potentially increasing ACL injury risk via cognitive saturation during a motor task. The management of a dual task, i.e. the concomitant execution of motor and attentional tasks, could thus be impaired in individuals with ACLR. This paradigm represents a task of a greater complexity and could reveal more easily differences between

---

[*] Corresponding author at: Sports Medicine Research Laboratory, Luxembourg Institute of Health, 76 Rue d'Eich, Luxembourg L-1460, Luxembourg.
E-mail address: alexis.lion@lih.lu (A. Lion).

https://doi.org/10.1016/j.gaitpost.2017.12.013
Received 18 May 2017; Received in revised form 11 December 2017; Accepted 13 December 2017

patients with ACLR and controls [10]. The evaluation of the ability to manage a cognitive challenge during a postural control task under visual and surface perturbations could inform the medical staff to clear their patients with ACLR to return to sport.

Therefore, we aimed to evaluate the effect of dual task on double-leg stance during different sensory situations in rehabilitated patients with ACLR. Compared to controls, we hypothesized that postural control is influenced differently by a cognitive challenge in patients with ACLR than controls, especially during more challenging postural situations such as absence of visual feedback and unstable support.

2. Methods

2.1. Participants

Rehabilitated patients with unilateral ACLR were recruited between February 2015 and December 2015 within our Sports Clinic. Inclusion criteria were as follows: age 15–35 years, unilateral ACLR, no other previous knee injuries, no musculoskeletal disorders affecting postural performance, medical clearance to return to sports. From the 31 eligible patients, 19 agreed to participate in our study. All patients were involved in regular sports activities before injury. Their characteristics (type of sport, type of injury, lesion side, meniscal lesion, time since surgery, type of graft, meniscal repair) were collected from the ACL registry of our Sports Clinic [11]. Twenty-one healthy volunteers, practicing sport for a minimum of three hours/week, were selected for the creation of reference datasets. Healthy volunteers had no known previous knee and musculoskeletal injuries. All participants were free from neurological, visual and vestibular disorders that could affect postural control performance. They read and signed an informed consent form previously approved by the National Ethics committee (n°201101/05). A power calculation revealed that with 16 participants/group, an effect size of 1.0 for sway area and sway path (two main outcomes commonly used to characterize postural control) could be detected for group differences at an alpha level of 0.05 and a statistical power of 0.8.

2.2. Postural control evaluation

Participants were tested using two adjacent force platforms (Arsalis 800 × 500; Arsalis SPRL; Louvain-la-Neuve, Belgium) each equipped with four three-dimensional force transducers (i.e. triaxial strain gauges). Tests were performed barefoot with one foot on each force platform. Foot placement was standardised using marks on the force platforms to avoid interference with the postural stability (Fig. 1). Feet were directed at an angle of 14°, heels 17 cm apart and arms along the sides [12]. Ground reaction forces generated while standing on the force platforms during the 20-s recordings were sampled at 1000 Hz. Although the use of two force platforms would have allowed to quantify the changes of the centre of mass projection within each foot, only the net results were considered here [13]. Thus, the individual signals of each force platform were combined together to determine the overall trajectory of the centre of mass projection on the ground and to compute total sway area (95% of prediction ellipse area, in mm^2) and sway path (mean distance, in mm) per recording [13]. Sway area is considered as an index of overall postural performance [14]. Sway path quantifies the magnitude of the two-dimensional displacement based on the total distance travelled and is considered to be a valid outcome measurement in studies investigating balance conditions [14]. Efficient postural control is mainly reflected by low values of sway area and sway path, conveying precision and efficiency of postural control, respectively [14]. Prior to analyses, a 4th order low-pass bidirectional Butterworth filter with a cut-off frequency of 10 Hz was applied, followed by a down-sampling of the records to 100 Hz [15]. The sway area covered and the sway path travelled by the centre of foot pressure were calculated in the horizontal plane according to the equations by Schubert and colleagues [15]. All data processing was performed using a custom-written Matlab GUI (Matlab R2014a, MathWorks, Netherlands).

Postural control was evaluated in eight randomized situations combining two visual (eyes open, eyes closed), two surface (stable support, foam support) and two cognitive conditions (single task, dual task). Participants were asked to remain upright on the force platforms, as stable as possible during three valid 20-s recordings per situation. A trial was considered invalid in case of loss of balance requiring a step. For each situation, the three recordings (or more if necessary) were performed sequentially. Participants were allowed to relax and move about while remaining in an upright position for at least one minute between the recordings. Randomization of the situations neutralized potential fatigue and learning effects. In the eyes open condition, participants were requested to stare at a point which was drawn at eye level on the opposite wall at a distance of two meters. To influence somatosensory information, a 5-cm-thick foam support (density: $50\,kg.m^{-3}$; Airex® Balance, Sins, Switzerland) was placed on each force platform (without overlapping) for the foam condition (Fig. 1). Before the recordings on foam supports, participants were allowed to stand on the foam for a few seconds to familiarize with this condition. The dual task was a silent backward counting in steps of seven, starting from a different random 3-digit number provided by the examiner at the beginning of each trial. Participants were requested to count backward silently to avoid movements of the jaw during articulation [16] and provided the final result at the end of the recording. Performance in the dual task during the postural control tests was evaluated based on the speed (average number of operations across the 3 trials) and accuracy (correct: 2 or 3 error-free trials; incorrect: less than 2 error-free trials of the 3 valid ones) of calculations. The aim was to test for potential group differences in the test execution strategy (e.g. “postural first” or “cognitive first” strategies). Prior to the postural control tests, dual task performance was also evaluated in a neutral, sitting position, to assess any systematic group differences at baseline.

2.3. Statistics

Student *t*-tests and χ^2-tests were performed as appropriate to compare the baseline characteristics of the two groups under study. Normality of the residuals was assessed with the Shapiro-Wilk test. When data distribution was not Gaussian, log-transformation was applied to the entire dataset (for a given parameter). General Linear Mixed-Models (GLMMs) were used to analyse the interactions and the main effects of groups (patients with ACLR vs. controls) and visual (eyes open vs. eyes closed), surface (stable support vs. foam support) and cognitive (single task vs. dual task) conditions on sway area and sway path. Similarly, GLMM was performed for the speed of the calculations of the dual task, testing for interactions and main effects of groups (patients with ACLR vs. controls), visual context (eyes open vs. eyes closed) and support stability (stable support vs. foam support). To respect the assumptions of the GLMMs, sphericity was tested on each main effect or interaction with Mauchly’s sphericity test, with the Greenhouse-Geisser procedure applied to correct the p-value in case of significance. χ^2-tests (or Fisher’s exact tests) were performed to test the effect of groups on the accuracy of the calculations, while McNemar tests were performed to test the main effects of visual context and support stability. Significance was set at $p < 0.05$, except for the multiple comparisons in the GLMMs. Here, the Bonferonni-Holm method [17] was used to set the p-level of significance as follow: $H_1 \dots H_m$ were the null hypotheses and $p_1 \dots p_m$ were their corresponding p-values, where m was the total number of possible comparisons (15 comparisons for sway area and sway path, 7 comparisons for speed of the calculations). These p-values were then ranked in an increasing order, and significance (denoted as *) was accepted if $p_k < \alpha/(m + 1 - k)$, with k being the rank index and $\alpha = 0.05$.