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Technical and measurement report

Frame-difference analysis of video-recorded laser-beam projections

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ABSTRACT

Laser beams have been applied in many human motion research contexts to project movements in specific motor tasks. Currently, there are no objective analysis methods for laser projection recordings. The principal aim of this study was to investigate the feasibility of quantifying motion by applying frame differencing and image analysis methods to video streams of laser beam projections. The laser projection was controlled by a mechanical device that produced pseudo random rotations. The 2D motion recorded by the video was compared with recordings obtained with an electromagnetic system where a sensor was fixed to the same device as the laser. High correlations in the time and frequency domains were found between the methods. We conclude that the proposed method can accurately quantify complex motion patterns from laser beam projections.

1. Introduction

Laser beam projections have been applied as a means of presenting tracking or repositioning tasks in many research contexts. In particular, this so-called laser method is common in clinical research in which the quantification of head motion is an important objective. For example, the assessment of the kinematics and the performance of head movement tasks applies to clinical work within a broad spectrum of cervical pathologies originating from trauma, rheumatic diseases, neurological conditions, or acquired pain-related limitations (Michiels et al., 2013). The assessment of the qualitative and quantitative aspects of cervical sensorimotor control is an important part of the diagnostic process in these conditions as disturbances might manifest as a reduced range of motion, poor coordination, and reduced overall performance in voluntary or task-specific head movements (Roijezon et al., 2010; Woodhouse et al., 2010).

The application of laser-based methods in studies of cervical sensorimotor control more specifically involves fixing a laser-pointing device on top of a participant's head where the movement of the laser projections (generated by the head movements) can track static or dynamic stimuli. For example, the assessment of the cervical joint repositioning error, which is considered to be a measure of kinaesthesia (Kristjansson et al., 2001; 2003), typically involves active head rotations to and back from a neutral position. The repositioning error (the difference between the starting point and the endpoint) are manually recorded from laser projections on a dartboard-shaped target embedded with coordinates (Hill et al., 2009).

To obtain the aspects of head movements while subjects conduct various tasks, the laser method has been combined with high-precision methods for measuring head kinematics, such as electromagnetic tracker systems, ultrasound motion-analysis devices or marker-based motion capture systems. Such systems provide accurate information about the task kinematics but do not necessarily generate data on all of the aspects of task *performance*. In the context of tasks requiring cervical sensorimotor control, this performance applies to gathering data on the specific tracking of dynamic/static stimuli (i.e., repositioning error, deviations from specific course etc.). Although custom-made labs may have incorporated both stimuli-responses and kinematics, there appears to be no objective method for recording the movement of laser projections. Reviewing the published experimental protocols suggests that these potential data on task performance are not quantified or

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were recorded manually by markings on paper (e.g., Roren et al., 2009; Park et al., 2012). In either case, it appears that there is an opportunity to analyse aspects of the accuracy of the performance of the task, which is not further examined.

In this study, we propose a novel and simple method for the objective measurement of laser-beam movements using video recordings and a subsequent frame-differencing analysis (FDA) of the captured images. Given that the background is static, the FDA detects the frame-by-frame changes in the pixels. Only the point of the laser beam will be moving in the captured frames. Existing FDA approaches have been applied successfully to track human movements in previous psychological and medical studies (Adde et al., 2013; Paxton and Dale, 2013).

To determine the feasibility of the video-FDA approach, we conducted a mechanical experiment where a laser pointing device and a sensor in an electromagnetic field were fitted on an engine-driven device that produced a series of preprogrammed superimposed sinusoidal oscillations in the horizontal plane. We assessed the agreement between the video-based measurements and recordings from an electromagnetic system under these controlled rotations by comparing the frequency-domain and time-domain data from the two systems.

2. Methods

2.1. Materials and equipment

A schematic drawing of the experimental set-up can be found in Fig. 1. The motion was driven by a brushed DC motor with a 1:308 gear ratio (Maxon Motor, Sachseln, Switzerland, part no. 353295) that was controlled by a LabVIEW program via an NI 9505 DC Brushed Servo Drive (both from National Instruments Corporation, Austin, TX, USA). The same waveform was used for all of the repetitions (60 s) and was composed of the following harmonics: 37, 49, 71, 101, 143, 211, 295, 419, 589, and 823 at a fundamental frequency of 0.005 Hz, resulting in frequencies between 0.185 and 4.117 Hz. The velocity amplitudes decreased as the frequency increased: 20°/s from 0.185 to 0.355 Hz, 19°/s from 0.505 to 1.056 Hz, 16°/s from 1.476 to 2.096 Hz, 15°/s at 2.947 Hz, and 13°/s at 4.117 Hz. The lowest frequency (4.117 Hz) corresponded to the largest harmonic angular excursion of ±17°. A laser pointer (Model TI-306, Clas Ohlson, Great Britain) and a 6-dof Liberty sensor (Polhemus, Inc., Colchester, Vermont, USA) were fixed to the custom-made device. Metallic objects, drives/computer equipment and other peripheral devices that could potentially distort the electromagnetic tracking were kept at a far distance from the electromagnetic field, and the transmitter was equipped with a built-in shield that omitted cross-talk from other sources. The Liberty sensor has been found to reliably record angular and positional data (Jordan et al., 2000; Amiri et al., 2003). Data collected with the Liberty sensor (sample rate 240 Hz) were analysed in Matlab (Mathworks Inc., Ma, USA). A Samsung NX210 camera positioned next to the device captured the laser beam, which was projected on a white background (distance 1.6 m) at a sample rate of 30 Hz. A total of 25 1-min recordings were obtained and analysed.

2.2. Signal analysis

Raw MPEG4 video files containing the laser beam projections were imported into Matlab R2013a v.8.1.0604 and converted into greyscale colour. In the next step, the frame-by-frame difference in the greyscale images were found through the application of the *imabsdiff* command. This command calculates the absolute difference between two images. This procedure, due to the constant background, generates a set of images containing grey laser 'dots' on a black background, which represents the laser movements from image to image. To locate the specific *xy*-position of the laser point

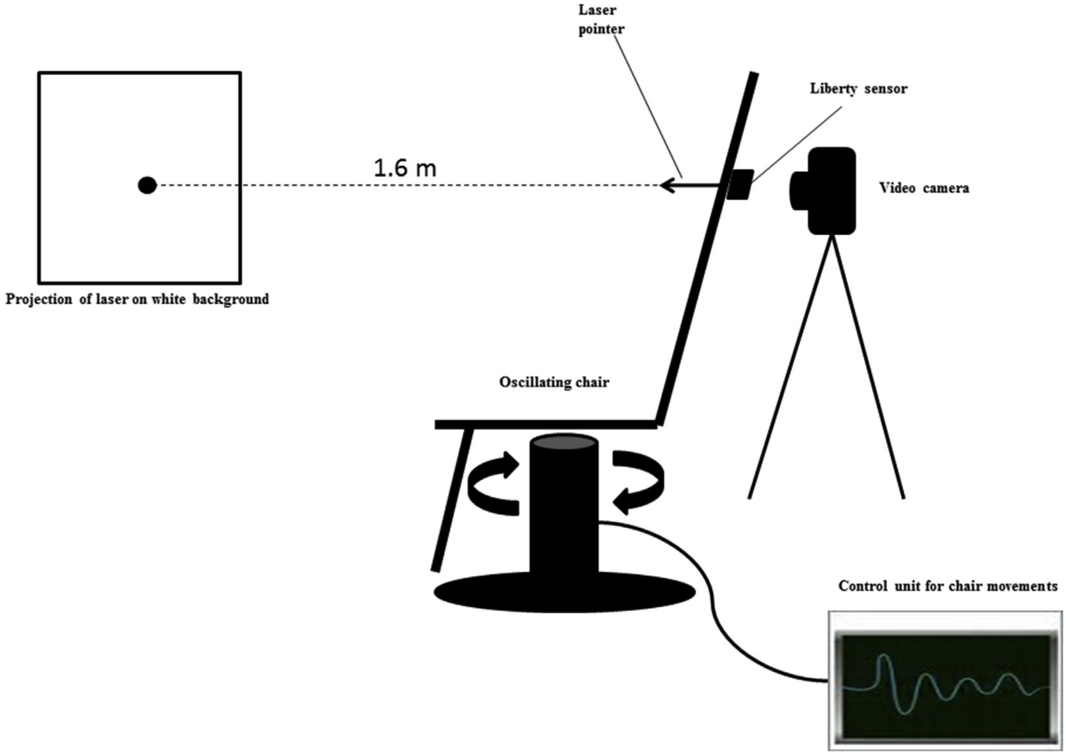

Fig. 1. Experimental set-up.