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Technical and measurement report

Evaluating the neck joint position sense error with a standard computer and a webcam

Angelo Basteris*, Ashley Pedler, Michele Sterling

Recover Injury Research Centre, Menzies Health Institute Queensland, Griffith University, Southport, QLD, Australia

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ABSTRACT

Joint Position Sense Error (JPSE) is a measure of cervical spine proprioception, and a simple method for measuring the JPSE could help in monitoring and evaluating the outcomes of rehabilitation of people with neck pain.

In this study we demonstrate preliminary results of a method for measuring JPSE that does not require the participant to wear any equipment. Based on free publicly available head tracking software, compatible with any webcam, we developed a webpage which instructs the participant in performing a self-administered version of the test. The aim of this proof-of-concept study was to demonstrate the viability of this system.

We compared our absolute error values (3.68 ± 1.2° after extension, 3.46 ± 1.66° after flexion, 3.89 ± 2.34° after rotation to the left and 4.02 ± 1.82° after rotation to the right) to values from literature, finding that our results do not differ from those of 6 out of 11 studies (which used more complex and expensive setups).

The results indicate that our system allows assessment of the JPSE with a standard computer. Being based on a website, the system has potential for telemedicine use. Further research is required to validate the system before it can be recommended for use in clinical practice.

1. Introduction

The Joint Position Sense Error (JPSE) test is a quantitative assessment of cervical spine proprioception in which the participant is asked to move the head and (re)position it to a neutral starting position (Strimpakos, 2011). A recent review found that greater JPSE in people with neck pain compared to controls was reported in 50% (4/8) of studies including patients with traumatic neck pain (whiplash associated disorders) and 44% (4/9) of studies including patients with non-traumatic neck pain (de Vries et al., 2015).

All previous studies have required participants to wear equipment of some kind (e.g. laser pointers or electromagnetic trackers). Requiring specialised equipment makes the procedure less practical, especially for clinical use. Also, the reliability of the measurement may be affected by sensor misalignment. Differences in sensor placement may result in alteration of movement patterns or sensory input resulting in systematic errors in JPSE data.

The primary aim of our study was to demonstrate the viability of an application to measure the JPSE based on free, markerless, head tracking software.

2. Methods

2.1. Participants

A sample of 22 healthy volunteers (13 females, age 36 ± 11) was recruited via advertising flyers within the university campus. Respondents were screened for and excluded if they had a history of whiplash injury or had sought treatment for neck pain in the last 6 months. Participants provided written informed consent to participate prior to enrolment and visited our laboratory at Griffith University (Gold Coast, Australia) for a single session. This study was approved by the University Ethics Committee (protocol AHS/23/15/HREC).

2.2. Software

We developed a web page that instructed the participants through the test procedure. Head movement was measured by

* Corresponding author. Griffith University, Gold Coast Campus G05 — room 3.16, 4222 Southport, Australia. Tel.: +61 755529201.
E-mail address: angelobasteris@gmail.com (A. Basteris).

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software which is publicly available for free download (xLabs, Australia). The software can track the participant's head motion without any marker or device to be worn, and it does not require a calibration phase. It provides the 2D projection of the head position on the screen at a frequency of 17 Hz, by extracting 77 facial features using the Active Shape Model (ASM) algorithm from the video acquired via a standard webcam (Cootes et al., 1995).

2.3. Task

Participants sat on a chair in front of a personal computer running Windows 7, with a 23″ display. The chair was positioned so that the participant's head was approximately 90 cm from the screen. The position of the chair and the computer was maintained for all subjects by markers on the floor and on the table. All participants used the mouse with their right hand, while the position of their left hand was not prescribed.

Participants were requested to align themselves with the webcam mounted on the top of the screen. Their task consisted of the active–active head to neutral repositioning task. They were asked to turn their head maximally in one of four directions (extension, flexion, left and right rotation) and return to match the initial position at their preferred speed.

For each trial, the system provided these instructions by speech synthesis:

1. Move a green dot, controlled through the movement of the head, over a cross representing the centre position and keep it steady for 2 s.
2. "Close the eyes and click". The position acquired at this stage represents the reference position for each trial.
3. "Move the head (in one of the directions) to the max, back to the original position, and click".
4. "Move the head a little and then open the eyes". In clinical practice the test is performed with patients blindfolded, and in this phase the head is passively relocated to the centre position by the clinician (Humphreys, 2008; Treleaven, 2008). However, we could not adopt this option due to the risk of interference with the tracking software. By requiring the movement of the head prior to the opening of the eyes, we ensured that the participant did not receive feedback about their performance from the previous trial.

The experiment consisted of six trials in each direction (Swait et al., 2007). The order of movement directions was pseudo-randomised so that no consecutive trials required head movement in the same direction.

2.4. Analysis

The head tracking software provides output in screen coordinates (in cm), with the origin being the centre of the screen. For each repetition, we recorded the head position at the time of mouse click which corresponds to selection of the reference (starting) position and the final position by the participant (items 2 and 3 of the task, respectively). Data were processed using Python (x,y) (van der Walt et al., 2011).

We computed several measures of error, summarized in Table 1, where α and x are respectively the angle and the distance between the final and reference position for each trial (Hill et al., 2009). Since errors in the JPSE are reported in degrees in literature, we estimated α as the inverse tangent of x divided by the distance from the screen (assumed constant at 90 cm).

We calculated mean values of absolute error and 95% confidence intervals for individual and combined movement directions, and then considered whether the respective mean values from 11 studies reported in de Vries et al. (2015) fell within our confidence interval.

3. Results

All the participants were able to complete the experiment within five to ten minutes, with no issues or interaction with the experimenter.

Table 2 shows our measurements of absolute error, averaged over one or more directions, compared with values reported in 11 previous studies. Half of the comparisons (11 out of 28) suggest that our mean values are not significantly different than previously reported values. These include values from 6 out of 11 prior studies.

Fig. 1 shows the error measurements (AE, R, CE, VE and RMSE) over the six repetitions, averaged for all participants, in each direction. Data from healthy participants reported in other studies are shown for comparison.

With respect to AE, our measurements are more similar to literature values for flexion and extension than rotation movements which our data may overestimate. R shows similar relocation accuracy to AE, and has a similar trend among directions.

The constant error is the only measure indicating whether the participant under or overestimated the target position. We observed a tendency to overshoot when returning from extension and to undershoot when returning from rotation.

Higher values of VE after return from rotations are indicative of a larger spread of the final positions after such movements in comparison to flexion/extension.

RMSE is computed based on CE and VE, and we obtain a trend among directions similar to those for the VE, with errors after head rotations higher than those after flexion and extension.

4. Discussion

Our results demonstrate that our method allows measurement of JPSE with a webcam and computer. With further evaluation, this test could have clinical utility given that it requires no specialised equipment and has the potential for remote application. This method of assessing JPSE also removes the potential confounding influence of altered sensory input that occurs when participants are required to wear sensors.

Table 1
Measurements of error for the JPSE.

Absolute error	*AE*	$\sum_{n=1}^{N} \frac{\|\|\alpha\|\|}{N}$	It is the most used measure, representing the accuracy without directional bias.
Positional error	*R*	$\sum_{n=1}^{N} \frac{\|\|x\|\|}{N}$	Similar to AE, but with the trial error measured in cm. It is rarely used in literature.
Constant error (directional bias)	*CE*	$\sum_{n=1}^{N} \frac{\alpha}{N}$	Captures the tendency to undershoot (CE < 0) or overshoot (CE > 0)
Variable error (variability)	*VE*	$\sqrt{\sum_{n=1}^{N} \frac{1}{N}(\alpha - \mathrm{CE})^2}$	Represents consistency of the responses at each target.
Root mean squared error	*RMSE*	$\sqrt{\mathrm{CE}^2 + \mathrm{VE}^2}$	It is an overall measure of how successful the subject was in achieving the target and it has higher reliability than CE and VE (Lee et al., 2006)

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