Database of movement control in the cervical spine

Reference normal of 180 asymptomatic persons

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Introduction

No database of reference normal values exists for movement control of the cervical spine. The Fly Test is a clinical test designed to detect impaired neck proprioception while subjects are moving their head and neck [[1](#_ENREF_1)]. Recently the Fly Test was developed further and was found to be both a reliable and a valid test for detecting deficient movement control of the cervical spine. The test has been carried out on patients with traumatic and non-traumatic neck pain as well as asymptomatic persons [[2](#_ENREF_2)]. The Fly Test addresses an important proprioceptive function, which is the regulation of movements, i.e. the detection and correction of errors through feedback and reflex mechanisms, while performing active movements [[2-4](#_ENREF_2)]. There are three outcome measures in the Fly Test, amplitude accuracy (AA), directional accuracy (DA) and smoothness of movement indicated by jerk index (JI). These variables represent three different but interrelated aspects of movement control [[3](#_ENREF_3), [5-8](#_ENREF_5)].

 In the reliability testing of the Fly Test, progressively wider limits of agreement (LOA) were observed across the study groups; control – non-trauma neck pain – whiplash-associated disorders (WAD). In order to detect clinically important changes between two measurements, for example as a result of treatment intervention, LOA with 95% confidence interval can be used as a reference range [[9](#_ENREF_9)]. According to the wide LOA in the WAD group it became clear that to be capable of detecting a real change in performance on the test, individual improvement would have to exceed the scores of the asymptomatic group. Instead of using LOA as a reference range, a reference normal of asymptomatic persons, classified according to age and gender was suggested to be more useful when assessing improvements in the symptomatic groups. In a one year prospective study, the Fly Test revealed diverging courses of impaired cervical movement control in persons involved in motor vehicle collisions [[10](#_ENREF_10)]. Half of the participants who depicted the worst results at the start of the study improved their movement control gradually over the one-year period without any form of treatment whereas the opposite was true for the other half of the participants [[10](#_ENREF_10)]. Therefore it is important in practice to have reference normal values, which the 2 divergent courses of movement control in the cervical spine can be measured against.

 A 3-space Fastrak system was used in the Fly Test to track the position of sensors positioned on the subject’s head. This instrumentation has been widely used in research and has been shown to be accurate [[11](#_ENREF_11)], but for clinical use it is expensive and inconvenient. Advances in wireless technologies have stimulated the development of miniature motion sensors which can be implemented for human movement analysis in addition to being relatively inexpensive. Given that a considerable data from the Fly Test have been collected by using the Fastrak system, it would be beneficial to determine whether using a wireless motion sensor would give comparable results.

 The main purpose of this current paper is to publish a normative database of movement control of the cervical spine, measured by the Fly Test, and to make the database available to interested clinicians and researchers. Secondly, to provide a method for converting the values from the Fastrak measurements to corresponding values for the wireless orientation motion sensors (InertiaCube BT™).

Materials and Methods

Participants

The participants in the study were 182 asymptomatic individuals, 83 men and 99 women; the age range was 16-74 years. The mean height was 175 cm (± .08), mean weight was 76.6 kg (±14.8) and mean body mass index (BMI) was 24.9 (± 4.0). To be included the participants should not have had symptoms from the head, neck or shoulder area for at least 1 year before testing, a score below 10 on the Neck Disability Index (NDI)[[12](#_ENREF_12)] and no pain on a Visual Analogue Scale (VAS). The participants were divided into 6 age groups (16-24, 25-34, 35-44, 45-54, 55-64, and 65-74 years)(Table 1). Recruitment for the study was performed by contacting various schools and companies in Reykjavik for volunteers. Individuals were excluded if they had a history of musculoskeletal pain or injury to the neck and during the last year any symptoms of dizziness or visual disturbances. Systematic diseases or psychological disorders of any kind excluded participation. All participants completed questionnaires recording demographic data and general health. Informed consent was obtained from the participants after ethical clearance from the National Bioethics Committee.

Measurements

Neck movement was recorded using a 3-space Fastrak system and the Fly Test, which is a custom-made software program. Further detailed description of the experiment can be found in previously published papers by Kristjansson et al.[[2](#_ENREF_2)]. Data collection was carried out in a variety of community locations (e.g. schools, offices, companies etc.), a portable system linked to a laptop computer was utilized.

Two cursors, 1 blue and 1 black, were seen on a computer screen. The blue cursor (derived from the Fastrak system) indicated movements of the head. The black cursor (derived from the Fly software program) traced the movement patterns represented by x(t) and y(t) in a coordinate system on the computer screen. Only the cursors were visible on the computer screen, not their trajectories, which made prediction of movements difficult. A software program was used to format and process the data for analysis. The participants were asked to use the cursor, derived from the sensors on the head to follow as accurately as possible, the cursor of the Fly. Three different movement patterns of varying difficulty; easy, medium, difficult, were used for the test procedure (Figure 1). The outcome measures were amplitude accuracy (AA), directional accuracy (DA) and Jerk index (JI). AA was recorded by continuously calculating the absolute distance (radius) in millimeters between the two cursors during the test sequence. For DA, the percentage of the total time spent within, ahead of, and behind a zone surrounding the target (the fly)[[2](#_ENREF_2)] during a trial, was calculated. This represented DA’s time on target, overshoots and undershoots, respectively. Jerk, or smoothness of movement was calculated and represented by an index normalized by the smoothness of the path of the Fly itself (JI). This was done by calculating the third derivative of the two-dimensional position data x(t) and y(t) and integrate the quadratic sum over time, using the equation based on the works of Teulings et al.[[13](#_ENREF_13)].

The integral was evaluated for both the path that the Fly covered, JFly and the path created by the patient, Jp. The normalized jerk value was calculated using the relation

This ensured that geometrical and temporal features of various curves of the Fly did not influence the jerk value.

 A second set of measurements was conducted one year after the collection of data took place. Ten persons from the earlier measurements were asked to perform in the test again in the same manner. Measurements were conducted separately with the Fastrak sensors and with the InertiaCube BT™ sensor (Intersense, Billerica, MA, USA), this was done twice with each sensor, in random order across sensors. The InertiaCube BT (IC-BT) is a wireless three degree of freedom sensor providing real-time orientation data via a standard Bluetooth® interface to the computer. The accuracy (RMS) is 1° in yaw and 0.5° in pitch & roll. The update rate is 180 Hz, and the maximum angular range is 1200°/s.

Procedure

The participants were provided with written and verbal information about the test procedure and demographic data were recorded. The intention and nature of the task required of the participants was explained. To familiarize them with the task, all participants executed one movement pattern twice. This pattern was not used for measurements. The participants were then required to repeat each of the 3 movement patterns 3 times, with a 10-second interval between each trial. The test was performed in random order across patterns and trials. The participants had no knowledge about the different difficulty grades of the patterns. The same examiner performed all measurements.

Data analysis

Number and means with standard deviation (SD) were used for description of data. Analysis of variance (ANOVA) with repeated measures was used for comparison of the dependent variable, patterns. The multivariate General Linear Model with post hoc analysis was used to determine the significance of difference in AA, DA and JI respectively, for the main factors age and sex. Pearson correlation analysis was used to ascertain the association between the test results versus the weight, height and BMI. The absolute error in millimeters was used to indicate AA. DA or time on target, overshoots versus undershoots, were identified as the percentage of the total time used to perform the trial. Finally, the normalized jerk, JI value was calculated. The mean of 3 trials for each movement pattern was calculated for each subject for the three dependent variables. Paired t-test was used to compare the results from the two sensors. Analysis was performed with the procedures implemented by the SPSS 18.0. The significance level was set at p < 0.05.

Results

Normative database

The multivariate analysis of variance indicated a statistically significant effect for age (p < 0.001), but not for gender (p > 0.05). Therefore normative data were only distributed according to age. The 65-74 age group had the highest AA test results for all 3 movement patterns, indicating less accurate performance, which was significantly less accurate than each of the other age groups´ performances (Table 2). For DA (time on target, overshoots and undershoots) the 65-74 age group showed lower test results than the younger age groups, indicating decreased accuracy (Tables 3-5). For DA the 65-74 age group was significantly less accurate than most other age groups, except for the 55-64 age group where the difference was not significant. Slightly higher JI was observed with increasing age, but overall the JI test results did not differ significantly with age (Table 6), except in some cases in the easy and/or medium patterns; The 45-54 and 55-64 age groups had significantly higher JI than each of the younger age groups in the easy and medium patterns. The test results (AA, DA and JI) did not correlate with weight, height or BMI (r < 0.08).

Fastrak versus InertiaCube BT™

The comparison between the two sensors revealed a slightly better accuracy by the use of the InertiaCube BT sensor. A conversion formula was found for each pattern in each of the two outcome measures AA and DA by dividing into each Fastrak value, the ratio between the Fastrak mean value and the IC-BT mean value (Table 7).

Discussion

 The study focused on the construction of a new database of reference normal for movement control in the cervical spine. The Fly Test is useful in discriminating patients with WAD from those with non-trauma neck pain, as well as asymptomatic persons [[2](#_ENREF_2)]. The main purpose of publishing such data is to provide clinicians with a reference to use for comparison when using the Fly Test. Knowledge of normative values for the Fly Test is important and useful in identifying and monitoring symptoms and treatment interventions in patients with impaired cervical kinesthetic sensibility of traumatic or non-traumatic origin.

 Intentionally the database contains a larger group of persons in the younger age groups. It has been revealed that the incidence of neck strain/sprain peaks in the 20-24 year age group [[14-17](#_ENREF_14)] and that younger age was associated with slightly higher risk of WAD compared with age 55 years and older [[18](#_ENREF_18), [19](#_ENREF_19)]. Females tend to have a higher incidence of emergency department-treated neck strain/sprain than males [[14](#_ENREF_14)]. The effect of gender as a prognostic or risk factor of outcome in WAD appears to be modest, although it seems that females are at slightly greater risk [[19](#_ENREF_19), [20](#_ENREF_20)]. In our asymptomatic study group, there was no effect of gender but the performance in the Fly Test was affected by age, as the performances deteriorated with increasing age. Clinical studies have demonstrated that older adults exhibit impaired proprioception; both impaired joint position sense and difficulty in regulation of body orientation during cervical proprioceptive disturbances [[21-23](#_ENREF_21)].

 The AA and DA values in the present study showed a slightly less accuracy in performances than the asymptomatic group in our reliability study of the Fly Test [[2](#_ENREF_2)]. This might be due to a more homogenous group in the reliability study or to the fact that different settings were used during the measurements for the database, as a portable system was used in different locations. The precision and reproducibility of the measurements is critical and requires full cooperation of the persons being measured, in the way that they are required to perform at a maximal level. In the present study test results were calculated from 9 repetitions in random order across patterns The results indicated consistency in performances, as there was no effect of repetitions in AA and DA. In the current study, the results of the jerk calculations were not considerably affected by age, although some of the younger age groups showed significantly lower JI in the easy and medium patterns than two of the older age groups. Therefore JI would serve well as a normal reference for the performances in the three different movement patterns, irrespective of age. Calculation of movement jerk as an indicator of smoothness, characterizing coordinated human movements, has been assessed in patients with neck pain of insidious and traumatic origin, and the results have indicated motor control disturbances [[24](#_ENREF_24), [25](#_ENREF_25)].

 For measurements to be clinically and scientifically useful they must be reliable and sufficiently sensitive to detect clinically important changes after treatment interventions. It became clear in the reliability testing of the Fly Test, that higher means and wider LOA across patterns and subject groups might be inherent in the Fly Test and the subject groups tested [[2](#_ENREF_2)]. The wider LOA in the WAD group may parallel the clinical observation that symptoms in patients with WAD tend to change more from one day to another, when compared to patients with non-traumatic neck pain [[2](#_ENREF_2)]. Using LOA as a reference range to detect changes after treatment interventions, the difference before and after treatment for a patient must be outside this reference range, to represent a clinically important change. It is clear that the smaller the reference range, the more sensitive the measurements are and that although the measurements can be highly reliable, the reference range may be too wide to be clinically or scientifically useful [[9](#_ENREF_9)]. In the case of monitoring treatment progression in whiplash patients with deficient cervical movement control, comparison with normal reference values according to relevant age group in the Fly Test, will be highly beneficial for the clinician.

 The second set of measurements including both types of sensors was done in order to compare the results and find out, if needed, whether it was possible to convert the Fastrak values from the Fly Test to the values collected by the IC-BT sensor, for comparable results. The group of 10 persons tested with the 2 sensors (Table 7), were specially instructed to be as accurate as possible when performing in the Fly Test, in order to get as similar results as possible with both sensors. Wireless orientation sensors - InertiaCube3 (IC3) - have earlier been verified against the Fastrak, electromagnetic motion analysis system [[26](#_ENREF_26)]. It was revealed that the IC3 were accurate for measuring head motion and cervical range of motion in the primary plane, and showed high cross-correlation and low root mean errors [[26](#_ENREF_26)], and the data collected were similar to those reported in previous studies using the Fastrak device. The IC3 and the IC-BT are sensors manufactured by the same company and have corresponding specifications.

 In conclusion, a database of movement control in the neck has been constructed, measured by the Fly Test, using the Fastrak device. Conversion coefficient has been provided, to link the results with the use of IC-BT sensors. This database may help in assessing the performance and monitoring progress of patients with WAD and other neck disorders, by providing a baseline data set for one part of cervical kinaesthesia, - the movement sense.

Limitations

When comparing the results from the 2 sensors, simultaneous recordings would have made more accurate comparison from both sensors during the performance in the Fly Test. A larger group in this part of the study would have given more reliable results for calculating the conversion formula.

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