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Original article

Database of movement control in the cervical spine. Reference normal of 182 asymptomatic persons

Gudny Lilja Oddsdottir [a,*], Eythor Kristjansson [b], Magnus Kjartan Gislason [c]

[a] Faculty of Medicine, University of Iceland, Reykjavik, Iceland
[b] Landspitali, University Hospital, Reykjavik, Iceland
[c] Department of Mechanical Engineering, University of Strathclyde, Glasgow, UK

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ABSTRACT

In this study, the first normative database of movement control in the cervical spine has been established. For this purpose the Fly Test was used, which is a reliable and valid clinical test capable of detecting deficient movement control of the cervical spine in patients with neck pain and its associated disorders. One hundred and eighty-two asymptomatic persons, eighty-three men and ninety-nine women, aged 16–74 years, divided into six age groups, were recruited. The Fly Test, using a 3-space Fastrak device, recorded the accuracy of cervical spine movements when tracking three incrementally difficult movement patterns. Amplitude accuracy (AA), directional accuracy (DA), and jerk index (JI) were compared across patterns and age groups. A multivariate analysis of variance revealed a significant effect for age ($p < 0.001$) but not gender ($p > 0.05$). Lower accuracy for AA and DA in all three movement patterns was observed in the groups of subjects aged 55–64 and 65–74 years, and also for JI in the easy and medium patterns. Knowledge of normative values for the Fly Test is important and useful in identifying impaired movement control and monitoring the effectiveness of treatment interventions in patients with neck pain of traumatic and non-traumatic origin.

1. 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 (Kristjansson et al., 2004). 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 (Kristjansson and Oddsdottir, 2010). The test has been carried out on patients with traumatic and non-traumatic neck pain, as well as asymptomatic persons (Kristjansson and Oddsdottir, 2010). 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 (Gandevia and Burke, 1992; Prochazka, 1996; Kristjansson and Oddsdottir, 2010). There are three outcome measures in the Fly Test, amplitude accuracy (AA) and directional accuracy (DA), which have been found to be reliable and valid measures, as well as smoothness of movement indicated by jerk index (JI), which has not been validated yet. These variables represent three different but interrelated aspects of movement control (Woodworth, 1899; Taylor and McCloskey, 1988; Gandevia and Burke, 1992; Gandevia et al., 1992; Elliott et al., 2001).

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) (Kristjansson and Oddsdottir, 2010). 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 (Lexell and Downham, 2005). 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 (Kristjansson and Oddsdottir, 2010). Unpublished data indicates that intervention by the Fly exercise program narrows LOA in the WAD group. However, 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 for the first time diverging courses

* Corresponding author. Skildinganes 12, IS-101 Reykjavik, Iceland. Tel.: +354 899 6406; fax: +354 564 1799.
E-mail addresses: glodds@me.com, glo@hi.is (G.L. Oddsdottir).

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of impaired cervical movement control, in persons involved in motor vehicle collisions (Oddsdottir and Kristjansson, 2012). 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, whereas the opposite was true for the other half of the participants (Oddsdottir and Kristjansson, 2012). Therefore it is important in practice to have reference normal values, which the two divergent courses of movement control in the cervical spine can be measured against.

The main purpose of this 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.

2. Methods

2.1. 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 (±8.2), 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 one year before testing, a score below ten on the Neck Disability Index (NDI) (Vernon and Mior, 1991) and no pain on a Visual Analogue Scale (VAS). The participants were divided into six 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 the Reykjavik municipal area and asking for volunteers. Individuals were excluded if they had a history of musculoskeletal pain or injury to the neck during the last year, symptoms of dizziness or visual disturbances. Systemic 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.

2.2. Measurements

Neck movement was recorded using a 3-space Fastrak system and the Fly Test, which is a custom-made software program. Fig. 1 shows the experimental set-up. Further detailed description of the experiment can be found in previously published papers by Kristjansson et al. (2004) and Kristjansson and Oddsdottir (2010). 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, one blue and one 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. The duration time is fixed, but the velocity of the Fly (target) varies between movement patterns as well as the path curvature within each pattern, so that the Fly moves faster on straight segments and slower in bends. Three different movement patterns of varying difficulty were used for the test procedure (Fig. 2): easy, medium, and difficult. 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 millimetres between the two cursors during the test sequence. The criterion used was error magnitude (test accuracy). The absolute value (unsigned) was calculated in pixels and converted into millimetres by multiplying by .36 (1 pixel = .36 mm in this test). For DA, an invisible free zone was created surrounding and moving with the target (the Fly). During a trial, the percentage of the total time spent within, ahead of, and behind the free zone represented DA's time on target, overshoots and undershoots, respectively. The shape and size of the free zone was determined by plotting the coordinates (x,y) of ten healthy individuals and this determined a zone representing the difference between the actual points and the pre-defined points. By using vectors $(A_t(P_t - Q_t))$, a scatter plot was obtained which was distributed around the centre of the coordinate system. The circle around the centre was divided into 24 equally large sectors. Then for each of the 24 sectors, quartiles were

Fig. 1. Experimental set-up. The placement of the 2 sensors was on the forehead and the back of the head. The participants were seated in front of a computer screen and were asked to find their natural head posture facing forward. The distance from the participants' earlobe to the computer monitor was 100 cm.

Table 1
Number of participants in each age group.

Age-group	Gender		Total
	Male	Female	
16–24	13	26	39
25–34	26	23	49
35–44	15	24	39
45–54	10	19	29
55–64	5	7	12
65–74	14	0	14
Total	83	99	182

Fig. 2. From left to right: easy, medium and difficult movement patterns traced by the Fly, which the participants were required to follow by moving their head and neck. The duration of the patterns was 25, 40 and 50 s, respectively.

found and standard deviations of the distance from the centre were measured. In this study, the size of the free zone was decided to be two standard deviations from the centre (Kristjansson and Oddsdottir, 2010).

Jerk, smoothness or ease 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 integrating the quadratic sum over time, using the equation based on the works of Teulings et al. (1997):

$$J = \int \left[\left(\frac{d^3x}{dt^3} \right)^2 + \left(\frac{d^3y}{dt^3} \right)^2 \right] dt$$

The integral was evaluated for both the path that the Fly covered, J_{Fly} and the path created by the patient, J_p. The normalized jerk value was calculated using the relation:

$$J_{norm} = \frac{J_p}{J_{Fly}}$$

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

2.3. 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 three movement patterns three times, with a 10 s 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.

2.4. 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 millimetres was used to indicate AA. DA or time on target, overshoots versus undershoots, were each indicated as the percentage of the total time used to perform the trial. Finally, the normalized jerk, JI value was calculated. The mean of three trials for each movement pattern was calculated for each subject for the three dependent variables. Analysis was performed with the procedures implemented by the SPSS 18.0. The significance level was set at $p < 0.05$.

3. Results

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 oldest age group (65–74) had the highest AA test results for all three movement patterns, indicating less amplitude accuracy, which was significantly less accurate than for each of the other age groups (Table 2). For DA (time on target, overshoots and undershoots) the oldest age group (65–74) showed significantly less directional accuracy than most other age groups, except for the 55–64 age group, where the difference was not significant (Tables 3–5). 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 ($r < .08$).

4. 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 (Kristjansson and Oddsdottir, 2010). The main purpose of publishing such data is to provide clinicians with a reference to use

Table 2
Normative database for the Fly Test – amplitude accuracy in mm.

Amplitude accuracy	Age-group	Mean	Standard deviation	95% confidence interval	
				Lower bound	Upper bound
Easy	16–24	2.6	.6	2.4	2.7
	25–34	2.2	.6	2.1	2.3
	35–44	2.4	.7	2.3	2.6
	45–54	2.5	.7	2.4	2.7
	55–64	2.5	.4	2.3	2.8
	65–74	3.2	1.1	3.0	3.4
Medium	16–24	2.8	.7	2.6	3.0
	25–34	2.5	.6	2.4	2.6
	35–44	2.7	.8	2.5	2.9
	45–54	2.7	.7	2.5	2.9
	55–64	2.9	.7	2.7	3.2
	65–74	3.9	1.4	3.6	4.1
Difficult	16–24	3.2	.8	3.0	3.4
	25–34	2.9	.8	2.8	3.1
	35–44	3.0	.9	2.9	3.2
	45–54	3.1	.8	2.9	3.3
	55–64	3.3	.6	3.0	3.6
	65–74	4.3	1.4	4.0	4.6

Table 3
Normative database for the Fly Test – directional accuracy – time on target (%).

Directional accuracy time on target	Age-group	Mean	Standard deviation	95% confidence interval	
				Lower bound	Upper bound
Easy	16–24	39.0	15.6	35.9	42.1
	25–34	49.7	19.2	46.9	52.5
	35–44	42.6	17.9	39.3	45.4
	45–54	40.9	16.9	37.3	44.5
	55–64	36.5	11.9	30.9	42.1
	65–74	27.7	14.6	22.6	32.9
Medium	16–24	36.6	16.3	33.6	39.6
	25–34	44.3	17.4	41.6	47.0
	35–44	38.6	17.8	35.6	41.6
	45–54	37.5	16.0	34.0	41.0
	55–64	28.6	13.3	23.2	34.0
	65–74	20.3	13.8	15.3	25.3
Difficult	16–24	28.3	11.9	25.9	30.6
	25–34	33.9	14.4	31.8	36.0
	35–44	30.8	14.1	28.5	33.2
	45–54	29.3	12.1	26.6	32.0
	55–64	24.6	9.6	20.4	28.8
	65–74	15.9	9.3	12.0	19.8

Table 4
Normative database for the Fly Test – directional accuracy – overshoots (%).

Directional accuracy overshoots	Age-group	Mean	Standard deviation	95% confidence interval	
				Lower bound	Upper bound
Easy	16–24	17.2	11.1	15.4	18.9
	25–34	15.3	8.1	13.7	16.9
	35–44	16.5	10.1	14.8	18.3
	45–54	16.1	10.3	14.0	18.1
	55–64	13.6	8.0	10.5	16.8
	65–74	11.6	9.4	8.6	14.5
Medium	16–24	12.0	7.5	10.9	13.1
	25–34	10.0	5.7	9.0	11.0
	35–44	10.4	6.3	9.3	11.6
	45–54	9.9	6.3	8.7	11.3
	55–64	7.4	4.9	5.4	9.5
	65–74	7.4	4.5	5.5	9.3
Difficult	16–24	14.2	8.6	12.9	15.5
	25–34	13.0	7.3	11.8	14.1
	35–44	11.7	6.7	10.4	12.9
	45–54	12.0	6.9	10.5	13.5
	55–64	7.8	4.2	5.5	10.2
	65–74	8.6	5.6	6.5	10.8

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 kinaesthetic sensibility of traumatic or non-traumatic origin.

According to the incidence distribution of WAD, the database contains a larger group of persons in the younger age groups as research has consistently found a peak in the younger age groups at 16–24 years (Spitzer et al., 1995; Bring, 1996; Ferrando et al., 1998; Quinlan et al., 2004) and that younger age was associated with slightly higher risk of WAD compared with age 55 years and older (Berglund et al., 2003; Holm et al., 2008). However, larger subject numbers in the older groups would have increased the veracity of the findings in these groups. Females tend to have a higher incidence of emergency department-treated neck strain/sprain than males (Quinlan et al., 2004). 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 (Carroll et al., 2008; Holm et al., 2008). In our asymptomatic study group, there was no effect of gender but the performance in the Fly Test was affected by age, as worse performance for AA and DA was observed in the

Table 5
Normative database for the Fly Test – directional accuracy – undershoots (%).

Directional accuracy undershoots	Age-group	Mean	Standard deviation	95% confidence interval	
				Lower bound	Upper bound
Easy	16–24	43.8	19.6	40.3	47.3
	25–34	34.9	19.2	31.8	38.0
	35–44	41.1	21.1	37.6	44.6
	45–54	43.0	17.4	38.9	47.0
	55–64	49.8	15.5	43.5	56.1
	65–74	60.7	19.1	54.8	66.5
Medium	16–24	51.4	18.3	48.2	54.6
	25–34	45.6	17.3	42.8	48.5
	35–44	50.9	19.7	47.7	54.1
	45–54	52.5	16.4	48.8	56.2
	55–64	63.9	14.2	58.2	69.7
	65–74	72.3	14.3	66.9	77.6
Difficult	16–24	57.4	15.9	54.7	60.2
	25–34	53.1	16.1	50.7	55.5
	35–44	57.4	16.3	54.8	60.2
	45–54	58.7	12.7	55.5	61.8
	55–64	67.5	11.7	62.6	72.4
	65–74	75.4	10.2	70.9	79.9

Table 6
Normative database for the Fly Test – jerk index (normalized values).

Jerk index	Age group	Mean	Standard deviation	95% confidence interval	
				Lower bound	Upper bound
Easy	16–24	1.7	.2	1.6	1.7
	25–34	1.7	.1	1.6	1.7
	35–44	1.7	.2	1.6	1.7
	45–54	1.8	.2	1.7	1.8
	55–64	1.7	.1	1.7	1.8
	65–74	1.7	.2	1.6	1.8
Medium	16–24	1.7	.1	1.6	1.7
	25–34	1.7	.1	1.6	1.7
	35–44	1.7	.1	1.6	1.7
	45–54	1.8	.1	1.7	1.8
	55–64	1.8	.1	1.7	1.8
	65–74	1.8	.2	1.7	1.8
Difficult	16–24	1.4	.1	1.4	1.5
	25–34	1.5	.1	1.4	1.5
	35–44	1.5	.1	1.3	1.5
	45–54	1.5	.1	1.4	1.5
	55–64	1.5	.1	1.4	1.5
	65–74	1.5	.1	1.4	1.5

Significant differences between patterns; easy and medium in the age group 25–34; medium and difficult in all age groups.

groups of subjects aged 55–64 and 65–74 years. Clinical studies have demonstrated that older asymptomatic adults exhibit impaired proprioception; both impaired joint position sense and difficulty in regulation of body orientation during cervical proprioceptive disturbances (Shaffer and Harrison, 2007; Teng et al., 2007; Patel et al., 2010).

The AA and DA values in the present study were slightly higher than for the asymptomatic group in our reliability study of the Fly Test (Kristjansson and Oddsdottir, 2010). 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 are critical and require the full co-operation 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 nine 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 (Feipel et al., 1999; Sjölander et al., 2008).

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 (Kristjansson and Oddsdottir, 2010). 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, presumably related to a broader range of signs and symptoms, when compared to patients with non-traumatic neck pain (Kristjansson and Oddsdottir, 2010). 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 (Lexell and Downham, 2005). 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 main limitation of the study was how few subject were recruited in the older age groups and therefore the results for those age groups cannot refer to the general population. The aim is to enlarge the database for all age groups.

5. Conclusion

A database of movement control in the neck has been constructed, measured by the Fly Test, using the Fastrak device. This database may help in assessing the performance and monitoring progress of patients with neck pain and its associated disorders, by providing a baseline data set for movement sense, one aspect of cervical kinaesthesia.

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The Fly method will be made available for clinicians over the Internet.

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