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Original article

The long-term course of deficient cervical kinaesthesia following a whiplash injury has a tendency to seek a physiological homeostasis. A prospective study☆

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A B S T R A C T

Background: No research exists for the long-term course of deficient cervical kinaesthesia following a whiplash injury. Prior results depicted two divergent courses of deficient cervical kinaesthesia at 1 year.
Objectives: First, to determine the actual course(s) of untreated deficient cervical kinaesthesia from 1 year to 6–8 years post-collision and second, to investigate the association between the test results versus self-reported disability.
Design: A follow-up study was conducted to measure persons who had experienced whiplash from January 2007–September 2009.
Method: The two clinical tests for cervical kinaesthesia, the Head–Neck Relocation (HNR) test and the Fly test are conceptualised to measure two distinct "percepts" of neck proprioception: position sense and movement sense, respectively. In both tests, the mean error of three trials was calculated for each individual and represented the kinaesthetic accuracy. These values were used for analysis.
Results: Forty-one participants out of an initial forty-seven (response rate = 87.2%) were able to participate at the 6–8 years follow-up. The two divergent courses at 12 months had a tendency to seek a physiological homeostasis at the 6–8 years follow-up. Overall, very slight improvements were revealed in disability levels between the 2 assessment points.
Conclusions: Untreated deficient cervical kinaesthesia has a tendency to seek a physiological homeostasis somewhere from 1 year to 6–8 years post-collision. We therefore recommend that cervical kinaesthesia be monitored and treated early, as deficient cervical kinaesthesia may lead to adaptive compensatory patterns secondary to the remaining functional kinaesthetic deficits.

1. Introduction

No research exists for the long-term course of deficient cervical kinaesthesia following a whiplash injury. Our prior 1-year longitudinal study identified, for the first time, two different courses of deficient cervical kinaesthesia in symptomatic people after motor vehicle collisions (MVCs). In this study, significantly diverging results were depicted at 1 month versus at 12 months post-collision in both the Head–Neck Relocation (HNR) test and the Fly test. Those who had poorer results at the start improved their performances significantly during the 1-year course, whereas the opposite was true for those who had better results at the start (Oddsdottir and Kristjansson, 2012). These results cannot be attributed to regression to the mean (RTM) effects, because analysis of covariance – ANCOVA – was used, and the coefficient *b* from the regression analysis is the estimated treatment effect adjusted for RTM (Barnett et al., 2005).

It has been estimated that approximately one half of all people with acute whiplash will recover within 3 months regardless of the interventions, while the other half will experience delayed recovery or chronic problems beyond that time (Kamper et al., 2008; Carroll et al., 2008). There have been a series of systematic reviews (SRs) and data syntheses published for both traumatic and non-traumatic neck pain (Walton et al., 2013a). The most consistent findings amongst these SRs for poor prognosis are initial pain intensity (score > 5.5/10 on Visual Analogue Scale VAS) or high aggregate scores on self-reported disability (score > 14.5/50 on

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Neck Disability Index) (Walton et al., 2013a, 2013b), which individually provide little guidance for intervention decisions (Walton et al., 2013a). Other significant, but moderately confident, predictors of poor outcome following whiplash at inception are report of headache, report of low back pain, a prior history of neck injury, less than postsecondary education, older age, high catastrophizing, post-traumatic stress disorders (PTSD), cold hyperalgesia and female sex (Croft et al., 2001; Walton et al., 2013a, 2013b).

Many potential structures and processes are affected in whiplash-associated disorders (WAD). The deficiency of comprehensive structural and physiologic diagnostic regimens may mean that the sequelae of undocumented impairments on these domains are manifested through higher pain and self-report. Without such diagnostic tools, the physiologic and psychological components of neck disorders can be difficult to disentangle (Walton et al., 2013a). There is a great lack of long-term follow-up studies on diverse physical impairments, which have been demonstrated in WAD, including deficient cervical kinaesthesia.

The primary aim of this study was to determine the actual course(s) of deficient cervical kinaesthesia from 1 year to 6–8 years post-collision in patients diagnosed with WAD. The two clinical tests for cervical kinaesthesia are conceptualised to measure two distinct "percepts" of proprioception: relocation accuracy (position sense) and movement control accuracy (movement sense), respectively (McCloskey, 1973; Proske, 2006). As Sherrington stated "posture follows movement like a shadow". There are therefore two primary elements in the co-ordination of movement, the tonic or postural element and the phasic or movement element (Sherrington, 1906, p. 417). The former test, the Head–Neck Relocation test (HNR test), replicates Revel et al. (1991). The latter test, the Fly test, replicates Kristjansson et al. (2004).

The secondary aim of this study was to investigate the association between the test results of cervical kinaesthesia versus self-reported neck disability and fear of movement.

2. Methods

2.1. Study design

A 6–8 years follow-up study was conducted to measure persons who had experienced MVCs, from January 2007–September 2009. They were originally examined for deficient cervical kinaesthesia at 1, 3, 6, and 12-month post-collision (Oddsdottir and Kristjansson, 2012). The data in the current study was collected from February 18th–April 1st, 2015.

2.2. Participants

The participants, who were originally recruited through the Emergency Department at X were contacted by telephone after receiving a letter and asked if they were willing to participate. Table 1 shows their demographics. They were originally included in the study if they met the criteria of WAD I–III, according to the Québec Task Force (QTF) (Spitzer et al., 1995). WAD IV or multiple traumas, concussion or head injury from MVCs; previous history of whiplash injury; or prior symptoms from the head or neck such as neck pain and/or headache, systemic diseases or psychological disorders of any kind excluded participation. During the first year after injury the participants were instructed to "act as usual" but data was collected regarding received treatment and medication during the whole study period. Sixty-seven percent received physiotherapy, 5.4% had massage and 66.2% used simple analgesic and/or opioid medication in variable combinations or alone. None had received specific treatments to improve their kinaesthetic deficits during the study period. All participants gave informed consent after ethical clearance from the National Bioethics Committee.

2.3. The Head–Neck Relocation test

The HNR test measures the accuracy of relocation of the head (absolute error) to self-assessed natural head position in degrees. The Fastrak device (Fastrak, Polhemus, USA) was used, with one sensor placed on the forehead and the other adhered over C7. The software program that was written for this test transformed the data collected by the Fastrak system directly into angle files and graphs to visualise the real-time process on the screen from the starting position through the excursion of the movement. For more detailed description, see Kristjansson et al. (2003).

2.4. The Fly test

The Fly is a clinical test that measures the accuracy (absolute error) of cervical spine movements in millimetres. Tracking sensors (Fastrak, Polhemus, USA) were fastened on the patient's head. They were asked to use neck movements to track, as accurately as possible, a moving fly (a cursor) on a computer screen. Two cursors were seen on the computer screen; a blue one (derived from the Fastrak system) indicated movements of the head, and a black fly (derived from the Fly software program) traced three generated movement patterns separately (Fig. 1). Since only the cursors are visible on the computer screen but not their trajectories, prediction of movements is difficult. For more detailed description, see Kristjansson et al. (2004).

2.5. Self-assessment

The participants were asked to consider their condition during the previous week and based on that, completed the Neck Disability Index (NDI) (Vernon and Mior, 1991), measuring activity limitations due to neck pain, and the Tampa scale of kinesiophobia (TAMPA), an indicator of fear of movement/re-injury (Crombez et al., 1999; Vlaeyen &, Linton, 2000).

2.6. Procedure

The participants answered the questionnaires before the measurements took place. After receiving explanation on the intention and nature of the tasks and the test procedures, the participants were instructed to assume a comfortable sitting position facing straight forward, with relaxed shoulders and hands resting in their laps. The HNR test was performed first, followed by the Fly test, so the HNR test, which takes 1 min; would not be affected by the Fly test, which takes 9 min.

The starting position in the HNR test was sitting with the head in natural resting posture; the participants were asked, while blindfolded, to remember that position. They were then asked to

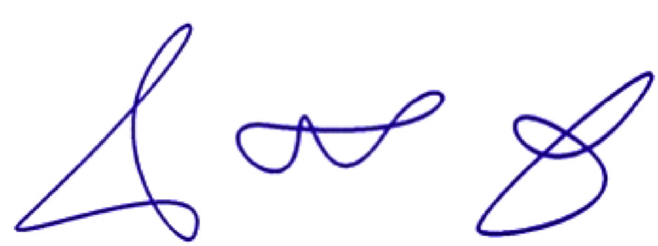

Fig. 1. The movement patterns A, B and C (from left to right) traced by the Fly, the duration of each trial was 30, 20 and 40 s, respectively.

Table 1
Demographics and subdivision of study participants by improvement at 12 months after motor vehicle collision.

	Total (n = 41)	Fly-IG (n = 22)	HNR-IG (n = 22)	Fly-NIG (n = 19)	HNR-NIG (n = 19)
Age in years (mean ± SD)	41.9 ± 11.8	43.3 ± 12.3	43.0 ± 13.2	40.2 ± 11.4	40.6 ± 10.1
Time since collision in years (mean ± SD)	7.4 ± 0.6	7.2 ± 0.5	7.5 ± 0.5	7.7 ± 0.5	7.3 ± 0.6
Gender (% female)	63.4	63.6	59.1	63.2	68.4
Missing data from 12 months to 6–8 years (n)	6	1	3	5	3

Fly-IG: Fly improvement group; Fly-NIG: Fly non-improvement group; HNR-IG: Head–Neck Relocation improvement group; HNR-NIG: Head–Neck Relocation non-improvement group.

perform a full active rotation of the neck within comfortable limits at a self-selected pace and then return and verbally indicate, as accurately as possible, when they considered that they had relocated the starting position. This point was recorded by activation of the electronic marker switch. Three trials of each of the two movement directions, rotation left and right were performed. Between each trial, the subjects' head position was adjusted back to the original starting position by the examiner, who was guided by the real-time display on the computer screen.

In the Fly test, the participants were asked to use their neck movements to track, as accurately as possible, a moving fly on the computer screen. The participants were asked to repeat each of the three movement patterns – A, B and C – three times. The test was performed in random order across patterns and trials (Fig. 1).

Bland–Altman plots were used as a reliability measure for both tests, which showed good reliability for both tests; mean difference (±2SD) between days 1 and 2 (−0.8° ± 3.0°) for the HNR test (Kristjansson et al., 2001) and mean difference (±2SD) between days 1 and 2 (0.33 mm ± 1.8 mm) for the Fly test (Kristjansson et al., 2004), Bland–Altman plots are more accurate than the intraclass correlation coefficients (ICCs) and standard error of the mean (SEM) (Bland and Altman, 1986).

2.7. *Data analysis*

In the HNR test, the relocation error was calculated by using the mean of the absolute errors for the three trials of each movement direction, and these values were used for analysis. Paired *t*-tests showed no differences ($p > 0.05$) in relocation errors between left and right rotation; therefore, the mean relocation errors of both directions were used in further analysis.

In the Fly test, the mean error of the three trials for each movement pattern was calculated for each individual and represented the accuracy with which the subjects could follow the fly. Paired *t*-tests revealed no differences ($p > 0.05$) between the mean accuracy errors across patterns; therefore, they were combined, and the mean error of patterns A, B and C for each subject was used for further analysis.

Repeated measures general linear models, analysis of variance (ANOVA) were used to identify differences in the measurements over time. The dependent variables were the mean relocation errors in the HNR test, the accuracy errors in the Fly test and a within-subject factor of time with three levels: 1 and 12 months post-collision and 6–8 years post-collision. Bonferroni-adjusted multiple comparisons were used to identify differences at various time points. Due to missing data at the 6–8-years follow-up, analyses at earlier time points were repeated. Independent *t*-tests were used to calculate any between-group differences at each assessment time-point.

Classification into sub-groups was based on our previous work, in which each subject's test results at 1 month and at 12 months post-collision were used. Briefly, the subjects were divided into two subgroups based on performance on each of the two accuracy tests: HNR-improvement group (HNR-IG) and Fly-improvement group (Fly-IG) versus HNR-non-improvement group (HNR-NIG) and Fly-non-improvement group (Fly-NIG) (Oddsdottir and Kristjansson, 2012). Adjusting for the effects of the regression towards the mean (RTM) of the observed measurements, analysis of covariance – ANCOVA – was used. The coefficient *b* from the regression analysis was used as the estimated treatment effect adjusted for RTM (Barnett et al., 2005). The dependent variables in the ANCOVA were the mean relocation and accuracy errors in the HNR and Fly tests, respectively, from the 3rd measurement (6–8 years post-collision), with the group as a fixed factor and the mean relocation/accuracy errors from the 1st measurement, age and gender as covariates.

Paired *t*-tests were used to calculate potential differences from 12 months to 6–8 years with respect to pain and disability as well as fear of movement. Pearson's correlation coefficients were used to assess the relationship between kinaesthetic test results and the questionnaires at 6–8 years post MVCs. Number, subjects, means and SDs were used for description of data. Analyses were performed with the procedures implemented by the SPSS 20.0. The significance level was set at $p < 0.05$.

3. Results

Forty-one participants (15 males, 26 females) out of an initial forty-seven (response rate = 87.2%) were able to participate in the 3rd measurement of this 6–8-years follow-up study. Four could not be reached, and two had a recent medical condition that affected test results and were excluded. Table 1 shows the mean age at the 6–8-years follow-up and the mean time from the MVCs. Overall, when the total sample was analysed, no significant changes were observed in accuracy error ($p > 0.05$) on either test throughout the study period. No correlation was observed between the two tests at any of the time points post-collision.

3.1. *The HNR test*

Fig. 2 presents the results from the HNR test. The overall repeated measures analyses for the HNR test revealed marginal

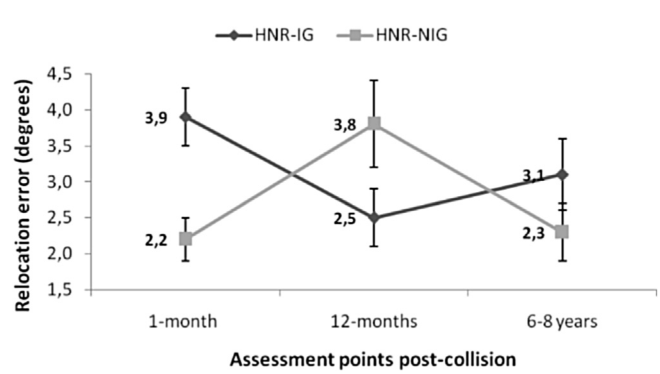

Fig. 2. The mean (SE) relocation error for improvement versus non-improvement groups performing the Head–Neck Relocation test at three time points following motor vehicle collision. The crossovers in performances take place during the first year and again between 12th month and 6–8 years post-collision. Subgroup differences were significant at 1st month (p = 0.003) and 12th month (p = 0.044).

changes throughout the assessment period for both the improvement group ($p = 0.052$) and significant changes for the non-improvement group ($p = 0.001$). The Bonferroni-adjusted multiple comparisons for the HNR-IG group revealed significant differences between the 1st and the 12th month ($p < 0.001$). Significant differences were observed for the HNR-NIG group between the 1st and the 12th month ($p = 0.002$) and between 12th month and 6–8 years ($p = 0.037$). At 1 month post-MVC, significantly less relocation error ($p = 0.003$) was observed among participants who did not improve on the test compared to those who improved. The opposite was observed at 12 months post-MVC ($p = 0.044$).

The adjusted difference between the subgroups was non-significant ($b = -0.24$; 95% confidence interval (CI): −1.59, 1.12). There was a significant effect of gender ($p = 0.030$) as men scored higher but not of age ($p = 0.486$) on the relocation errors in the HNR test.

3.2. The Fly test

Fig. 3 presents the results of the Fly test. Overall, the repeated measures analyses revealed significant changes throughout the assessment period for both the Fly-IG ($p = 0.046$) and the Fly-NIG ($p = 0.003$) group. The Bonferroni-adjusted multiple comparisons for the Fly-IG group revealed significant differences between the 1st and the 12th month (p = 0.009) and for the Fly-NIG group between the 1st and the 12th month ($p < 0.001$) and the 1st month and 6–8 years ($p = 0.045$). The mean accuracy error for the combined movement patterns among those who improved their accuracy was significantly greater compared to those who did not improve at 1 month post-collision ($p = 0.035$), whereas the opposite was observed at the 12th month ($p = 0.004$).

The change observed when adjusted for the effects of the RTM indicated non-significant adjusted differences between subgroups ($b = -0.36$; 95% CI: −1.02, 0.31). There was significant effect of age ($p = 0.007$) and gender ($p = 0.036$) on the accuracy error in the Fly test. The mean age was higher in the Fly-IG and women scored higher in both subgroups.

3.3. Self-assessment

The results show that participants scored similarly on the NDI at the 6–8 years follow-up as they did at 12 months post-collision (Fig. 4). On the other hand, as shown in Fig. 5, the participants scored significantly lower on TAMPA at 6–8 years compared to at 12 months post-collision ($p = 0.010$). Furthermore, subgroup comparisons revealed significant improvement among participants in the HNR-NIG ($p = 0.022$). Significant correlations were observed between the Fly test results and NDI among both the Fly-IG ($r = 0.551$; $p = 0.008$) and the Fly-NIG ($r = 0.532$; $p = 0.019$). No other correlations were significant.

4. Discussion

The results of this study show that the two different courses of deficient cervical kinaesthesia, revealed over a one-year period post-collision, has a tendency to seek a physiological homeostasis at 6–8-years follow-up (Figs. 2 and 3). This is especially the case for the Fly test (Fig. 3). At the 6–8-years follow-up, both subdivisions of the participants, i.e. the IG groups and the NIG groups, show the same trend in both kinaesthetic tests, although not statistically significant. The IG groups become slightly worse, and the NIG groups become slightly better from the 1-year to the 6–8-years assessment points. These results suggest that untreated deficient cervical kinaesthesia seeks physiological homeostasis in the long run.

The results of the NDI indicate that disability remains steady at the upper limits for "mild disability" (Vernon and Mior, 1991) from 1 year to 6–8 years post-collision (Fig. 4). The fact that significant correlations were observed between the Fly test and NDI, but not the HNR test and NDI, may indicate that the Fly test is better suited to capture the kinaesthetic disability of patients with neck pain of traumatic origin. The results of TAMPA indicate that the participants were moderately affected by kinesiophobia, which declined from 1 year to 6–8 years post-collision. None of the participants were affected by a high degree of kinesiophobia, i.e. a score of 40 or more (Lundberg et al., 2004), which strengthens the kinaesthetic test results; the kinesiophobia results seem not to affect the kinaesthetic test results (Fig. 5).

The significant effect of gender (not age) in the HNR test and the significant effect of age and gender on the accuracy error in the Fly test in this present study were unexpected findings. This has to be researched further in rigorous prognostic research designs (Moons et al., 2009; Peat et al., 2014) with larger sample size. The small sample size (in spite of good response rate) and uneven gender ratio is one of the main limitations in this study as relatively complex statistic was applied to small subgroups within each test.

The biologic causes of the two different kinaesthetic courses established in our prior study (Oddsdottir and Kristjansson, 2012) remains obscure. We suggest that the contractile and the inert structures may be targeted differently in low-speed acceleration/

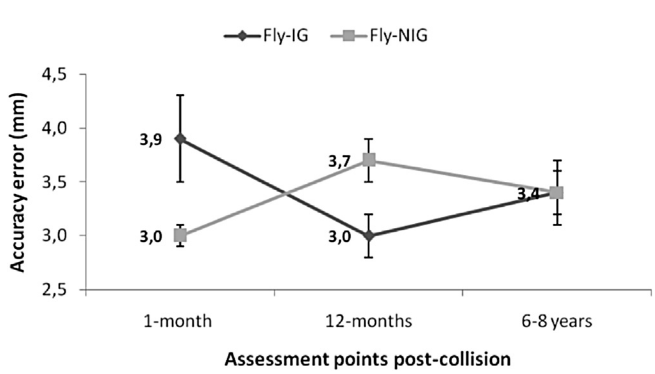

Fig. 3. The mean (SE) accuracy error for improvement versus non-improvement groups performing the Fly test at three time points following motor vehicle collision. The crossover in performances takes place during the first year post-collision but the two groups did not differ 6–8 years later. Subgroup differences were significant at 1st month (p = 0.035) and 12th month (p = 0.004).

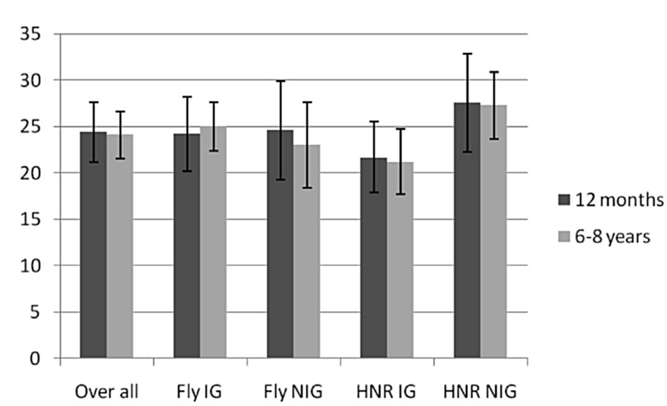

Fig. 4. Means and standard error of participants' scores on the Neck Disability Index at 12-month and 6–8 years post-collision. Results from over all analyses and stratified by improvement on kinaesthetic tests revealed no significant differences between the two time points.

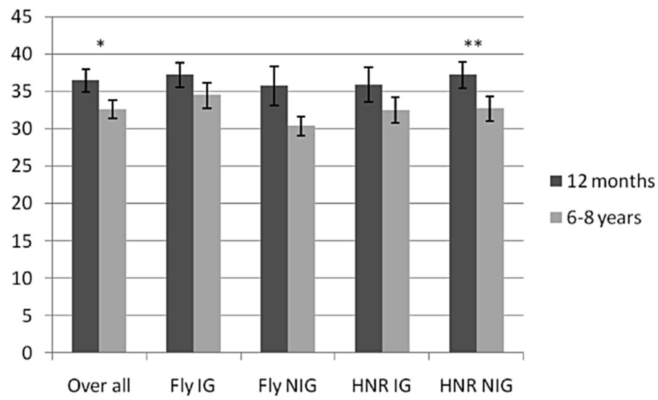

Fig. 5. Means and standard error of participants' scores on TAMPA at 12-month and 6–8 years post-collision. Results from over all analyses revealed significant differences between the two time points (*p = 0.010). Subgroup comparisons revealed significant differences among the HNR-NIG (**p = 0.022).

deceleration injuries of the cervical spine. The patients who improved in the prior study and had the poorer scores on the two kinaesthetic tests at 1 month post-collision may have sustained forced eccentric muscle contraction of the superficial neck muscles at a higher level of acceleration (>15 km/h) (Kumar et al., 2002). The participants who deteriorated in the course of a year and had the better scores on the two kinaesthetic tests at 1 month post-collision may, on the other hand, may have sustained greater injury to the inert structures at lower levels of acceleration (<15 km/h), as the neck muscles respond slower at lower compared to higher acceleration (Brault et al., 2000). If the statement holds true that about 65% of all insurance claims take place in cases with velocity changes of up to 15 km/h (Castro et al., 1997), it may support our speculation that the inert structures are more prone to injury at lower acceleration (<15 km/h).

Recently, joint position error in the cervical spine was tested by using neck torsion (head still, trunk movement) (Chen and Treleaven, 2013). The study showed that the torsion test might be more suitable than the conventional joint-position error test as a measure of cervical afferent dysfunction because vestibular stimulation is avoided. The present study used the prior version of the Fly test (Kristjansson et al., 2004), so the test results would be comparable to the 1-year follow-up study (Oddsdottir and Kristjansson, 2012). The main drawback of the prior Fly test is that no attempt was made to generate incrementally difficult sets of movement patterns to precisely grade the impairment level of each individual patient. The Fly method (test and exercise programme) was therefore developed further to address this shortcoming by creating 3 incrementally difficult classes of movement patterns: easy, medium and difficult (Kristjansson and Oddsdottir, 2010). We therefore suggest that the HNR test method, used by Chen and Treleaven (2013) and the new version of the Fly test (Kristjansson and Oddsdottir, 2010) will depict deficient cervical kinaesthesia most accurately in future research with additional variables included, not just absolute error.

The course of neck pain is best described as episodes occurring over a lifetime with variable degrees of recovery in between episodes (Guzman et al., 2008). Deficient cervical kinaesthesia is usually subtle (Kristjansson and Treleaven, 2009), and variable due to the fact that no correlation was seen between the two tests, and only half of the participants depicted similar diverging courses on the two tests (Oddsdottir and Kristjansson, 2012). Furthermore, given the results from the 1-year follow-up study, with two distinct and crossing courses (Oddsdottir and Kristjansson, 2012), and the results from the present study, which show a tendency to seek physiological homeostasis at 6–8-years follow-up, we recommend that cervical kinaesthesia be monitored and treated early after MVCs.

Deficient cervical kinaesthesia may lead to adaptive compensatory patterns secondary to the remaining functional kinaesthetic deficits. This may be manifested in the form of changed neuromuscular recruitment patterns with unrelenting muscle stiffness in the superficial neck muscles and decreases in daily performances (Falla and Farina, 2008; Meisingset et al., 2015). This is important, as deficient cervical kinaesthesia is a modifiable factor, presumably both a risk factor and a prognostic factor, for future disability. This needs to be clarified in future research. Empowering people with neck pain, the kinaesthetic treatment options (the Fly Exercise Program, the Head–Neck Awareness and Relocation Exercise Programs) will be made available through the Internet, so patients can improve their deficient cervical kinaesthesia by treating their own neck at home under guidance from their clinicians.

5. Conclusion

The results of this study suggest that untreated deficient cervical kinaesthesia has a tendency to seek a physiological homeostasis somewhere from 1 year to 6–8 years post-collision. The results suggest that deficient cervical kinaesthesia is subtle, not detected by conventional physical examination; and variable, as the 2 kinaesthetic tests only depict the same courses of about half of the participants; and divergent, as the results at 1 month versus 12 months show. We therefore recommend that cervical kinaesthesia be monitored and treated early after MVCs as deficient cervical kinaesthesia may lead to adaptive compensatory patterns secondary to the remaining functional kinaesthetic deficits. It can be inferred that the unrelenting muscle stiffness in the superficial neck muscles in the late whiplash syndrome may be one important manifestation of deficient cervical kinaesthesia.

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'Skjal' translation agency eliminated possible grammatical and spelling errors.

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