Supplementary file 1. Candidate predictors

General patient characteristics including previous musculoskeletal pain

Participants' demographic data will be recorded at baseline including gender and highest attained education level.

Psychosocial features

Pain Catastrophizing Scale (PCS)

The PCS will be used to evaluate the extent to which patients ruminate, magnify or feel helpless about controlling their pain [1]. It is a 13-item self-reported outcome consisting of three dimensions including rumination, magnification and helplessness to measure pain related catastrophizing. Subjects rate the frequency of experiencing catastrophic thoughts as 0 (not at all) or 4 (all the times) which produces an overall score of from 0-52 with higher scores indicating greater negative pain thoughts. The reliability and validity of the PCS have been established [1], and it has been used in patients with WAD [2, 3]. Moderate evidence of significant association shows that initial catastrophising was a risk factor for developing persistent symptoms in whiplash [4] with pooled odd ratio=3.77 (95% confidence intervals = 1.33 - 10.74) [5].

Tampa Scale of Kinesiophobia [TSK-11]

The TSK-11 is a self-reported outcome used to evaluate fear of movement or injury during activities [6]. It consists of 11-item of which each is scored from 1 ('totally agree') to 4 ('totally disagree') producing a total score from 11 to 44, with higher scores indicating higher fear of movement. The TSK-11 has showed excellent test-retest reliability and good construct validity in detecting changed in pain and disability [7]. Indirect association was found between fear of movement and higher neck pain and disability in patients with acute

WAD [8]; catastrophizing increases fear of movement which leads to decreased functional self-efficacy that results in higher pain and disability [8].

Recovery Expectation (high or low expectation of recovery)

Patients will be asked if they expect to fully recover within the next six months. Recovery expectations will be assessed by the question "In your opinion, how likely is it that you will be fully recovered with no persistent sequelae?" [9]. In response to this question, recovery expectations will be measured using NRS where a patient need to indicate how likely he/she would have completely recovered, by choosing a score from 0 ("not likely") to 10 ("very likely") [10]. Low expectation of making full recovery were found to be an independent predictive factor associated (odds ratio= 4.2 [95% CI = 2.1 - 8.5]) with higher disability in individuals with acute WAD [10].

Pain characteristics

Numeric Rating Scale (NRS)

Current neck pain intensity will be measured using NRS which is a 11-point scale range from 0 (no pain) to 10 (worst possible pain). Also, perceived pain intensity will be measured at the end of each physical measure of neck range of motion tasks, neck maximum contraction tasks, and neck submaximum contraction tasks. The reliability of NRS has been established in patients with neck pain (ICC:0.76) [11]. Also, participants will be asked remotely (through the app) where they have 'experienced pain during the last week' from several body locations [12]. Based on their response of chosen areas, pain intensity will be assessed using NRS. Finally, neck pain intensity following active movements will be measured through NRS. High evidence of significant association shows that initial neck pain intensity was a consistent risk factor for developing persistent symptoms in whiplash [4] with pooled odd ratio= 5.61 (95% CI = 3.74 - 8.43) [13].

Physical measures

Wearable sensor for motion detection (Neck range of movement, angular velocity, movement smoothness and proprioception)

A wearable BTS G-WALK® sensor system (BTS Bioengineering, Italy) will be utilised to assess neck range of motion, angular velocity, movement smoothness, and neck proprioception. The sensor connects to a computer via Bluetooth; at the end of each analysis an automatic report containing all the parameters recorded during the test, is displayed.

Active neck flexion, side-flexion, extension, and rotation will be measured at baseline. Impaired range of motion has been found in individuals with WAD compared to healthy controls [14, 15] and has also been found to be a factor associated with persistent disability at one year [16, 17], and neck pain and disability at 6 months [18, 19].

Besides range of motion, the angular velocity and movement smoothness will be recorded simultaneously during each neck movement. Each movement direction will be repeated five times and the average taken. These kinematic variables may provide more information about motor control disturbances [20]. A study found maximum angular velocity and acceleration were lower in subjects with chronic WAD when compared to healthy control [20]. The same finding (lower peak velocity) was found in cohorts of both WAD and insidious neck pain [21]. Moreover, significant differences in jerk indices were observed during active neck movements in a study comparing healthy controls to those with chronic neck pain of both insidious onset and traumatic onset [21].

Neck proprioception will be measured by calculating the Joint Position Error (JPE) following active neck rotation. JPE is defined as the ability to relocate the natural head position without the assistance of vision [22]. To assess this, the same wearable sensor (G-Walk) will be used. Patients will repeat active neck rotation with their eyes closed and will indicate when they think that they have returned to the starting position. JPE will be assessed three times for both right and left rotation and the average taken for each direction. Decreased head repositioning accuracy has been observed in people with idiopathic neck pain [23], but with greater repositioning errors found in individuals with neck pain attributed to a trauma [24], which is even more evident in those with moderate to severe pain and disability [14].

Dynamometer (maximal and sub-maximal isometric contractions)

At baseline, the participants will perform maximal and sub-maximal isometric contractions to measure maximum strength and control of sub-maximal forces. Cranio-cervical flexion, neck flexion and extension will be tested using a hand-held dynamometer for neck muscle testing (NOD, OT Bioeletronica, Italy).

1. Maximum voluntary contraction (MVC):

Two MVCs will be performed for cranio-cervical flexion, neck flexion, and extension. Each maximum MVCs will last for 3 seconds, separated by 1 minute rest in between [25]. The mean MVC for each direction will be calculated and used in the analysis [26, 27]. Patients will perform an initial trial to familiarise themselves with each movement under the guidance of a trained examiner with minimal force.

Cranio-cervical flexion strength testing will be performed with the participant in supine lying with the hip and knees flexed to approximately 90 degrees [28]. The head will be placed in neutral position and the dynamometer placed behind the upper cervical spine with the instruction being to nod as if saying yes but as hard as you can. Patients will be seated to measure neck flexion and extension strength with the participant seated comfortably on a chair with hip and knee flexed to 90 degrees with head in neutral position and feet flat on the ground. To measure neck flexion, the dynamometer will be placed over the forehead and against the resistance of the examiner, the patient will be instructed to “push as hard as you can as you try to bring your chin to your chest” [29]. The dynamometer will then be placed on the back of the head and the patient instructed to “push as hard as you can into the dynamometer as if trying to bring the back of the head to your neck” [29].

Patients with neck pain commonly present with reduced neck strength [29-32], although the extent of impaired strength is highly variable across patients [33]. Significant lower isometric MVC force has been observed in patients with chronic WAD compared to healthy controls [29]. Reduced neck muscle strength has been associated with the extent of disability [25, 34] and pain [34] in people with chronic neck pain..

2. Sub-maximal voluntary contractions:

In the same positions described for the MVC, participants will be instructed to perform a single submaximal contraction at 20% of their maximal force and hold this for 10 seconds for cranio-cervical flexion, flexion and extension. In addition, participants will perform 40%, 60%, 80%, and 100% of their maximal force for the cranio-cervical flexion only. Feedback on force will guide the participant to maintain specific degree of contraction from their MVC over the duration of the contraction.

Surface electromyography (EMG) (co-activation of the sternocleidomastoid and splenius capitis)

The amplitude of sternocleidomastoid (SCM) activity will be measured bilaterally during the isometric maximum and submaximal voluntary contractions of cranio-cervical flexion. In addition, both SCM and splenius capitis (SC) activity will be measured bilaterally during the maximum and submaximal voluntary contractions of neck flexion and extension.

Increased co-activation of the neck flexors and extensors has been observed in patients with chronic neck pain and headache [35], and is associated with reduced neck strength [35]. Changes in neck muscle activation has been observed in people with acute neck pain following a whiplash injury [14, 36].

Following gentle skin preparation, pairs of bipolar surface electrodes will be placed over SCM and SC bilaterally following published guidelines for electrode placement [37]. Signals will be detected using wireless EMG (Ultium® EMG, Noraxon, USA). Co-activation indexes will be calculated as described previously [38].

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