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# Derivation of a clinical prediction rule to identify both chronic moderate/severe disability and full recovery following whiplash injury

Carrie Ritchie *, Joan Hendrikz, Justin Kenardy, Michele Sterling

*Centre of National Research on Disability and Rehabilitation Medicine (CONROD), University of Queensland, Brisbane, Australia*

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ABSTRACT

Recovery following a whiplash injury is varied: approximately 50% of individuals fully recover, 25% develop persistent moderate/severe pain and disability, and 25% experience milder levels of disability. Identification of individuals likely to develop moderate/severe disability or to fully recover may help direct therapeutic resources and optimise treatment. A clinical prediction rule (CPR) is a research-generated tool used to predict outcomes such as likelihood of developing moderate/severe disability or experiencing full recovery from whiplash injury. The purpose of this study was to assess the plausibility of developing a CPR. Participants from 2 prospective, longitudinal studies that examined prognostic factors for poor functional recovery following whiplash injury were used to derive this tool. Eight factors, previously identified as predictor variables of poor recovery, were included in the analyses: initial neck disability index (NDI), initial neck pain (visual analogue scale), cold pain threshold, range of neck movement, age, gender, presence of headache, and posttraumatic stress symptoms (Posttraumatic Diagnostic Scale [PDS]). An increased probability of developing chronic moderate/severe disability was predicted in the presence of older age and initially higher levels of NDI and hyperarousal symptoms (PDS) (positive predictive value [PPV] = 71%). The probability of full recovery was increased in younger individuals with initially lower levels of neck disability (PPV = 71%). This study provides initial evidence for a CPR to predict both chronic moderate/severe disability and full recovery following a whiplash injury. Further research is needed to validate the tool, determine the acceptability of the proposed CPR by practitioners, and assess the impact of inclusion in practice.



## 1. Introduction

Whiplash-associated disorders (WAD) are the most common nonhospitalised injury resulting from a road traffic crash [11]. The consequent pain and disability experienced incur substantial socioeconomic costs [11,23]. Recent research indicates that improvements in pain and disability are likely to occur within the first 3 months [21]. However, only 50% of individuals with WAD experience full recovery; approximately 25% continue to experience persistent moderate/severe pain and disability, and 25% have milder levels of pain and disability [15,21,32,36,37]. It is the moderate/severe disability group that incurs the majority of associated costs [26]. Identification of individuals likely to develop moderate/severe disability or experience full recovery may help direct therapeutic resources and optimise treatment. Clinical prediction rules (CPRs) are one type of research-generated tool used to predict outcomes such as the likelihood of developing chronic moderate/severe disability or full recovery from whiplash injury.

CPRs use quantitative methods to analyse the contributions of specific patient characteristics and subsequently create pathways to assist clinicians in making predictions about patient outcomes [25,29]. CPRs are most useful when decision-making is complex [25] or uncertain [27], or there are possibilities for cost savings without compromising patient care [25]. Patients with WAD present with a complex profile, the recovery pathway is not homogenous [32], and outcomes following treatment are unclear [12,28]. Accumulating evidence indicates a biopsychosocial model of recovery, with numerous factors suggested to influence recovery [4,33,35]. Furthermore, although improvement in prognosis has been shown for some individuals following exercise and mobilisation therapy [41], emerging evidence suggests that early intensive health care may delay recovery [12,28]. It may be that specific subsets of patients benefit from specific treatment strategies, whereas the same therapies may be detrimental to others. Hence, given the

* Corresponding author. Address: Centre of National Research on Disability and Rehabilitation Medicine (CONROD), University of Queensland, Ground Floor, Edith Cavell Building, RBWH, Herston, Brisbane, QLD 4029, Australia. Tel.: +61 7 3365 5560; fax: +61 7 3346 4603.

*E-mail address:* c.ritchie@uq.edu.au (C. Ritchie).

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plethora of possible predictors of recovery, development of a dual-pathway CPR to predict both moderate/severe symptoms and full recovery may help consolidate current evidence and facilitate the design of treatment strategies to target specific subsets of patients.

Proposing to link the design of treatment strategies with probability of outcome necessitates a CPR with: factors amenable to change; a high specificity; and one that provides an enhanced probability of the outcome (positive predictive value [PPV]). To our knowledge, only one CPR has been published for prediction of chronicity from WAD [18], and no publications exist for the prediction of full recovery. The published tool underwent a derivation study only, was unique to the locality of the study, and did not consider the biopsychosocial factors amenable to change that are thought to contribute to chronicity [18,30,33].

The aim of the present study was to investigate the plausibility of developing a CPR for WAD. Specifically, this study was designed to: analyse previously identified predictor variables of poor recovery for inclusion within a CPR and to derive a dual-pathway CPR for whiplash injury that ensured an acceptable revised percentage (PPV) of those predicted to develop chronic moderate/severe symptoms or to recover fully.

## 2. Methods

A secondary analysis of data from 2 prospective, longitudinal studies was performed to develop a dual-pathway CPR. The designs of both studies adhered to Strobe criteria for cohort studies [43].

### 2.1. Participants

Participants were from 2 prospective, longitudinal studies that examined prognostic factors for poor functional recovery following whiplash injury, and these studies were conducted in 2006–2010 [32, unpublished data]. Participants for both studies were recruited via hospital accident and emergency departments, primary care practices, and via general advertisement. Eligibility for both studies was the same and included individuals with acute whiplash injury (ie, symptoms < 1 month in duration) following a motor vehicle crash with Quebec Task Force Classification of WAD I, II, or III [31]. Participants were excluded if they were WAD IV (fracture or dislocation), experienced concussion or head injury as a result of the accident, and if they reported a previous history of whiplash, neck pain, or headaches that required treatment. They were also excluded if they reported being diagnosed with or receiving treatment for a psychiatric or psychological condition either currently or in the past.

Participants were assessed at < 1 month (ie, baseline), 3, 6, and 12 months post injury at a university laboratory. Predictor variable data were measured at inception, and identification of final outcome (eg, moderate/severe pain and disability, mild pain and disability, or full recovery) was made from data collected at 12 months. No usual treatment was withheld or modified. Different treatments received by the participants were not expected to confound this study for 2 reasons. Firstly, data from our initial studies demonstrated that there were no differences in the types and numbers of treatments received between recovered and nonrecovered subjects [34]. Secondly, no current treatment has yet demonstrated a capability to lessen the transition to chronic symptoms. Participant sample details are shown in Fig. 1. Ethical approval was gained from the institutional Medical Research Ethics Committee, and all participants provided signed informed consent.

### 2.2. Dependent variable

The neck disability index (NDI) is a valid, reliable, and responsive measure [24,45]. An overall score (out of 100) is calculated by totalling responses to 10 questions, each with 6 potential Likert-type responses (eg, 0 = no disability to 5 = total disability) and multiplying the sum by 2 to yield a percentage. Previous research has suggested that an NDI $\geqslant$ 30% is indicative of moderate to severe levels of pain-related disability and an NDI $\leqslant$ 10% indicates full recovery [24,36,44].

### 2.3. Predictor variables

Although previous research has suggested numerous predictors of recovery following a whiplash injury [4,6,30,33,35,46], recent conclusions indicate that possible predictors are likely to include those that encompass a biopsychosocial model of recovery [4,33,35]. Given the complexity and plethora of possible variables, the following 8 previously identified biopsychosocial variables were selected for inclusion.

The recent validation of a prognostic model to predict chronic moderate/severe disability following whiplash injury confirmed the association of initial NDI, cold pain threshold, age, and post-traumatic stress symptoms with delayed recovery [34]. Hence, these 4 factors were included in the analyses for the present study. Additional factors included in the present study were: initial neck pain (visual analogue scale [VAS]), the only factor to consistently predict poor functional recovery from WAD in previously published cohort studies [20,21,30,32,36]; and factors proposed to predict recovery in previous reviews: gender [21], presence of headache [21,46] and range of neck movement (ROM) [46].

### 2.4. Measurement of predictor variables

Predictor variables were measured at baseline. Measurement of NDI is discussed in an earlier paragraph and the PDS is described in the following paragraph. Cold pain thresholds were measured over the mid-cervical spine using the Thermotest system (Somedic AB, Farsta, Sweden). Triplicate recordings were taken at each site and the mean values used for analysis, a process shown to be valid and reliable [33,36]. Age at last birthday was measured in years, and presence of headache at the time of assessment was measured as a yes/no response. Initial pain level over the past 24 hours was measured using an 11-point VAS with anchors of 0 = no pain and 10 = worst pain imaginable, a valid and reliable measure of pain [5]. Cervical ROM was measured using an electromagnetic, motion-tracking device (FASTRAK; Polhemus, Colchester, VT, USA) according to previously established methods shown to be reliable and valid [13,42]. Although the previous validation study [34] suggested inclusion of left neck rotation only, to ensure acceptance by clinicians, total neck rotation (ROM) (eg, sum of left and right neck rotation, flexion and extension) was included in the present study.

### 2.5. Posttraumatic diagnostic scale

Previous research with WAD has reported posttraumatic stress symptoms using 2 different self-reported scales: the Impact of Events Scale and the Posttraumatic Diagnostic Scale (PDS) [16,19]. Both scales have been shown to be reliable and valid [16,19], however, only the PDS scale includes a measure of hyperarousal [16]. Hyperarousal symptoms form 1 of the 3 necessary clusters of symptoms in the diagnosis and presentation of posttraumatic stress disorder (PTSD) [2]. The PDS maps the symptoms of PTSD onto the *Diagnostic and Statistical Manual of Mental Disorders* diagnosis of PTSD [16]. Hence, the PDS was deemed to be the more inclusive scale to measure posttraumatic stress symptoms.

The PDS comprises 49 items and is scored to provide a measure of total symptom severity in addition to 3 scale measures: re-experiencing, avoidance, and hyperarousal. A single scale containing 49 items was deemed to be too lengthy for a CPR. Hence, standard

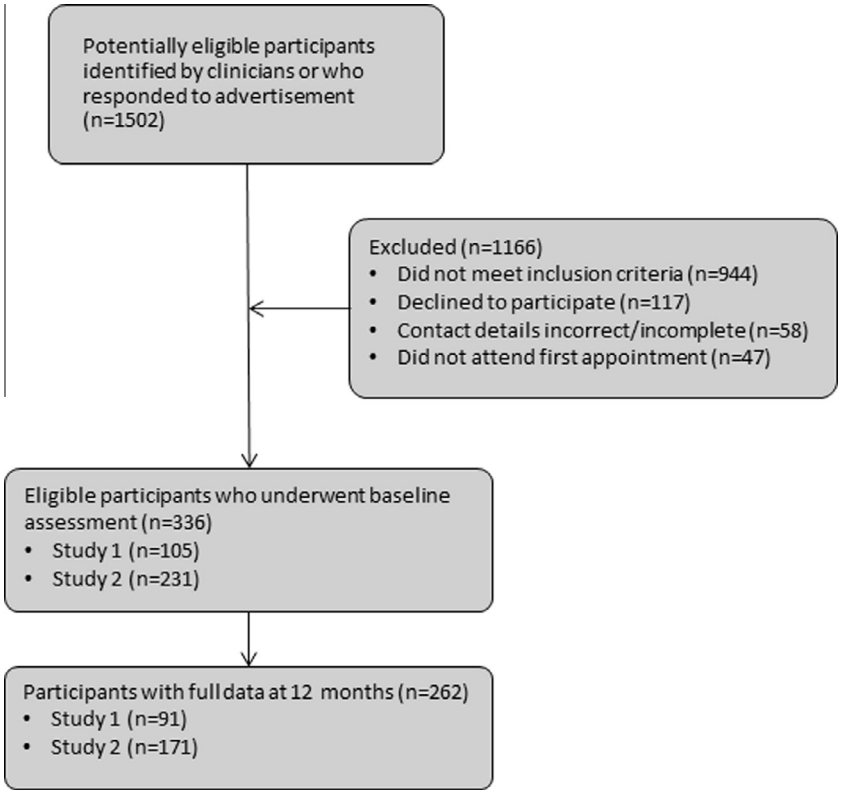


**Fig. 1.** Participant sample details.

multiple regression with 12-month NDI as the dependent variable was performed to determine whether or not a single subscale from the PDS would be valid for inclusion within a CPR.

### 2.6. Sample size

Ten to 15 subjects per potential predictor variable are required to ensure an adequate sample size for the development of a CPR [17,25,47]. Eight potential predictor variables were included within this study; hence, using this rule, a sample size of 80 to 120 was required. NDI measures at 12 months were available for 262 (79%) subjects. This number is also sufficient for calculating that the interval between any reported proportion or rate, for example, a rate of chronicity or a PPV, and its lower 95% confidence limit, is within 0.053, indicating an average confidence of being sure that the true proportion is no less than this lower bound.

### 2.7. Statistical analysis

Statistical tests were used to develop 2 pathways: prediction of chronic moderate/severe pain and disability and prediction of full recovery, where these are defined as the positive case for interpretation of accuracy statistics. To develop the "chronic moderate/severe" pathway, subjects were dichotomised as having developed chronic pain-related disability (NDI $\geqslant$ 30% after 12 months) or partially/fully recovered (NDI < 30% after 12 months) [24,36,44]. To develop the "full recovery" pathway, subjects were dichotomised as fully recovered (NDI $\leqslant$ 10% after 12 months) or mild/moderate/severe disability (NDI > 10% after 12 months) [24,36,44].

### 2.8. Identification of diagnostic cutoff points

There is increasing interest in the use of classification (or decision) trees to predict outcomes in clinical studies [3,9]; however, at present, logistic regression is the most common method employed in studies designing prediction models [9,17]. Consequently, both methods were initially used to examine cutoff points for the CPR. Chi-squared automatic interaction detection (SPSS version 20; IBM, Armonk, NY, USA) was the classification tree method used to examine the influence of all predictor variables found to have a univariate relationship and subsequently provide the best classification by splitting the sample into smaller subgroups. This method, however, produced meaningless classifications (eg, NDI = 36 or 56), hence, logistic regression was deemed to be the preferred statistical method for this study.

For each pathway, the 8 proposed predictor variables were tested for univariate relationship with chronic moderate/severe pain and disability or full recovery using univariate logistic regression analyses. Variables with a significance level of $P < 0.05$ were retained as potential prediction variables for development of the CPR. Using postanalytical discrimination methods, the next step was to use the output from the univariate analyses to calculate sensitivity to the positive case (true positives) and 1-specificity (false positives) for each of the significant continuous variables. These were plotted as a receiver operating characteristic (ROC) curve, and the variable value corresponding to the point on the curve nearest the upper left hand corner of the curve (derived mathematically) was defined as the cutoff value, with the best or optimal probability of a true diagnosis [9,17]. The resulting dichotomised potential predictor variables were then entered into a backwards stepwise multiple logistic regression to determine the best set for identifying either moderate/severe pain and disability or full recovery.

### 2.9. Clinical prediction rule

Previous research has shown that approximately 25% of individuals who experience a whiplash injury will develop chronic moderate/severe disability, 50% fully recover, and the remaining 25%

will continue to experience milder levels of disability [15,32,36,37]. Our dataset was examined to ensure a similar prevalence. Upon confirmation, accuracy statistics for the positive case (eg, sensitivity, specificity, positive likelihood ratio, PPV, negative predictive value) were calculated using various combinations of the variables in the optimal sets to determine whether or not they yielded an acceptable revised estimate of the probability (PPV) of subjects identified as being either potentially chronic moderate/severe disability or fully recovered.

## 3. Results

*t*-Tests and $\chi^2$ analyses were completed to determine differences in predictor variables between dropouts (n = 67 [21%]) and the participants (n = 262 [79%]) for this study. The only significant difference between these cohorts was that dropouts were significantly younger than participants (Table 1). Chi-squared analyses showed no significant differences between participants and dropouts with regards to gender ($\chi^2$ = .000, $P$ = 1.0) and presence of a headache ($\chi^2$ = 1.67, $P$ = 0.196).

### 3.1. Posttraumatic diagnostic scale

The results of a standard multiple regression showed that of the 3 PDS subscales, the hyperarousal subscale (B = 1.454, b = .307, SE = .433, $P$ < 0.001) was the only significant independent predictor of 12-month NDI. Neither the re-experiencing (B = .229, b = 0.46, SE = .429, $P$ < 0.594) nor avoidance (B = .235, b = 0.59, SE = .386, $P$ < 0.543) subscales reached significance. Consequently, only the hyperarousal subscale was included in further analyses.

### 3.2. Prediction of chronic moderate/severe disability

Twenty-six percent (n = 69) of subjects were identified as having ongoing moderate to severe disability 12 months after the whiplash injury.

Univariate logistic regression analyses showed that increases in age, initial VAS, initial NDI, initial cold pain threshold, and the initial hyperarousal subscale of the PDS, as well as decreases in initial ROM, were all significantly linked to increased odds of chronic moderate/severe disability vs recovered/milder disability (Table 2).

The cutoff points identified through ROC analyses for the 6 significant potential predictor variables are shown in Table 3. The positive likelihood ratios ranged from 3.2 to 1.5, with the strongest predictor being initial NDI. Predictive factors for use within a CPR need to be clinically meaningful. Hence, the cutoff values obtained from the ROC were adjusted to ensure an acceptable value. For example, a cutoff of 40 for initial NDI was deemed to be more acceptable than a cutoff of 39. Changes to the cutoffs for the other factors were: initial VAS $\geqslant$ 5.0, age $\geqslant$ 35 years, cold pain threshold $\leqslant$ 14°C, ROM $\leqslant$ 160°, and hyperarousal subscale $\geqslant$ 6.

Following a backwards stepwise multiple logistic regression, initial NDI, hyperarousal subscale, and age were positively associated with moderate to severe disability. These variables were retained in the model for the development of the prediction rule (Model $\chi^2$ = 62.1, $df$ = 3, $P$ < 0.000, Cox & Snell $R^2$ = 0.25, Nagelkerke $R^2$ = .36) (Table 4).

### 3.3. Prediction of full recovery

Forty-six percent (n = 120) of participants were identified as having fully recovered from the whiplash injury. The same variables analysed for the prediction of chronicity were used to assess the plausibility of developing a prediction rule for screening full recovery. Univariate logistic regression analyses showed that the odds of full recovery in participants vs mild/moderate/severe disability were significantly linked to the absence of headache, and decreases in age, initial VAS, initial NDI, and the initial hyperarousal subscale of PDS, as well as increases in initial ROM (Table 5).

The optimal cutoff points identified through ROC analyses for the 5 potential predictor variables (initial NDI, initial VAS, age, ROM, hyperarousal subscale) are shown in Table 6. The positive likelihood ratios ranged from 2.7 to 1.5, with the strongest predictors being initial NDI and initial VAS. To ensure acceptability of the prediction rule, the identified cutoff values were converted to whole numbers, and became: initial NDI $\leqslant$ 32, VAS $\leqslant$ 3, age $\leqslant$ 35, ROM $\geqslant$ 210°; arousal subscale $\leqslant$ 3.

Following a backwards stepwise logistic regression of full recovery on the variables listed in Table 6 and presence of headache, lower initial NDI and younger age were retained in the model for the development of the CPR to predict full recovery (Model $\chi^2$ = 37.9, $df$ = 2, $P$ < 0.0001, Cox & Snell $R^2$ = 0.16, Nagelkerke $R^2$ = 0.21) (Table 7).

### 3.4. Clinical prediction rule

PPV is useful if the study population has a similar proportion of disease to the established prevalence [39]. Similar to previous research [15,21,32,36,37], 26% of participants in the current study were identified as having developed chronic moderate/severe disability and 46% fully recovered from a whiplash injury. Hence, consideration of the revised PPVs was used to assess the plausibility of the proposed screening tools.

Backwards stepwise logistic regression analyses indicated that initial NDI $\geqslant$ 40 was the most significant predictor of chronic moderate/severe disability (Table 4), and initial NDI $\leqslant$ 32 was the most significant predictor of recovery (Table 7). Hence, measurement of initial NDI became the first step in the CPR to identify both individuals who are likely to fully recover from whiplash injury and individuals who may develop chronic moderate/severe disability (Fig. 2). As indicated in Fig. 2 and 3 pathways emerged: the pathway derived to predict moderate/severe disability, the pathway derived to predict full recovery, and a third pathway in which participants did not meet the criteria for either of the 2 derived pathways. For example, a patient who initially expressed low levels of pain-related disability and was older than 35 years, or a patient expressing higher levels of pain-related disability, was older, and reported a low level of hyperarousal symptoms would not meet the criteria for either the full recovery or moderate/severe disability pathways and would therefore be candidates for the middle cluster.

**Table 1**
Comparison of means (SD) between compliers and dropouts.

| Factor | Subjects (n = 262) | Dropouts (n = 67) | *t*-Value | *df* | *P*-value |
|---|---|---|---|---|---|
| Initial NDI | 32.9 (17.5) | 31.6 (18.1) | −0.54 | 325 | 0.820 |
| ROM | 201.4 (63.4) | 208.0 (59.0) | 0.78 | 320 | 0.547 |
| Hyperarousal subscale (PDS) | 4.8 (3.8) | 4.9 (4.1) | 0.15 | 293 | 0.976 |
| Initial VAS | 4.2 (2.1) | 4.3 (2.3) | 0.42 | 322 | 0.262 |
| Age, years | 37.1 (14.2) | 33.9 (11.8) | −1.74 | 327 | 0.029 |
| Cold pain threshold | 14.4 (7.7) | 15.8 (8.6) | 1.25 | 318 | 0.063 |

NDI, neck disability index; ROM, range of neck movement; PDS, Posttraumatic Diagnostic Scale; VAS, visual analogue scale.

**Table 2**
The results of univariate logistic regression analyses of 12-month NDI (chronic moderate/severe disability [n = 69] vs recovered/milder disability [n = 193]) on proposed variables.

| Factor | B | SE | *P*-value | OR = Exp(B) | 95% CI |
|---|---|---|---|---|---|
| Initial NDI | 0.071 | 0.011 | < 0.0001 | 1.07 | 1.051–1.097 |
| ROM | −0.012 | 0.002 | < 0.0001 | 0.989 | 0.984–0.991 |
| Hyperarousal subscale (PDS) | 0.197 | 0.041 | < 0.0001 | 1.22 | 1.123–1.319 |
| Initial VAS | 0.307 | 0.073 | < 0.0001 | 1.36 | 1.178–1.568 |
| Age | 0.024 | 0.010 | 0.015 | 1.03 | 1.004–1.045 |
| Cold pain threshold | 0.042 | 0.019 | 0.024 | 1.04 | 1.005–1.082 |
| Gender (female) | −0.129 | 0.296 | 0.662 | 0.88 | 0.492–1.570 |
| Presence of headache | −0.281 | 0.410 | 0.492 | 0.76 | 0.338–1.686 |

NDI, neck disability index; OR, odds ratio; CI, confidence interval; ROM, range of neck movement; PDS, Posttraumatic Diagnostic Scale; VAS, visual analogue scale.

**Table 3**
Cutoff points with discrimination statistics for true diagnosis, using ROC curve analyses, following univariate analysis of the chronic/severe disability pathway.

| | Cutoff | Sensitivity (%) to chronicity | Specificity (%) to some recovery | +LR | Area (95% CI) | SE | *P*-value |
|---|---|---|---|---|---|---|---|
| Initial NDI | ⩾39.0 | 70.6 | 78.1 | 3.2 | 0.82 (0.760–0.880) | 0.031 | < 0.0001 |
| ROM | ⩽161.4° | 46.4 | 85.0 | 3.1 | 0.69 (0.619–0.768) | 0.038 | < 0.0001 |
| Hyperarousal subscale (PDS) | ⩾5.5 | 62.9 | 72.5 | 2.3 | 0.69 (0.608–0.773) | 0.042 | < 0.0001 |
| Initial VAS | ⩾5.2 | 51.5 | 77.1 | 2.3 | 0.68 (0.604–0.758) | 0.039 | < 0.0001 |
| Age | ⩾36.5 | 66.7 | 57.5 | 1.6 | 0.60 (0.526–0.681) | 0.040 | 0.015 |
| Cold pain threshold | >13.5°C | 64.2 | 56.5 | 1.5 | 0.59 (0.508–0.670) | 0.041 | 0.035 |

ROC, receiver operating characteristic; LR, likelihood ratio; CI, confidence interval; NDI, neck disability index; ROM, range of neck movement; PDS, Posttraumatic Diagnostic Scale; VAS, visual analogue scale.

**Table 4**
Results of backwards stepwise multiple logistic regression showing factors associated with development of chronic moderate/severe disability.

| Variable | B | SE | *df* | *P*-value | OR = Exp(B) | 95% CI |
|---|---|---|---|---|---|---|
| NDI initial (⩾ 40) | 2.013 | 0.402 | 1 | < 0.0001 | 7.49 | 3.405–16.459 |
| Age (⩾ 35) | 0.811 | 0.373 | 1 | 0.014 | 2.25 | 1.083–4.674 |
| Hyperarousal subscale (PDS) (⩾ 6) | 0.796 | 0.396 | 1 | 0.032 | 2.22 | 1.020–4.817 |

OR, odds ratio; CI, confidence interval; NDI, neck disability index; PDS, Posttraumatic Diagnostic Scale.

**Table 5**
The results of univariate logistic regression analyses of 12-month NDI (recovered [n = 120] vs chronic mild/moderate/severe disability [n = 142]) on proposed variables.

| Factor | B | SE | *P*-value | OR = Exp(B) | 95% CI |
|---|---|---|---|---|---|
| Initial NDI | −0.053 | 0.009 | < 0.0001 | 0.95 | 0.932–0.965 |
| ROM | 0.007 | 0.002 | 0.002 | 0.993 | 0.989–0.997 |
| Hyperarousal subscale (PDS) | −0.166 | 0.039 | < 0.0001 | 0.85 | 0.785–0.914 |
| Initial VAS | −0.235 | 0.065 | < 0.0001 | 0.79 | 0.696–0.898 |
| Age | −0.026 | 0.010 | 0.007 | 0.98 | 0.955–0.994 |
| Cold pain threshold | −0.027 | 0.017 | 0.105 | 0.97 | 0.941–1.006 |
| Gender (female) | 0.386 | 0.261 | 0.139 | 1.47 | 0.882–2.454 |
| Presence of headache | −0.897 | 0.429 | 0.037 | 2.45 | 1.058–5.684 |

NDI, neck disability index; OR, odds ratio; CI, confidence interval; ROM, range of neck movement; PDS, Posttraumatic Diagnostic Scale; VAS, visual analogue scale.

**Table 6**
Cutoff points with discrimination statistics for true diagnosis, using ROC curve analyses, following univariate analysis of the full recovery pathway.

| | Cutoff | Sensitivity (%) to recovery | Specificity (%) to some disability | +LR | Area (95% CI) | SE | *P*-value |
|---|---|---|---|---|---|---|---|
| NDI | ⩽ 32.5 | 81.8 | 62.8 | 2.7 | 0.74 (0.669–0.800) | 0.033 | < 0.0001 |
| VAS | ⩽ 2.5 | 36.4 | 86.3 | 2.7 | 0.62 (0.542–0.688) | 0.037 | 0.003 |
| Age | ⩽ 35.5 | 62.7 | 60.0 | 1.6 | 0.58 (0.506–0.656) | 0.038 | 0.034 |
| ROM | ⩾ 211° | 61.7 | 60.5 | 1.6 | 0.61 (0.541–0.679) | 0.035 | 0.003 |
| Hyperarousal subscale (PDS) | ⩽ 3.5 | 84.5 | 43.0 | 1.5 | 0.65 (0.582–0.722) | 0.036 | 0.000 |

ROC, receiver operating characteristic; LR, likelihood ratio; CI, confidence interval; NDI, neck disability index; VAS, visual analogue scale; ROM, range of neck movement; PDS, Posttraumatic Diagnostic Scale.

### 3.5. Chronic moderate severe disability pathway

Accuracy statistics for possible chronic moderate/severe diagnostic pathways are shown in Table 8. PPV represents a revised probability of the development of moderate/severe disability for each pathway. A PPV of 71% was found if all 3 factors were present, and PPV = 61% if initial NDI ⩾ 40 was present with either age ⩾ 35 years or hyperarousal subscale ⩾ 6 (Table 8). Given that the

current evidence predicts 25% of patients will develop moderate/severe disability, a revised probability to 71% represents a potentially important advantage.

Furthermore, the likelihood ratio of 7 indicates a moderate and meaningful shift in probability [17]. The very high specificity indicates that most of those who did not have moderate/severe disability at 12 months did not meet the 3-factor criteria. As a result, an individual who meets the 3-factor criteria is likely to develop chronic moderate/severe disability (PPV). However, the lower sensitivity indicates that some of the individuals who developed chronic moderate/severe disability did not meet the criteria.

### 3.6. Full recovery pathway

The addition of age ⩽ 35 years to initial NDI ⩽ 32 yielded a PPV of 71% (Table 8). Current evidence suggests that 50% of patients with an acute injury will fully recover; hence, a revised PPV probability to 71% represents a potentially important diagnostic advantage. A likelihood ratio between 2 and 5 represents a small but sometimes meaningful shift in probability [9,17]. The very high specificity indicates that most of those who had some disability did not meet the 2-factor criteria. As a result, an individual who meets these criteria is likely to recover. The low sensitivity, however, indicates that individuals who did not meet the criteria had varied recovery pathways, including recovery.

## 4. Discussion

This study provides initial evidence for a clinical prediction rule to predict both chronic moderate/severe disability and full recovery following a whiplash injury. An increased probability of developing chronic moderate/severe disability was predicted in

**Table 7**
Results of backwards stepwise logistic regression analysis showing factors associated with recovery.

| Variable | B | SE | *df* | *P*-value | OR = Exp (B) | 95% CI |
|---|---|---|---|---|---|---|
| NDI initial (⩽ 32) | 1.856 | 0.310 | 1 | < 0.0001 | 6.397 | 3.484–11.747 |
| Age (⩽ 35) | 0.717 | 0.302 | 1 | 0.003 | 2.049 | 1.133–3.702 |

OR, odds ratio; CI, confidence interval; NDI, neck disability index.

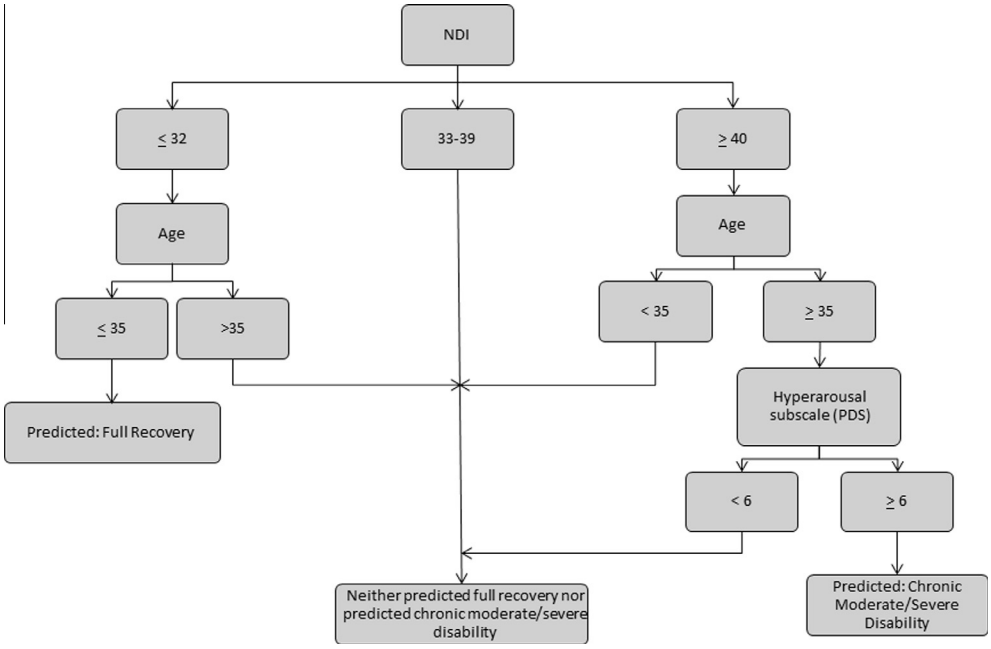


**Fig. 2.** Proposed clinical prediction rule to predict both chronic moderate/severe disability and full recovery following an acute whiplash injury. NDI, neck disability index; PDS, Posttraumatic Diagnostic Scale.

**Table 8**
Accuracy statistics (and 95% confidence intervals) for development of chronic moderate/severe disability or likelihood of full recovery using different combinations of the factors identified through backwards stepwise multiple regression.

| | Sensitivity (%) to chronicity | Specificity (%) to some recovery | +LR | −LR | PPV (%) | NPV (%) |
|---|---|---|---|---|---|---|
| *Chronic moderate/severe disability* | | | | | | |
| Presence of all 3 factors | 43.5 (31–55) | 93.8 (89–96) | 7.0 (3.8–12.9) | 0.6 (.5–.7) | 71.4 (55–84) | 82.3 (76–87) |
| NDI ⩾ 40 (+) age ⩾ 35 years | 51.5 (39–63) | 88.5 (83–92) | 4.5 (2.8–7.1) | 0.5 (.4–.7) | 61.4 (47–74) | 83.4 (77–88) |
| NDI ⩾ 40 (+) hyperarousal subscale (⩾ 6) | 58.8 (46–70) | 86.9 (81–91) | 4.5 (3.0–7.8) | 0.5 (.4–.6) | 61.5 (48–73) | 85.3 (79–89) |
| *Full recovery* | | | | | | |
| NDI ⩽ 32 and age ⩽ 35 years | 45.3 (35–54) | 84.5 (77–90) | 2.9 (1.9–4.5) | 0.6 (.5–.8) | 70.7 (59–80) | 64.5 |

LR, likelihood ratio; PPV, positive predictive value; NPV, negative predictive value; NDI, neck disability index.

the presence of older age, and initially higher levels of neck disability and hyperarousal symptoms. Conversely, the probability of full recovery was increased in younger individuals with initially lower levels of neck disability. Based on methodological recommendations for the derivation of a CPR [9,14,27], these factors were logical, simple to use, and confirmed current conclusions regarding factors that influence recovery from whiplash [30,32,36,37,46].

Given the high socioeconomic cost of WAD, previous research has examined a plethora of factors to predict ongoing pain and disability and thereby provide evidence for specifically designed interventions to avert the course to chronicity. Despite this extensive research, conclusions regarding predictive factors for recovery from WAD are equivocal [4,21,30,32,35–37,46]. Furthermore, emerging evidence suggests that overtreating individuals in the first 3 months following a whiplash injury may slow recovery [12,28]. Côté and colleagues [12] confirmed previous research which showed that early utilisation of intensive health care following an acute whiplash injury was associated with slower recovery. Pape et al. [28] also reported an increased risk of developing chronic neck pain following an early multidisciplinary intervention. Obviously, treatment strategies aim to restore health, alleviate pain, and reduce the risk of developing a disability. It may be that specific subsets of patients benefit from specific treatment strategies, whereas the same therapies may be detrimental to others. Hence, it is important to consolidate existing evidence and examine various patterns of care that facilitate recovery. Provision of a CPR such as the proposed tool is an initial step in this process.

The dual-pathway CPR provides a probability of prognosis and also indicates pathways that may assist in developing various treatment options based on likelihood of recovery. For example, the recommendation for patients who meet the full recovery criteria may be minimal treatment; whereas a multimodal treatment and referral process may be recommended for patients who meet the criteria for the development of moderate to severe pain-related disability. Recommendations for individuals who do not meet the criteria for either pathway, for example, the middle cluster, may be usual care or initial assessment with reassurance and follow-up as needed to ensure recovery does take place, or to institute more targeted treatment if it does not. Randomised controlled treatment trials are needed to identify optimal treatment recommendations.

Linking the design of treatment strategies with probability of outcome necessitates a CPR with factors that may be amenable to change, and a high specificity with an enhanced probability of the outcome (ie, criteria for ruling in [25,29]). Both the chronic moderate/severe disability (specificity = 94%) and full recovery (specificity = 83%) pathways were highly specific for the present CPR. Sensitivity of the rule to the positive case (chronic moderate/severe disability or full recovery) also contributes information about the degree of accuracy. These were low but reasonable for the current CPR (ie, chronic moderate/severe disability = 44%; full recovery = 48%), implying that utilisation of the CPR in its present form will not identify all individuals who develop chronic moderate/severe disability or those who do fully recover. To address the emerging evidence of possibly detrimental treatment strategies, it is important, however, to minimise false positives, that is, a high specificity is required. Furthermore, application of the proposed CPR provided an enhanced estimated probability of developing chronic moderate/severe disability of 71%, a substantial increase from the estimated 25% indicated in previous research. In addition, meeting the simple criteria of NDI ($\leqslant$ 32%) and age (< 35 years) in the acute phase provided an enhanced estimated probability of full recovery of 71%, an increase from 50%, as indicated in previous research.

To our knowledge, only one CPR has been designed previously to predict outcome from a whiplash injury [18]. The derivation-only study proposed a model with 3 factors associated with the specific location of the collision, presence of upper back pain, and presence of neck pain [18]. Although the sensitivity (91.5%) and specificity (51.4%) were reasonable, the factors considered for the development of this CPR were limited to local demographics, past and present self-report medical symptoms, circumstances surrounding the motor vehicle crash, and impact on work and leisure. To help ensure credibility, appropriate utilisation, and acceptability, methodological standards for the derivation of a CPR recommend inclusion of meaningful and relevant predictor variables [9,14,25]. Accumulated evidence from reviews [21,30,40,46], meta-analyses [21,46], and prospective research reports [4,7,10,20] proposes a biopsychosocial model for recovery from a whiplash injury [4,15,33,37]. The most parsimonious factors associated with predicting delayed recovery following an acute whiplash injury in the current study were age, initial neck disability levels, and the hyperarousal subscale of the PDS, thereby supporting a biopsychosocial model. Importantly, neck pain-related disability and hyperarousal are factors that may be amenable to change and therefore, treatment strategies may be designed to address these.

Higher levels of initial neck pain-related disability have been consistently associated with poor functional recovery from WAD [20,21,30,32,36]. Symptoms of posttraumatic stress disorder are emerging as an important psychological factor in the prediction of recovery from WAD [35,37,38]. Since whiplash injury occurs as a result of a motor vehicle crash, it is not surprising that most, if not all, individuals experiencing a whiplash injury display initial psychological distress [35–37]. In some individuals, this distress subsides with decreasing symptoms [38]; however, individuals who develop a chronic disability continue to express psychological distress [38]. There is some speculation that early intensive treatment may augment factors associated with posttraumatic stress and thereby result in poorer outcomes [28]. Our results indicated that high levels of hyperarousal symptoms in the acute phase were significantly associated with ongoing disability; however, an absence of hyperarousal symptoms did not appear to significantly influence prediction of full recovery. Further research is needed to explore the relationship between posttraumatic stress and recovery from whiplash.

Although age is not amenable to change, and age may be a proxy factor for perhaps natural musculoskeletal recovery [21], it appears important to consider age in the prediction of recovery from WAD. Several previous prospective studies [10,32,37] found older age to be related to poor recovery from WAD. Two systematic reviews with meta-analyses [21,46], however, concluded that age did not appear to be related to poor outcome from WAD. Both reviews recognised that the heterogeneity in the definition of "older age" may have contributed to the lack of significance as a predictive factor. Younger age (< 35 years) was also a factor in the proposed CPR-full recovery. Furthermore, similar to previous studies [7,8], dropouts in the present study were significantly younger than subjects who completed the 12-month protocol, and it may be that dropouts fail to continue because they do not have a chronic problem. Consequently, it may be that younger age is a stronger factor in predicting likelihood of full recovery. Further research is needed to investigate this possibility.

Clear recommendations exist for the development of a CPR: derivation, followed by validation, and finally, impact analysis [25]. Very few published CPRs have undergone impact analyses [29], and the majority of published CPRs for musculoskeletal pain are derivation-only studies [1]. The process undertaken to develop the proposed clinical prediction rule was based on methods to maximise study quality [17,22] and recommended standards for CPR derivation and validation [14,25]. These recommendations help guide the development of CPRs so that clinicians are better able to interpret the results and understand the strengths and weaknesses of the proposed CPR [14,25,27]. For example, to assess

methodological quality, Kuijpers and colleagues [22] developed an 18-question checklist that considers internal validity, generalisability, and precision. A score of 60% (eg, ⩾ 10 criteria met) or greater indicates a high-quality study [22]. The present study met the recommendations for a high-quality study with a score of 94% (17 criteria met). The only criterion that was not met was that the total number of participants at completion should be ⩾ 80% of the initial cohort; the completion rate for the present study was very close at 79%.

While the proposed clinical prediction rule is deemed plausible, there were several limitations to the present study. Firstly, other psychological factors such as catastrophising [40], recovery expectations [6], and self-efficacy [48] have been shown to be associated with poor recovery in WAD. Further research is needed to evaluate the influence of these and other psychological symptom clusters on recovery from whiplash. Secondly, the CPR needs to undergo a validation study and following this, research is needed to determine the acceptability of the proposed CPR by practitioners and assess the impact of inclusion in practice. Finally, additional research is also needed to examine the efficacy of linking treatment strategies with predicted prognosis.

## Conflict of interest statement

The authors have no conflict of interest related to this work.

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