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Original article

Reliability, measurement error and construct validity of four proprioceptive tests in patients with chronic idiopathic neck pain☆

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ABSTRACT

Background: There are different neck proprioceptive tests that are believed to be targeting different sources of proprioceptive information.
Objective: To assess the reliability, measurement error, discriminative validity and convergent validity of four proprioceptive tests (head repositioning to neutral – HRNT, torsion test - TT, head repositioning to 30° rotation – HR30T and figure of eight relocation test – F8T) in individuals with chronic idiopathic neck pain and asymptomatic individuals. A secondary aim was to assess the divergent validity of these tests by correlating them against measures of disability, pain catastrophizing and fear of movement.
Design: – Reliability and validity study.
Methods: – 66 participants (33 with chronic neck pain and 33 asymptomatic) were assessed using four proprioceptive tests, pain catastrophizing scale, neck disability index, tampa scale of kinesiophobia and visual analogue scale.
Results: Proprioceptive tests showed moderate to good reliability (ICC: 0.55 to 0.85), but high measurement error. All tests but the HR30T were significantly different between participants with and without neck pain ($p < 0.05$). Only the HRNT showed an area under the curve above 0.5 (AUC95% CI = 0.51; 0.78, $p \leq 0.042$). Between test correlations ranged between 0.35 and 0.61 and correlations between proprioceptive tests and catastrophizing, fear of movement and disability were, in general, lower than 0.3.
Conclusion: The four proprioceptive tests showed reliability and measurement errors good enough for group comparisons but of limited utility for individual comparisons. They seem to measure related but dissimilar constructs and the HRNT seemed better at discriminating individuals with and without NP and easier to perform in clinical practice.

1. Introduction

The orientation of the head in relation to the trunk and in space requires the use of visual, vestibular and cervical proprioceptive information (Rix and Bagust, 2001; Dugailly et al., 2015; Revel et al., 1991). The deep muscles of the neck are very rich in proprioceptors and seem to play a relevant role in neck position sense (Kulkarni et al., 2001; Boyd-Clark et al., 2002). However, in the presence of neck pain (NP), proprioceptive function may be compromised (Stanton et al., 2016; de Vries et al., 2015) and several potential contributing mechanisms have been proposed: inhibition of the discharge of the gamma motor neuron (Djupsjöbacka et al., 2008; Treleaven et al., 2006); distorted perception of the amount of force generated, with individuals with pain overestimating force production (Proske and Gandevia, 2012; Weerakkody et al., 2003); cortical reorganization and disuse (Rix and Bagust, 2001; Revel et al., 1991). Proprioception is vital for functional joint stability and motor control and impaired proprioception may be associated with changes in muscle recruitment timing, movement control and accuracy (Hillier et al., 2015; Riemann and Lephart, 2002a, 2002b), and, consequently, impaired proprioception may have a role in the maintenance of NP. Previous studies have suggested that impaired proprioception may be more marked in traumatic NP, but it is also present in chronic idiopathic NP (de Vries et al., 2015), which represents a different clinical condition (Bogduk and McGuirk, 2006), is

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Abbreviations

AUC	area under ROC curve
CI	confidence interval
F8T	figure of eight relocation test
HR30T	head repositioning to 30° rotation
HRNT	head repositioning to neutral
ICC	intraclass correlation coefficient
JRE	joint repositioning error
LR	left rotation
MDD	minimal detectable difference
NDI	Neck Disability Index
NP	neck pain
PCS	Pain Catastrophizing Scale
RR	right rotation
SEM	standard error of measurement
SPSS	Statistical Package for the Social Sciences
TSK-13	Tampa Scale of Kinesiophobia, 13-itens
TT	torsion test
VAS	visual analogue scale

more prevalent in the general population (Fejer et al., 2006) and presents more frequently for physiotherapy. Therefore, it is argued that proprioception should be both part of the assessment and a treatment target in patients with chronic idiopathic NP (Jull et al., 2007).

Several different proprioceptive tests have been used in idiopathic chronic NP (de Zoete et al., 2017). The most commonly used is the head to neutral repositioning test (HRNT) (de Zoete et al., 2017). However, it has been argued that by using a simple movement of the neck and a common daily position, this test relies on memory rather than on proprioception (Kristjansson et al., 2003) and that it does not eliminate information from the vestibular system (Stanton et al., 2016; Chen and Treleaven, 2013). Alternative tests attempting to overcome these potential limitations have been suggested. The rotation of the neck from the neutral position to an end position of 30° rotation (HR30T), which is a less commonly adopted position; the torsion test (TT) which involves maintaining the head in a neutral position while rotating the trunk and is believed to eliminate information from the vestibular system (Stanton et al., 2016); or the figure of eight test (F8T), representing a complex pattern of movement (Kristjansson et al., 2003). Previous research comparing the head-to-neutral repositioning test and the torsion test suggests that they measure different constructs (de Zoete et al., 2018). Furthermore, it seems that the ability to discriminate between individuals with and without NP may depend on the test used (Kristjansson et al., 2003). Nevertheless, investigations comparing head-to-head the validity, reliability and measurement error of those four different proprioceptive tests are scarce (Kristjansson et al., 2003; de Zoete et al., 2018) and further studies are needed to inform on the differentiating capabilities of existing tests (de Zoete et al., 2017), particularly of tests that not require expensive equipment and are easy to use in clinical practice. Furthermore, reliability and measurement error are valuable indicators to decide on the quality and clinical usefulness of a test (de Vet et al., 2010) and data on reliability and measurement error for the TT, the HR30T and the F8T in individuals with chronic idiopathic NP are scarce (Kristjansson et al., 2003) or contradictory (Kristjansson et al., 2003; de Vet et al., 2010). From a clinical and research perspective, knowing how different tests compare will inform the decision on which one to choose for a specific situation and aim and whether a combination of more than one test would be needed. Therefore, this work aimed to assess the reliability, measurement error, discriminative validity and convergent validity of four proprioceptive tests (HRNT, TT, HR30T and F8T) in individuals with chronic idiopathic NP and asymptomatic individuals. A secondary aim was to assess the divergent validity of these tests by correlating them against measures of disability, pain catastrophizing and fear of movement.

2. Methods

2.1. Ethical considerations

The study was approved by the Council of Ethics and Deontology of the University of Porto. Before entering the study, participants had to give their written consent.

2.2. Participants

Participants were a convenience sample of both individuals with and without NP recruited between February and April 2018 from a private clinical practice and from the general population, respectively. Chronic NP was defined as pain in the neck region that was not related to any known pathology or disease and was felt at least once a week in the last 3 months (En et al., 2009). The asymptomatic group was required to report no NP in the last 12 months. Participants in both groups were matched for age (± 2 years) and gender. Participants with a history of cervical or head trauma, cervical radiculopathy and/or myelopathy, surgery, inflammatory rheumatic disease, any known disease affecting the nervous system or vestibular system were excluded (Stanton et al., 2016; Misailidou et al., 2010), since these pathologies may affect the variables under analysis in this study.

2.3. Procedures

Participants attended for assessment on two occasions separated by a minimum of 24 h and a maximum of 48 h. Measurements were performed by a physiotherapist with three years of experience. In the first session, participants were assessed for NP, disability, kinesiophobia and catastrophizing and performed four different cervical proprioceptive tests (HRNT; HR30T, TT and the F8T). Scales and questionnaires were applied only in the group with NP and in the first session. In the second session, participants repeated the proprioceptive tests. Instructions were standardized by a written protocol and the order of tests was randomized using an online software (https://www.randomizer.org) but was the same in both sessions.

NP intensity at the time of data collection was assessed using the visual analogue scale (VAS), which has good psychometric properties (Carlsson, 1983). In addition, pain frequency ("How often did you feel pain in the last week?"), pain duration ("How long have you had pain in the neck area?") and pain location were also assessed. Pain location was assessed using a body chart and then categorized as: upper NP or lower NP if located above or below an imaginary transverse line through C4 (Misailidou et al., 2010) and as pain in the left, right or both.

The Portuguese version of the Neck Disability Index (NDI), which showed good internal consistency (Cronbach $\alpha = 0.77$) and high test-retest reliability (intraclass correlation coefficient - ICC = 0.95), was used (Pereira et al., 2015). The maximum NDI score is 50 and higher scores are indicative of higher disability.

The Portuguese version of the Tampa Scale of Kinesiophobia, 13-itens (TSK-13), was used to assess fear of movement. This version has been shown to have acceptable internal consistency (Cronbach $\alpha = 0.66$) and high levels of reliability (ICC = 0.99) (Cordeiro et al., 2013). The total score varies between 13 and 52, with higher scores indicating higher fear of movement.

Catastrophizing was assessed using the Portuguese version of the Pain Catastrophizing Scale (PCS), which showed good internal consistency (Cronbach $\alpha = 0.91$) (Jácome and Cruz, 2004). This instrument consists of 13 statements and total score varies between 0 and 52, where higher values correspond to higher levels of catastrophic

thoughts (Sullivan et al., 2004).

2.4. Proprioceptive tests

A laser pointer was placed on the top of a cycling helmet (0.312 kg) (Rix and Bagust, 2001) for all the 4 tests – Fig. 1. Participants were blindfolded with a sleeping mask, seated in a standard chair placed at a distance from the target (an A3 sheet of millimetric paper on a wall) of 90 cm. Before starting the tests, participants remained relaxed and held their head in the neutral position for 2–3 s in order to record the point where laser light struck the sheet of paper (Lee et al., 2006). The neutral position corresponded to the participant looking straight ahead and was the starting position for all tests except the HR30T. Before data collection, and as familiarization procedures, participants performed i) one trial without being blindfolded and ii) the whole protocol consisting of the four tests followed by 5 min of rest in both sessions. For each of the four proprioceptive tests, six repetitions for right and six repetitions for left rotations were performed to increase test-retest reliability as recommended by Swait et al. (2007). The starting position as well as right and left repositioning for all repetitions were marked in the millimetric sheet of paper with a pen of different color. Then, the joint repositioning error (JRE), was calculated in degrees for each repetition, based on the values of the absolute distance between the initial/reference position and the final position in centimeters (absolute error regardless of direction measured in two-dimensions (Clark et al., 2015)) as marked in the millimetric paper, and the distance of the participant to the target as: $\theta = tang^{-1}\frac{JRE}{90}$ (Roren et al., 2009). Between each repetition, the examiner manually adjusted the participant's head to match the initial position, no feedback was given on the accuracy of the movement (Kristjansson et al., 2003) and a rest period of 1 min was given between tests (Lee et al., 2006).

The HRNT was conducted in line with Revel et al. (1991). Participants were asked to turn their heads completely to the left and return to the initial neutral position. The TT was performed as described by Chen & Treleaven, 2013; the researcher helped participants to maintain their head in a neutral position and then asked them to completely turn the trunk and return to the initial neutral position. In this test, a second laser beam was fixed at the level of the sternum and the JRE was calculated for the trunk. The HR30T was performed as described by Loudon et al. (1996); the researcher positioned the participant's head at 30° with the aid of a universal goniometer and marked this point on the target; subsequently, the participant moved the head to the neutral position and then back to 30° of rotation. To define the 30° of rotation, the axis of the goniometer was placed over the center of the cranial aspect of the head, the fixed arm was parallel to an imaginary line between the two acromial processes and the mobile arm was aligned by the tip of the nose. In this test two more sheets of A3 paper were placed to register the 30° rotation position to the left and right. The F8T test was developed to evaluate repositioning accuracy after performing a complex motion (Kristjansson et al., 2003). Participants were asked to perform a movement with their head describing a figure of eight starting from a neutral position of the head, which corresponded to the midpoint of the eight. Before being blindfolded for measurements, participants performed three practice trials with their eyes opened. As a guide, a 10-cm diameter diagram of each circle of the figure of an eight lying sideways (∞) was fixed 90 cm away from the participant.

2.5. Data analysis

The Statistical Package for the Social Sciences (SPSS) version 24.0 for Windows was used in the statistical analysis. Descriptive statistics were used to describe the sample and the variables of interest. Mean and standard deviation were used for continuous variables and counting and proportion for categorical variables. Data normality was assessed using the Kolmogorov-Smirnov test, and most of the variables followed a normal distribution. The intraclass correlation coefficient (ICC), two-way random and absolute agreement (2,1), and its 95% confidence interval were used for reliability analysis (for both within and between session intra-rater reliability) and interpreted as poor (ICC < 0.50), moderate (ICC = 0.50–0.75), good (ICC = 0.75–0.90) or excellent (ICC ≥ 0.90) (Portney and Watkins, 2000). Measurement error was assessed through the standard error of measurement (SEM) and the minimal detectable difference (MDD) as: SEM = Standard deviation * √(1-ICC) and $MDD_{95\%}$ = SEM* 1.96 * √2 (Donoghue and Stokes, 2009). To explore differences in the JRE between sessions for the same test, a paired *t*-test or a Wilcoxon test were used depending on whether data had a normal distribution or not. For discriminative validity (i.e. comparison between participants with and without NP) we used data from session 1 and a Student's t-test (data with normal distribution) or a Mann Whitney *U* test. In addition, the area under ROC curves was also calculated to determine the accuracy of proprioceptive tests discriminating individuals with and without NP. To assess convergent validity among the four proprioceptive tests and divergent validity between the proprioceptive tests and the measures of disability, pain catastrophizing and fear of movement we used a Pearson's correlation coefficient (continuous variables) or a Spearman's correlation coefficient (ordinal variables). Based on previous studies we defined the following hypothesis: i) the HNRT would be better at discriminating between individuals with and without NP (Stanton et al., 2016); ii) the four tests, despite potential differences are all considered to be tests of sensorimotor control (de Zoete et al., 2018), and would show correlations among them between 0.3 and 0.5 as expected for correlations between instruments measuring related but dissimilar constructs (Prinsen et al., 2018); iii) the correlations between the four proprioceptive tests and measures of disability, catastrophizing and fear of movement would be < 0.3 as suggested by previous research (Amiri et al., 2077; Ghamkhar et al., 2018) and expected for correlations between instruments measuring unrelated constructs (Prinsen et al., 2018). The significance level was set at $p < 0.05$.

3. Results

3.1. Sample characteristics

The sample consisted of 66 participants, divided into two subgroups, one group with NP (n = 33) and the other without NP (n = 33). In both groups, 26 (78.8%) participants were females and 7 (21.2%) were males. Mean (± SD) age was 43.6 (± 13.3) years for the pain group and 43.5 (± 14.1) years for the asymptomatic group (Table 1).

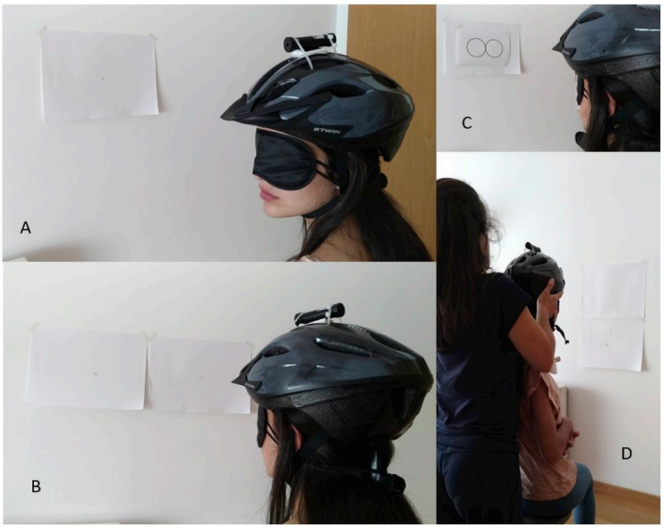

Fig. 1. Proprioceptive tests: A) head repositioning to neutral; B) head repositioning to 30° rotation; C) figure-of-eight relocation test and D) torsion test.

Table 1
Sample characteristics.

Characteristics		Neck Pain (n = 33)	Asymptomatic (n = 33)	p
Gender	Female, n (%)	26 (78.8)	26 (78.8)	
	Male, n (%)	7 (21.2)	7 (21.2)	
Age, y	Mean ± SD	43.6 ± 13.3	43.5 ± 14.1	0.971
Weight, kg	Mean ± SD	69.8 ± 12.9	64.9 ± 9.7	0.085
Height, cm	Mean ± SD	162.6 ± 6.8	161.4 ± 7.6	0.506
Headache/dizziness (yes)		19 (57.6)	6 (18.2)	0.001
Pain in at other body sites (yes)		29 (87.9)	16 (48.5)	0.001
	Thoracic	20 (60.6)	8 (24.2)	0.003
	Lumbar	25 (75.8)	10 (30.3)	0.000
	Sacral	11 (33.3)	1 (3.0)	0.001
	Lower limbs	13 (39.4)	5 (15.2)	0.027
	Upper limbs	22 (66.7)	8 (24.2)	0.001
NP duration n (%)	> 3 mo and < 6 mo	2 (6.1)		
	≥ 6 mo and < 1 y	6 (18.2)		
	≥ 1 y and < 2 y	10 (30.3)		
	≥ 2 y and < 5 y	7 (21.2)		
	≥ 5 y	8 (24.2)		
NP frequency n (%)	Once a week	2 (6.1)		
	2-3 times/wk	15 (45.5)		
	> 2–3 times/wk	6 (18.2)		
	Always	10 (30.3)		
NP location – upper/lower NP n (%)	Upper NP	3 (9.1)		
	Lower NP	18 (54.5)		
	Upper & lower NP	12 (36.4)		
NP location – left/right n (%)	Left side NP	3 (4.5)		
	Right side NP	8 (12.1)		
	Both sides	22 (33.3)		
NP intensity (0–10)	Mean ± SD	4.8 ± 2.0		
NDI (0–50)	Mean ± SD	12.9 ± 5.3		
TSK (13–52)	Mean ± SD	31.5 ± 6.7		
PCS (0–52)	Mean ± SD	23.6 ± 10.6		

y = year; Kg = kilograms; cm = centimeters; SD = standard deviation; mo = month; NDI = Neck Disability Index; PCS = Pain Catastrophizing Scale; TSK = Tampa Scale of Kinesiophobia; SD = standard deviation.

There were no significant differences between groups for age, weight and height ($p > 0.05$). NP characteristics are also presented in Table 1.

3.2. Intra-rater reliability and measurement error

The ICC for within session intra-rater reliability ranged from moderate to excellent in both the group of participants with NP (ICC between 0.73 and 0.93) and the asymptomatic group (ICC between 0.75 and 0.93; Table 2). All tests showed good to excellent reliability except the HR30T in the NP group, which showed moderate to good reliability. $MDD_{95\%}$ varied between 1.77° and 3.63° in the NP group and between 1.36° and 3.35° in the asymptomatic group. Similar values were obtained for session 2 (Appendix 1).

The ICC for between session intra-rater reliability (Table 3) ranged from moderate to good for both the group of participants with NP (ICC between 0.58 and 0.85) and the asymptomatic group (ICC between 0.55 and 0.83). The HRNT and the F8T showed moderate to good reliability in both groups and the TT and the HR30T showed moderate reliability. $MDD_{95\%}$ varied between 2.77° and 4.55° in the NP group and between 2.0° and 3.10° in the asymptomatic group.

ICC, SEM and MDD were also calculated for the whole sample (n = 66; Appendix 2).

Table 2
Within session intra-rater reliability (session 1).

		Neck Pain (n = 33)			Asymptomatic (n = 33)		
		ICC (95% CI)	SEM (°)	$MDD_{95\%}$ (°)	ICC (95% CI)	SEM (°)	$MDD_{95\%}$ (°)
HRNT (°)	LR	0.93 (0.88–0.96)	1.0	2.7	0.89 (0.82–0.94)	0.9	2.4
	RR	0.90 (0.84–0.95)	1.0	2.8	0.79 (0.65–0.88)	1.1	3.1
TT (°)	LR	0.88 (0.81–0.94)	0.7	2.0	0.75 (0.60–0.86)	0.8	2.2
	RR	0.90 (0.84–0.94)	0.6	1.8	0.87 (0.79–0.93)	0.5	1.4
HR30T (°)	LR	0.73 (0.56–0.85)	1.3	3.6	0.86 (0.76–0.92)	0.9	2.6
	RR	0.79 (0.65–0.88)	1.3	3.6	0.78 (0.63–0.88)	1.2	3.4
F8T (°)	LR	0.89 (0.82–0.94)	1.0	2.7	0.83 (0.73–0.91)	1.0	2.7
	RR	0.93 (0.88–0.96)	1.1	3.0	0.93 (0.88–0.96)	0.8	2.1

° = degrees; ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDD = minimal detectable difference; LR – left rotation; RR – right rotation; HRNT - head repositioning to neutral; TT = torsion test; HR30T = head repositioning to 30° rotation; F8T = figure-of-eight relocation test.

Table 3
Between sessions intra-rater reliability.

		Neck pain (n = 33)					Asymptomatic (n = 33)				
		Mean ± SD	p*	ICC (95% CI)	SEM (°)	$MDD_{95\%}$ (°)	Mean ± SD	P*	ICC (95% CI)	SEM (°)	$MDD_{95\%}$ (°)
HRNT (°)	LR	S1: 5.0 ± 3.3 S2: 4.9 ± 2.8	0.936	0.85 (0.69–0.92)	1.2	3.2	S1: 3.9 ± 2.1 S2: 3.6 ± 2.1	0.117	0.80 (0.59–0.90)	0.9	2.6
	RR	S1: 5.1 ± 2.7 S2: 4.4 ± 2.0	0.085	0.61 (0.20–0.81)	1.4	4.0	S1: 3.8 ± 1.7 S2: 3.2 ± 1.4	0.024	0.75 (0.49–0.88)	0.8	2.2
TT (°)	LR	S1: 3.3 ± 1.7 S2: 3.3 ± 1.4	0.897	0.58 (0.14–0.79)	1.0	2.8	S1: 2.5 ± 1.1 S2: 2.0 ± 1.2	0.028	0.59 (0.18–0.80)	0.7	2.1
	RR	S1: 3.4 ± 1.7 S2: 3.2 ± 1.4	0.936	0.71 (0.40–0.85)	1.6	4.6	S1: 2.7 ± 1.2 S2: 2.2 ± 1.04	0.021	0.57 (0.13–0.79)	0.7	2.0
HR30T (°)	LR	S1: 4.5 ± 1.7 S2: 4.3 ± 2.5	0.609	0.70 (0.38–0.85)	1.2	3.2	S1: 3.8 ± 2.0 S2: 3.3 ± 1.5	0.348	0.76 (0.50–0.88)	0.8	2.3
	RR	S1: 4.6 ± 2.0 S2: 4.7 ± 3.2	0.208	0.67 (0.33–0.84)	1.5	4.1	S1: 3.8 ± 1.8 S2: 3.3 ± 1.5	0.162	0.55 (0.09–0.78)	1.1	3.1
F8T (°)	LR	S1: 5.0 ± 2.3 S2: 4.7 ± 2.0	0.393	0.66 (0.32–0.83)	1.3	3.5	S1: 3.9 ± 1.8 S2: 3.4 ± 2.1	0.034	0.83 (0.66–0.92)	0.8	2.2
	RR	S1: 5.7 ± 3.6 S2: 5.1 ± 3.3	0.176	0.85 (0.70–0.93)	1.3	3.7	S1: 4.5 ± 2.5 S2: 3.9 ± 2.4	0.096	0.80 (0.60–0.90)	1.1	3.0

P values are for comparisons between session 1 and session 2 using a repeated measures *t*-test or a Wilcoxon signed-rank test depending on whether data were normally distributed or not; ° = degrees; ICC = intraclass correlation coefficient; SEM = standard error of measurement; MDD = minimal detectable difference; LR – left rotation; RR – right rotation; HRNT - head repositioning to neutral; TT = torsion test; HR30T = head repositioning to 30° rotation; F8T = figure-of-eight relocation test; S1 = session 1; S2 = session 2; SD = standard deviation.

Table 4
– Between group differences (data from session 1).

		Neck pain (n = 33)	Asymptomatic (n = 33)	p
		Mean ± SD	Mean ± SD	
HRNT (°)	LR	5.01 ± 3.25	3.87 ± 2.10	0.042*
	RR	5.12 ± 2.67	3.79 ± 1.71	0.019*
TT (°)	LR	3.33 ± 1.65	2.50 ± 1.09	0.033*
	RR	3.37 ± 1.65	2.72 ± 1.16	0.135
HR30T (°)	LR	4.50 ± 1.66	3.75 ± 1.93	0.092
	RR	4.57 ± 2.00	3.75 ± 1.80	0.084
F8T (°)	LR	4.99 ± 2.34	3.94 ± 1.80	0.045*
	RR	5.74 ± 3.60	4.52 ± 2.49	0.153

*p < 0.05; LF – left rotation; RR – right rotation; HRNT - head repositioning to neutral; TT = torsion test; HR30T = head repositioning to 30° rotation; F8T = figure-of-eight relocation test; p values are from t-tests or Mann Whitney U tests depending on whether data had a normal distribution or not.

Table 5
Between-test correlation for both participants with neck pain and asymptomatic participants (session 1; n = 66).

	HRNT	TT	HR30T	F8T	HRNT	TT	HR30T	F8T
	Left vs. Left				Right vs. right			
HRNT	1	0.37**	0.22	0.35**	1	0.20	0.57**	0.61**
TT	–	1	0.31*	0.24	–	1	0.12	0.29*
HR30T	–	–	1	0.56**	–	–	1	0.55**
F8T	–	–	–	1	–	–	–	1

*p < 0.05; **p < 0.01; HRNT - head repositioning to neutral; TT = torsion test; HR30T = head repositioning to 30° rotation; F8T = figure-of-eight relocation test; For the TT, trunk rotations to the right and left were compared against head rotations to the left and right, respectively, in order to compare rotations of the neck for the same side.

3.3. Discriminative validity

All tests but the HR30T were significantly different (higher in the NP group) between participants with and without NP for at least one rotation movement (p < 0.05) (Table 4). Only the HRNT showed an AUC and respective 95% confidence interval above 0.5 for both right and left rotations ($AUC_{95\%}$ = 0.51; 0.78, p ≤ 0.042). Please see Appendix 3.

Table 6
Correlation between disability, fear of movement, and catastrophizing for participants with neck pain (session 1).

		NDI	TSK	PCS
HRNT	LR	−0.11	−0.15	−0.24
	RR	0.03	−0.13	−0.37*
TT	LR	0.30	0.23	−0.03
	RR	0.56**	0.23	0.09
HR30T	LR	0.01	−0.03	−0.07
	RR	−0.14	−0.49**	−0.20
F8T	LR	0.17	0.20	0.12
	RR	0.11	−0.19	−0.28

*p < 0.05; **p < 0.01; HRNT - head repositioning to neutral; TT = torsion test; HR30T = head repositioning to 30° rotation; F8T = figure-of-eight relocation test; LR = left rotation; RR = right rotation; NDI = Neck Disability Index; PCS = Pain Catastrophizing Scale; TSK = Tampa Scale of Kinesiophobia.

3.4. Convergent validity

The F8T showed correlations above 0.3 with the HR30T (r = 0.56 for left rotation and r = 0.55 for right rotation) and the HRNT (r = 0.35 for left rotation and r = 0.61 for right rotation). In addition, the HRNT showed correlations higher than 0.3 with the TT for left rotation (r = 0.31) and with the HR30T for right rotation (r = 0.57) (Table 5). The TT showed correlations with the other three tests that were, in general below 0.3. Similar results were found in session 2 (Appendix 4).

3.5. Divergent validity

Most correlation coefficients between proprioceptive tests and disability, fear of movement and catastrophizing were lower than 0.3 (Table 6).

4. Discussion

This study assessed the reliability, measurement error, discriminative validity and convergent validity of four proprioceptive tests (HRNT, TT, HR30T and F8T) in individuals with chronic idiopathic NP and asymptomatic individuals. In addition, it assessed the divergent validity of these tests by correlating them against measures of disability, pain catastrophizing and fear of movement.

4.1. Reliability and measurement error

The HRNT is the most commonly reported in the literature (Stanton et al., 2016) and our study results regarding its reliability are similar to previous studies (Roren et al., 2009; Alahmari et al., 2017; Pinsault et al., 2008). We were able to find only one study assessing the reliability of the TT and F8T, with ICC values between 0.72 and 0.74 for the first and of 0.67 for the latter (Kristjansson et al., 2001). The HR30T was shown to have excellent reliability in patients with whiplash-associated NP with an ICC of 0.98 or higher (Loudon et al., 1996) while Kristjansson et al. (2001) reported an ICC suggesting moderate reliability (0.69–0.74) in asymptomatic participants. Nevertheless, considering that an ICC above 0.70 is appropriate for group comparisons and of 0.9 or above for individuals comparisons (Aaronson et al., 2002), the present study ICC and respective 95% CI values suggest that the four tests can be used to compare groups but have limited value to assess the progression of a patient. Furthermore, mean JRE in the group of patients with NP varied between approximately 3° to 5° and the minimal amount of change in a patient's total score that can be considered a real change (MDD) varied between approximately 2° to 4° degrees. This represents an error of at least 40% (considering a mean JRE of 5° and a MDD of 2°) and means that the JRE would need to be as small as 1° after the intervention, which is a JRE smaller than that found in asymptomatic participants. These findings further highlight the limited utility of the proprioceptive tests to assess the impact of treatment on individual proprioception.

4.2. Discriminative, convergent and divergent validity

Only the HRNT was able to identify significant between group differences for JRE both after left and right rotations and when considering the 95% CI for the area under the curve, only the HRNT showed values for JPE both after right and left rotations above 0.50. These results suggest, as was hypothesized, that this test is better than the other three tests at discriminating individuals with and without idiopathic NP. Furthermore, our experience running the four tests suggests that this is also the easiest test to implement in clinical practice.

Despite the fact that all the four tests are assumed to assess neck proprioception, correlations among them were, in general, between 0.3 and 0.5 or close to this limit, indicating that tests are measuring related but dissimilar constructs (Prinsen et al., 2018). These findings seem to support the assumption that the different tests may rely on different sources of information. It has been argued that the HRNT is influenced by neck proprioception and the vestibular system (Stanton et al., 2016), while the TT limits the influence of the vestibular system emphasizing the contribution of the neck proprioceptive system (Chen and Treleaven, 2013). The HRNT uses the complete rotation range of motion with articular and muscular contributions of both the upper and lower neck and deep and superficial muscles (Kapandji, 2008), while the HR30T uses only 30° of rotation occurring at the upper cervical spine and activating the deep muscles (Kapandji, 2008). The F8T requires a complex pattern of movement that occurs at the upper cervical spine (Kristjansson et al., 2001) and is believed to also assess the performance of the dynamic feedback system involved in the control, coordination and execution of movement (Stanton et al., 2016). The different joint and muscular contribution as well as the potential contribution of different systems may explain the results found for between test correlations. A recent study correlating the HRNT and the TT found similar results (r = 0.37) and concluded that each of these tests is assessing different subsystems of sensorimotor control (de Zoete et al., 2018).

Correlation coefficients between the four tests and measures of disability, catastrophizing and fear of movement were, in general, below 0.3, in line with previous research (Amiri et al., 2077; Ghamkhar et al., 2018) and as expected for correlations between instruments measuring unrelated constructs (Prinsen et al., 2018). These results suggest that these factors had a limited impact on JRE. Contrary to what would be expected, the HR30T and the HRNT showed one correlation each that was ≤-0.3, suggesting that higher catastrophizing and fear of movement were associated with smaller JRE. These results are consistent with the findings of Lee et al. (2005). However, the reasons for this inverse association are unclear. It is possible that participants with higher levels of fear of movement and catastrophizing have increased their attention to movement due to fear of increasing pain or that they have performed less rotation in the HRTN (Dugailly et al., 2015).

Interestingly, there was a significant decrease in JRE in the TT and HRTN (right rotation) from session 1 to session 2 in the asymptomatic group, but not in the group of participants with neck pain. This finding could suggest a lower ability to learn the repositioning task in the presence of neck pain, which might be due to pain interference with neuroplasticity and motor learning (Boudreau et al., 2010). It has already been shown that patients with chronic tension-type headache showed significantly less motor learning than asymptomatic individuals (Vallence et al., 2012).

4.3. Study limitations

The investigator collecting data was not blind to whether participants had NP. Test velocity was self-selected by each individual and was not assessed. However, this is unlikely to have affected results as natural self-selected neck motion speeds seem to increase accuracy (Dugailly et al., 2015). Participants performed 54 trials in each session and, conceivably, fatigue and decreased concentration may have impacted results. We did not assess inter-rater reliability, which usually shows lower ICC and higher measurement error than intra-rater reliability (Weir, 2005). However, in clinical practice repeated measurements are usually taken by the same therapists. The time delay between measurements may be short compared to within-subject measurements taken in clinical practice. A short time period between measurements aimed to minimize changes in the participants condition. The limited number of participants with unilateral pain on the same side, precluded us from exploring whether JRE differs between the painful and the non-painful sides. It is unclear whether this impacted the between group comparison and future studies could explore whether such a difference exists.

5. Conclusion

The HRNT, the TT, the HR30T and the F8T showed reliability and measurement errors good enough for group comparisons but of limited utility for individual comparisons. This raises the question as to whether there are other tests that are both easy to implement in clinical practice and sensitive to individual changes. Tests measured related but different constructs and the HRNT seemed to be slightly better at discriminating individuals with and without NP and easier to perform in clinical practice.

Conflicts of interest

Authors declare no conflicts of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.msksp.2019.07.010.

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