**TITLE**: Determining the reliability of a custom built seated stadiometry set-up for measuring spinal height in participants with chronic low back pain

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**Abstract**

Indirect measurement of disc hydration can be obtained through measures of spinal height using stadiometry. However, specialised stadiometers for this are often custom-built and expensive. Generic wall-mounted stadiometers alternatively are common in clinics and laboratories. This study examined the reliability of a custom set-up utilising a wall-mounted stadiometer for measurement of spinal height using custom built wall mounted postural rods. Twelve participants with non-specific chronic low back pain (CLBP; females n = 5, males n = 7) underwent measurement of spinal height on three separate consecutive days at the same time of day where 10 measurements were taken at 20 second intervals. Comparisons were made using repeated measures analysis of variance for 'trial' and 'gender'. There were no significant effects by trial or interaction effects of trial x gender. Intra-individual absolute standard error of measurement (SEM) was calculated for spinal height using the first of the 10 measures, the average of 10 measures, the total shrinkage, and the rate of shrinkage across the 10 measures examined as the slope of the curve when a linear regression was fitted. SEMs were 3.1mm, 2.8mm, 2.6mm and 0.212, respectively. Absence of significant differences between trials and the reported SEMs suggests this custom set-up for measuring spinal height changes is suitable use as an outcome measure in either research or clinical practice in participants with CLBP.

**Key Words:** Disc hydration; Spinal height; Stadiometer; Shrinkage

## 1.0 Introduction

Chronic low back pain (CLBP) is a highly prevalent condition (WHO, 1998; ONS, 2000; Waddell & Burton. 2000; Walker et al. 2000; NICE, 2009) representing an enormous economic cost worldwide (Van Tulder et al., 1995; Guo et al., 1999; Maniadakis & Gray, 2000; Ekman et al., 2001; Waddell et al., 2002; Stewart et al., 2003; Ricci et al., 2006; Katz, 2006; NICE, 2009; Freburger et al., 2009). CLBP is a multifactorial condition with a variety of associated symptoms (National Research Council, 1998; National Research Council & Institute of Medicine, 2001), abnormalities in the intervertebral discs being a common association, and also suspected as a potential source of pain in CLBP (Adams and Roughley, 2006; Adams et al., 2010). A frequent disc abnormality and one which is known to be potentially painful when associated with nerve root deformation/displacement is disc herniation (DeLeo & Winkelstein, 2002). Disc herniation is thought to typically occur in younger more hydrated discs (Adams & Muir, 1976; Adams & Hutton, 1985) whereas older degenerated discs are generally characterised by cracks (Goel et al., 1995). However, more recently researchers have shown that degenerated discs with lower osmotic pressures and decreased annular stresses are more likely to enhance the opening of cracks in the anullus and lead to herniation (Wognum et al., 2006). In fact Videmann and colleagues (1995) documented that vertebral body osteophytes are highly associated with end plate irregularity and disc bulging, yet osteophytes are generally accepted as secondary to disc and end plate trauma despite taking years to develop (McGill, 2007). Thus degenerative discs may be at greater risk of herniation.

Loss of disc hydration and disc height is commonly considered indicative of degenerative processes as opposed to being age related (Adams & Roughley, 2006;

Griffith et al., 2007). Disc hydration is often measured via magnetic resonance imaging (MRI; Paajanen et al., 1994), but indirect measurement can be obtained through measures of spinal height using stadiometry (Kourtis et al., 2004). As such, for researchers wishing to examine the effects of potential interventions upon CLBP and associated symptoms such as disc hydration, as well as for clinicians examining changes in their patients, the use of stadiometry may be of value as an outcome measure.

A number of studies have used stadiometry, both standing and seated, to examine the effects of different variables upon spinal height. There is a well-documented effect of time of day (diurnal variation) upon stature (Reilly et al., 1984; Tyrell et al., 1985) similar in both standing and seated stadiometry, suggesting most stature loss comes from the spine (McGill et al., 1996). Using MRI, research confirms a diurnal loss in disc height to support this (Paajanen et al., 1994). Changes in stature have been used to examine the effects of loading patterns upon changes in spinal height also. Resistance type exercise elicits a reduction in spinal height (Wilby et al., 1987; McGill et al., 1996), as do plyometric drop jump and pendulum based exercises (Fowler et al., 1997). Changes in recovery postures, such as lying supine with or without hyperextension, have also been shown to elicit recovery of stature loss from loading (Magnusson et al., 1996; Healey et al., 2004; Kourtis et al., 2004). In turn, recovery of stature has been shown to be associated with recovery of disc height via MRI also (Kourtis et al., 2004).

In addition to indirect determination of disc hydration, shrinkage in stature over time during a measurement trial is a well observed phenomenon also that represents the

deformation in both discs and musculo-ligamentous tissue (Stothart & McGill, 2000). It is often used as a measure of the spinal 'creep' (i.e. change in spinal height over time) that occurs due to its visoelastic properties and may reflect the potential for structures of the spine to experience time related changes in biomechanical stresses (Magnusson et al., 1990; Van Dieen & Toussaint, 1993). Kanlayanaphotporn et al. (2003) have shown that, although measures of spinal creep using seated stadiometry differ between CLBP participants and asymptomatic controls (older CLBP participants showing greater creep), it is a reliable measure in both groups (Kanlayanaphotporn et al., 2002). They reported a standard error of measurement (SEM) of ~1-2 mm using a custom built stadiometer designed to control for participant posture during testing using pressure transducers at various anatomical landmarks (Kanlayanaphotporn et al., 2002). Thus they concluded that a change in shrinkage in excess of 2 mm was needed to confidently state that an applied intervention had been responsible for the observed change.

Use of stadiometers to examine factors relating to spinal height has potentially valuable application in examination of both acute and chronic occupational loading or ergonomic factors that might impart stresses to the spine and increase the risk of injury (McGill et al., 1996). Indeed such measures may offer indirect measurement of the overall robustness of the spine to resist such loading as it has been found there is a correlation between trunk strength and stature loss (Wilby et al., 1987). Methods such as those described by Kanlayanaphotporn et al., (2002; 2003) are arguably quite robust as they are able to control for spinal posture using pressure transducers. However, stadiometers such as this, specifically designed for accurate measurement of stature as an outcome measure, are often expensive or are custom built for purely

research purposes. Alternatively many laboratories and clinical facilities have access to wall mounted stadiometers typically used for measuring standing stature as a participant demographic characteristic. A set of simple wall mounted postural rods were custom produced (Southampton Solent University, Southampton, UK) for use with a wall mounted stadiometer in order to control for posture whilst taking seated measurements. However, in order for custom built apparatus to be considered useful the reliability of the system requires investigation and the determination of measurement error in order to differentiate it from changes as a result of intervention. The value of such a system might be determined further by whether it could reliably detect the typical magnitudes of stature changes seen from conditions investigated in the extant literature (Voss et al., 1990). Indeed the value of stadiometer use in general for ergonomics research has been argued to be dependent primarily upon its reliability (McGill et al., 1996).

The feasibility of this simple custom set-up to be used within a research or clinical setting for examining changes in seated stature or shrinkage has not yet been determined. Thus the present study sought to investigate the between-day reliability of the device through calculation of the SEM of seated stature and shrinkage over consecutive measurements.

## 2.0 Material and Methods

### *2.1 Participants*

Twelve participants (males n = 7, females n = 5) were recruited through posters, group email and word of mouth from Southampton Solent University. Inclusion criteria were as follows: participants had to have suffered from non-specific low back pain for longer

than 12 weeks (Frymoyer, 1980). Exclusion criteria included: acute (not re-occurring) low back injury occurring within the last 12 weeks, pregnancy, evidence of sciatic nerve root compression (sciatica), leg pain radiating to below the knee, paraesthesia (tingling or numbness), current tension sign, lower limb motor deficit, current disc herniation, previous vertebral fractures or other major structural abnormalities. All participants were screened for exclusion criteria by either their General Practitioner or a Chiropractor in the research group and provided written informed consent. The study was approved by the ethics committee at Southampton Solent University and conducted within the Sport Science Laboratories at Southampton Solent University.

*2.2 Equipment*

Participants' standing stature (for demographic purposes) and seated stature (for determination of spinal height) were measured using a wall mounted stadiometer (Holtan Ltd, Crymych, Dyfed). Details of seated stature measures are detailed below. Body mass was measured using scales (SECA, Germany) and Body Mass Index (BMI) calculated. Pain was measured using a 100 mm point visual analogue scale (VAS; Ogon et al. 1996), and disability measured using the revised Oswestry disability index (ODI; Fairbank et al., 1980). A customised wooden seat in addition to custom built wall mounted adjustable postural rods (Figure 1; Southampton Solent University, Southampton) were used with the wall mounted stadiometer for seated stature measurements in order to ensure participants adopted the same posture within the sagittal plane for each retest trial. The back rest of the wooden seat was removed and replaced with a short solid wooden backboard for positioning of the sacral crest and a similar wooden board placed across the rear of the seat's legs to position and secure it against the foot board of the wall mounted stadiometer. The placement of the

postural rods mounted to the wall was noted as the vertical distance measured from the floor to the top of the mount and was also traced as a line on the wall with the participants ID noted next to it. This was to ensure that the vertical position of the postural rods was the same for each test. The horizontal distance of the postural rods was ensured by measuring and recording the horizontal distance of the rod from its base to the left most insertion of the rod clamp. Spirit level vials were attached to each of the postural rods also to ensure that the rods themselves were level in the coronal plane when setting up and taking measurements. Figure 1 also shows a schematic depiction of the set-up for measurement of seated stadiometry.

*2.3 Testing*

All measurements were completed at the same time of day and participants were instructed to avoid heavy lifting for at least two days prior to testing (McGill et al., 1996). Three measurement sessions over three consecutive days were conducted at the same time of day in order to calculate the SEM for each participant. In order to normalise spine height prior to measurement the participant was instructed to lie in the supine position for 10 minutes with his or her hands resting on the stomach, head in a neutral position and supported by a pillow, and legs uncrossed with a pillow under the knees for support, as per the standard procedures used in the extant literature (Magnusson et al., 1996; Stothart & McGill, 2000; Rodacki et al., 2001; Kanlayanaphotporn et al., 2002; Rodacki et al., 2003). A custom set-up (See Figure 2) was used in combination with the wall mounted stadiometer used for standing measurements. Once 10 minutes elapsed participants were seated in the stadiometer setup with their sacral crest against the rear board of the seat, hip, knee and ankle angles at $90^{o}$, and arms rested comfortably on a pillow across their lap. A line traced

along the centre of the wooden seat was used to guide the participants in sitting centred when moving into the seat. The participants' feet were supported by mats if necessary to ensure hip, knee and ankle angles were at 90$^{o}$ with the number of mats used recorded and used during each test. Five anatomical points were identified and custom built adjustable rods were used to note the position of these for repeated testing (Healey et al., 2011). The points identified were: 1) the most posterior distension of the head; 2) the deepest point of the cervical lordosis; 3) the most prominent point of the thoracic kyphosis; 4) the deepest point of the lumbar lordosis; 5) the buttocks at the sacral crest (against the seat backboard). Control of these points (by noting during initial testing and replicating throughout further testing the vertical, horizontal and coronal position of the postural rods) ensured that participants adopted the same posture during all testing. After participants were seated in the stadiometer their heads were aligned in the Frankfurt plane (i.e. the lower border of the eye socket and the upper border of the ear opening formed a horizontal parallel line with the floor) through visual inspection to control their position and they were instructed to breathe in deeply maintaining their posture. They were instructed to hold their breath for 2-3 seconds whilst the head platform of the stadiometer was lowered until it made contact with the top of the head and measurement was taken. The testing was conducted by the lead researcher; however, measurements were recorded by a research assistant and the results not disclosed to the primary investigator until both pre and post data were collected in order to avoid investigator bias. The measurement dial on the stadiometer was obscured from the researchers' view during testing. Ten repeated measurements were taken as close as possible to every 20 seconds over a period of ~3 - 3.5 minutes with the participant remaining in the stadiometer between measurements (Stothart & McGill, 2000).

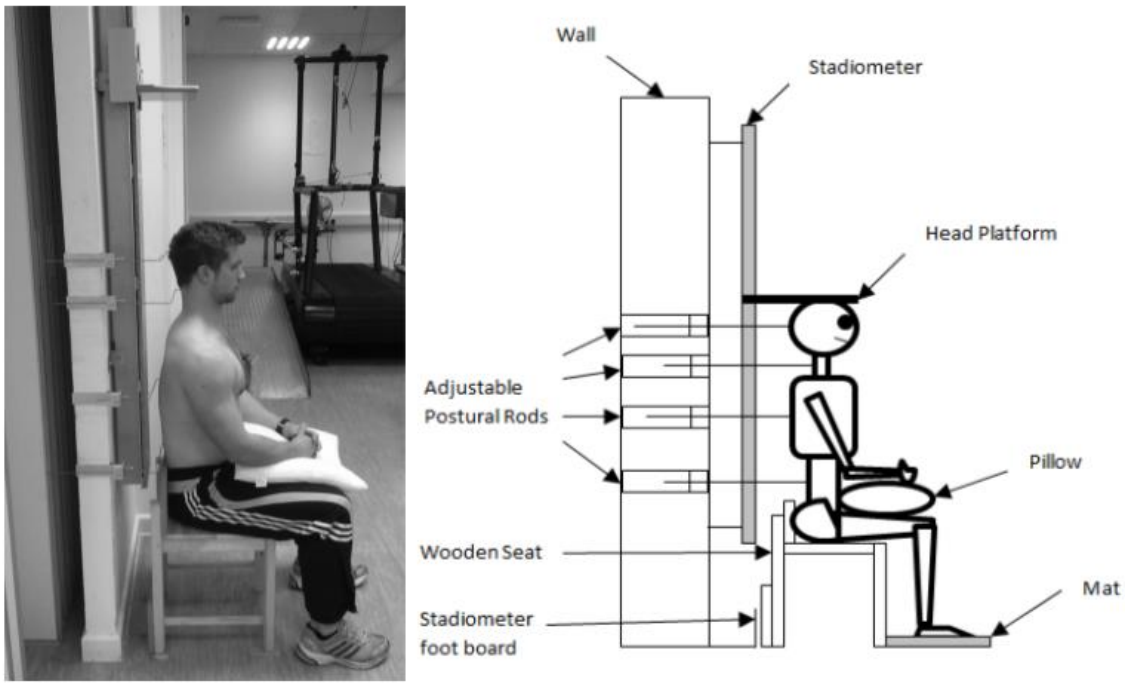


Figure 2. Schematic of seated stadiometry setup.

*2.4 Data Analysis*

Spinal height was calculated by subtracting the seat height (445 mm) from the stature recorded during seated stadiometry measurement. Intra-individual absolute SEM was calculated among the 3 seated stadiometry measurement trials for both spinal height for the first measurement of each trial, average spinal height across the 10 measurements, total shrinkage defined as the difference between the last and first of the 10 measurements (i.e. a negative value represented loss of spinal height), and rate of shrinkage as the slope of the curve fitted using a linear regression model for time and spinal height (a higher value indicating a steeper slope and greater rate of shrinkage). Outcomes were examined for within trial effects and by gender using a 3x2 repeated measures analysis of variance (ANOVA) for the factors ‘trial’ and ‘gender’. SEM was used to reflect the variation of an individual’s measured values

upon repeated testing (Hopkins, 2000) in order to determine the minimum required observable change in repeated measures to be confident an intervention was responsible. First the standard deviation across the 3 measurement trials for all volunteers was determined, this was then squared and the absolute SEM calculated as the following equation (Perini et al., 2005):

$$\text{Absolute SEM} = \sqrt{\frac{\sum \sigma_i^2}{2n}} \qquad \text{Equation 1.}$$

Where:

$\sum \sigma^2$= summation of standard deviations squared

*n* = number of participants measured

*i* = number of standard deviations

Calculations were performed using Microsoft Office Excel 2013 (Microsoft Corporation, Redmond, WA, USA) and statistical analysis performed using IBM SPSS Statistics for Windows (version 20; IBM Corp., Portsmouth, Hampshire, UK) and $p \leq .05$ set as the limit for statistical significance.

## 3.0 Results

Participant demographic characteristics are shown in table 1. Participants' spinal height for 1st measurement and average across 10 measurements, in addition to total and rate of shrinkage for the 3 trials, are presented in table 2. Reliability of each of these measures in terms of absolute SEMs is reported in table 3 for both combined genders and males and females separately.

Repeated measures ANOVA with sphericity assumed did not reveal any significant effects by trial or interaction effect of trial by gender for any of the examined outcomes, Figure's 3, 4 and 5 show the mean spinal height measures across the 10 measurements for the 3 measurement trials with linear regression lines overlaid.

Table 1. Participant Baseline Demographic Characteristics

| | Female n = 5 | Male n = 7 | Combined |
|---|---|---|---|
| Age (years) | 59±7 | 43±13 | 51±12 |
| Stature (cm) | 159.1±4.5 | 174.1±6.1 | 168.2±8.7 |
| Body Mass (Kg) | 61.85±8.51 | 86.4±8.4 | 77.0±14.5 |
| BMI ($Kg/m^2$) | 24.3±2.1 | 28.5±2.5 | 27.0±3.0 |
| Symptom Duration (years) | 21±16 | 10±8 | 13±13 |
| VAS (mm) | 38±26.1 | 25.9±19.2 | 31.9±21.1 |
| ODI (points) | 28.8±13.7 | 25.7±10.1 | 26.8±10.7 |

Note: Results are mean ±SD

Table 2. Seated stature and shrinkage for 3 trials (both genders)

| | Trial 1 | Trial 2 | Trial 3 |
|---|---|---|---|
| Seated Stature - 1st Measure (mm) | 870.8±42.0 | 873.25±42.8 | 872.1±41.5 |
| Seated Stature – Average (mm) | 869.7±42.3 | 870.25±42.0 | 869.49±40.9 |
| Shrinkage – Total (mm) | 1.8±3.3 | 4.3±3.3 | 3.3±3.9 |
| Rate of Shrinkage (Slope) | -0.248±0.297 | -0.419±0.317 | -0.308±0.358 |

Note: Results are mean ±SD

Table 3. Absolute SEMs

| | Female n = 5 | Male n = 7 | Combined |
|---|---|---|---|
| Seated Stature - 1st Measure (mm) | 3.5 | 2.9 | 3.1 |
| Seated Stature – Average (mm) | 3.4 | 2.3 | 2.8 |
| Shrinkage – Total (mm) | 2.0 | 2.3 | 2.6 |
| Rate of Shrinkage (Slope) | 0.245 | 0.186 | 0.212 |

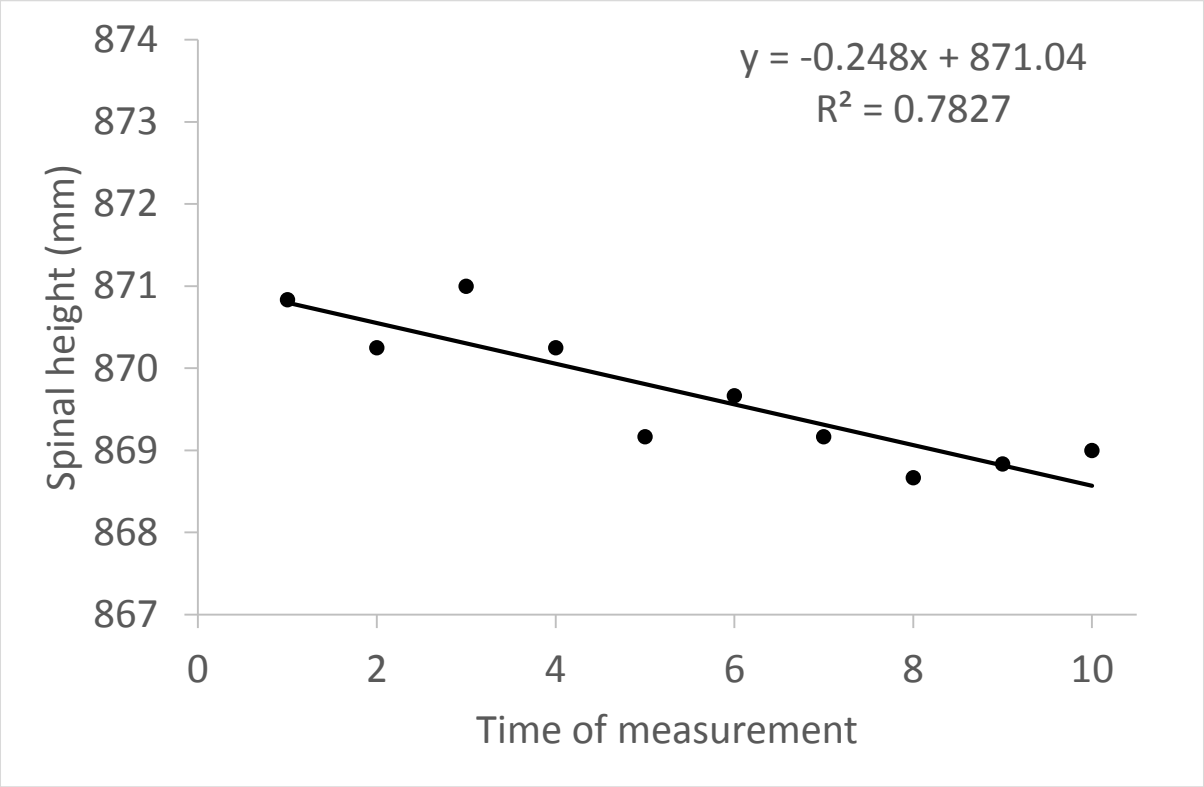


Figure 3. Mean spinal height measures across the 10 measurements for trial 1 (both genders).

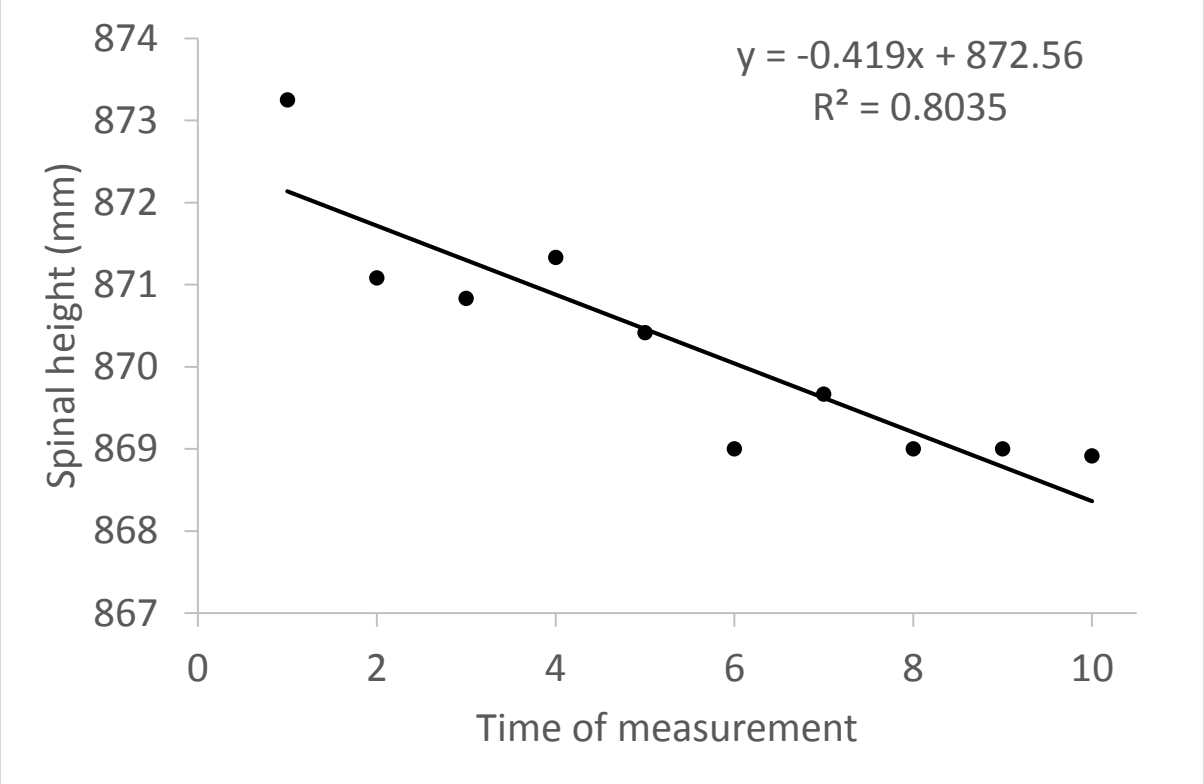


Figure 4. Mean spinal height measures across the 10 measurements for trial 2 (both genders).

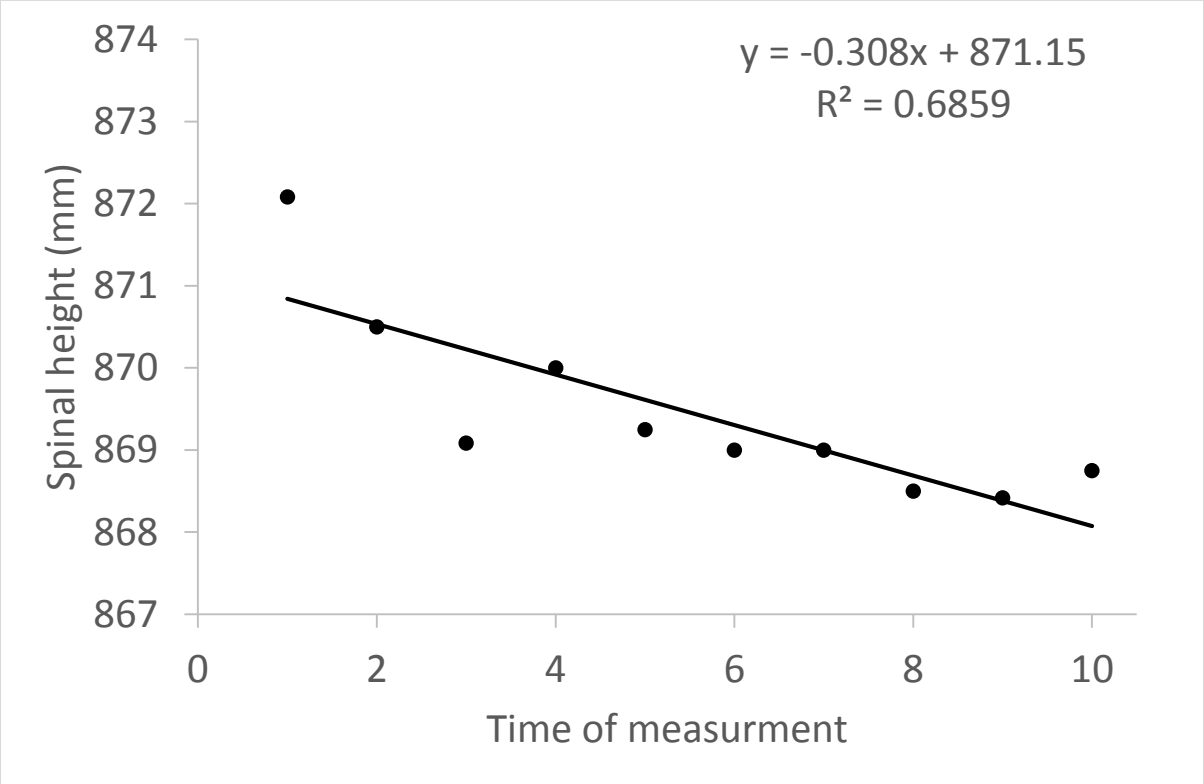

Figure 5. Mean spinal height measures across the 10 measurements for trial 3 (both genders).

## 4.0 Discussion

The aim of the present study was to examine the reliability of a custom set-up using wall mounted adjustable postural rods for seated stadiometry in participants with CLBP. A range of variables were examined to determine the suitability of their use as outcome measures for intervention based research or in clinical practice. No differences were found for between trial comparisons across the three trial days nor were there any effects by gender.

The absolute SEMs for the first seated stature measurement of each trial a showed an error of 3.1mm. Prior research examining the effects of different variables upon measures of stature suggest that for some changes this reliability may be sufficient for confident detection. For example, diurnal variation in stature has been shown to typically change by around ~17-19mm (Reilly et al., 1984; Tyrell et al., 1985; Healey et al., 2011). This would suggest that, using the custom set-up used in the present study, it would be possible to confidently assess changes as a result of the time of measurement across diurnal cycles when using a single stature measurement. That diurnal variation in stature has been shown to correlate with changes in intervertebral disc height as measured by MRI (Paajanen et al., 1994) suggests that this may therefore be a useful proxy indicator of disc hydration.

Further studies using various interventions have found differing magnitudes of change suggesting the set-up used in this study may be able to more confidently assess

changes in some interventions than others. Loading patterns have been assessed using stadiometry and show a range of effects upon acute reduction in measured stature. Exercise has also been shown to induce loss of spinal height. For example, weight based training can induce a stature loss of ~4-5mm (Wilby et al., 1987), and walking, both loaded and unloaded, of 8500m at self-selected pace ~12mm and ~6mm, respectively (Fowler et al., 2006) suggesting sufficient magnitude for confident detection of change by the present custom set-up. Plyometric based exercise though has been reported to induce stature loss of only around ~1.7-2.7mm and thus may not be a suitable area of study for this method as change in mean stature may be difficult to differentiate from measurement error (Fowler et al., 1997).

Recovery patterns of stature, including the adoption of different postures, may also be an area of study possible with this set-up, though varied results are present in the literature. The use of both hyperextension and flexion based postures induce stature recovery after loading ranging from ~0.5mm (Healey et al., 2004), to ~3mm (Owens et al., 2009), ~5mm (Kourtis et al., 2004), and ~7.5 - 10mm (Magnusson et al., 1996). The study by Healey et al. (2004) utilised a standing measurement compared with the seated measurements used by the other three studies (Magnusson et al., 1996; Kourtis et al., 2004; Owens et al., 2009) and the present study. Thus the consistently greater reduction reported for seated measures might suggest that in fact the present set-up is suitable for use in determining recovery of spinal height as a result of postural interventions. Traction as a tool for stature recovery has also been examined showing gains of ~6-7mm (Rodacki et al., 2007), again suggesting sufficient magnitude for detection by this custom set-up.

In the present study spinal height was measured continuously across the 3 – 3.5 minute trials including 10 repeated measures. The primary purpose of this was to examine time-dependent stature loss; however, the reliability of the use of average stature measurements across the 10 measures in each trial was also examined. Participants remained seated in the stadiometer for this, which has been shown to significantly reduce measurement error as a result of postural repositioning (Stothart & McGill, 2000). Our results appeared consistent with revealing that the SEM of these average measures across the 3 trials showed a slightly lower degree of measurement error (2.8mm) suggesting it may also be suitable for examining changes as a result of intervention. The difference in SEM between the first and average measures was small and so it is not clear as to which would be most useful in practice. However, if spinal shrinkage is also of interest then it may still be useful to include the 10 repeated measures.

Time dependent loss of stature, or shrinkage, is related to loading experienced by the spine, both body mass and additional loading. It is often considered as an indicator of 'creep' in the spine due to its visoelastic properties and may reflect the potential for structures of the spine to experience time related changes in biomechanical stresses as a result of postures or occupational loading (Magnusson et al., 1990; Van Dieen & Toussaint, 1993). Indeed stature shrinkage across a constant load static condition differs between asymptomatic controls and CLBP participants (Kanlayanaphotporn et al., 2003). Reliability of measures between these populations appears similar. Kanlayanaphotporn et al. (2002) have reported SEMs of ~2mm for both populations. The present study elicited a similar SEM for total shrinkage measured over a period of 3 – 3.5 minutes (2.6mm). Thus changes in total shrinkage measured under these

conditions as the result of either population comparisons (i.e. asymptomatic controls compared to CLBP participants) or as the result of an intervention in CLBP participants might be interpreted with reasonable confidence as long as it exceeds the SEM reported.

Rate of shrinkage was also examined as the slope of the curve for a linear regression model fit to the 10 repeated measurements with a higher value indicating a steeper slop and greater rate of shrinkage. Our results suggested that between the trials there were no differences for rate of shrinkage which would indicate similarity. We adopted the measurement technique of Stothart & McGill (2000) to control for postural changes relating to entry/exit of the stasiometer and demonstrated similarly the consistent and apparently biological phenomena of time-related spinal height loss. This would suggest face validity of the set-up used in the present study. All three measurement trials revealed time dependent loss of spinal height (figures 3, 4, and 5). Despite its apparent face validity this appears to be the first study to examine the reliability of rate of shrinkage examined as the slope of the curve. Therefore it is not known whether the SEM for rate of shrinkage found here (0.212) should be considered acceptable. Further research should seek to examine the typical rates of shrinkage (slope) under the conditions examined here for comparison. Considering the relationship between rates of spinal shrinkage and trunk extension strength (Wilby et al., 1987) it is of value to understand this and to further examine the interaction of such variables with occupational loading as it has been suggested that deconditioning of the spinal musculature is related to injury and pain (Steele et al., 2014).

The limitations of the present study should be noted. Firstly, though similar to earlier studies examining stature measures reliability, the sample size used was relatively small. Also, though no significant effects were found by gender it may be that these comparisons were confounded by the smaller sample sizes of the two genders resulting in a type II error. This is an issue with many studies in this area and thus future work might look to establish reliability using larger samples. Further, though face validity was established through consistent observation of time-dependent loss of stature, comparison was not made to a gold standard method of examining spinal height. Lastly, this study only utilised CLBP participants. Previous work has shown that though there are differences in stature measures between symptomatic and asymptomatic participants there is remarkably similar reliability (Kanlayanaphotporn et al., 2003). However, we cannot conclude from the data presented here that the reliability of the present set-up will translate to other populations and as such future work might look to examine its reliability in asymptomatic participants.

The reliability of stature measures is of considerable importance in appropriately interpreting changes in such data that are the result of time or intervention as opposed to measurement error (Voss et al., 1990). The present study has demonstrated that a custom set-up that attempts to control for participant posture is suitable for measurement of spinal height as an outcome measure in either research or clinical practice in participants with CLBP. Thus it might be a low cost measurement that could feasibly implemented in future research or clinical practice to examine both the acute and chronic effects of interventions such as occupational loading and postures.

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