BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-019371
Article Type:	Research
Date Submitted by the Author:	14-Sep-2017
Complete List of Authors:	Heneghan, Nicola; University of Birmingham, Centre of Precision Rehabilitation for Spinal Pain, School of Sport, Exercise and Rehabilitation Sciences Baker, Gemma; Sandwell and West Birmingham Hospitals NHS Trust, Physiotherapy Thomas, Kimberley ; Heart of England NHS Foundation Trust, Physiotherapy, Solihull Hospital Falla, Deborah; University of Birmingham, Centre of Precision Rehabilitation for Spinal Pain, School of Sport, Exercise and Rehabilitation Sciences Rushton, Alison; University of Birmingham, Centre of Precision Rehabilitation for Spinal Pain, School of Sport, Exercise and Rehabilitation Sciences
Keywords:	physical activity, spine mobility, spinal pain, sedentary behaviour, thoracic spine

TITLE

The influence of sedentary behaviour and physical activity on thoracic spinal mobility in young adults: an observational study

Authors

Heneghan NR, Baker G, Thomas K, Falla D, Rushton A

Affiliations

Dr Nicola Heneghan
Lecturer Physiotherapy
Centre of Precision Rehabilitation for Spinal Pain
School of Sport, Exercise and Rehabilitation Sciences
University of Birmingham
Birmingham, West Midlands
UK

Miss Gemma Baker
Physiotherapist
Sandwell and West Birmingham Trust
Birmingham, West Midlands
UK

Miss Kimberley Thomas
Physiotherapist
Solihull Hospital
Heart of England NHS Foundation Trust
Birmingham, West Midlands
UK

Professor Deborah Falla
Professor in Rehabilitation Science and Physiotherapy

Centre of Precision Rehabilitation for Spinal Pain

School of Sport, Exercise and Rehabilitation Sciences

University of Birmingham

Birmingham, West Midlands

UK

Dr Alison Rushton Reader in Musculoskeletal Rehabilitation Sciences

Centre of Precision Rehabilitation for Spinal Pain

School of Sport, Exercise and Rehabilitation Sciences

University of Birmingham

Birmingham, West Midlands

UK

Correspondence:

Nicola R Heneghan

Centre of Precision Rehabilitation for Spinal Pain (CPR Spine),

School of Sport, Exercise & Rehabilitation Sciences

University of Birmingham, Edgbaston,

Birmingham. B15 2TT. UK

Email: n.heneghan@bham.ac.uk

Tel: +44 121 415 8367

Keywords

Sedentary behaviour, physical activity, thoracic spine, spinal mobility, spinal pain

Word count

2171

ABSTRACT

Objective

Sedentary behaviour has long been associated with neck and low back pain, although relatively little is known about the thoracic spine. Contributing up to 33% of functional neck movement, understanding the effect of sedentary behaviour and physical activity on thoracic spinal mobility may guide clinical practice and inform research of novel interventions in spinal pain research.

Design

An assessor blinded prospective observational study designed and reported in accordance with STROBE.

Setting

UK university (June to September 2016)

Participants

A convenience sample (18-30 years) was recruited and assigned to one of three groups based on self-report behaviours: 1] sitters (S) - sitting >7 hours/day + physical activity < 150 minutes/week, 2] physically active (PA) - moderate exercise >150 minutes/week + sitting < 4 hours/day, and 3] low activity (LA) - sitting 2-7 hours/day + physical activity <150 minutes/week.

Outcome Measures

Thoracic mobility was assessed in the heel sit position using Acumar digital goniometer; a validated measure. Descriptive and inferential analyses were used with analysis of covariance (ANCOVA) for between group differences and Pearson product coefficients for *post hoc* analysis of associations.

Results

The sample (n=92) comprised: S n=30, PA n=32 and LA n=30. Groups were comparable with respect to age and BMI.

Thoracic spine mobility (mean [SD], 95% CI) for the S, PA and LA group were 64.75[1.20] 62.37, 67.14°), 74.96[1.18] 72.61, 77.31°), 68.44[1.22] 66.02, 70.86°) respectively. Significant differences in thoracic mobility were detected between S and LA, S and PA (p<0.001). Correlations between thoracic rotation and exercise duration (r=0.67, p<0.001), sitting duration (r=-0.29, p<0.001) and days exercised (r=0.45, p<0.001) were observed.

Conclusions

Findings evidence reduced thoracic mobility in individuals who spend >7 hours/day sitting and <150 minutes/week of physical activity. Further research is now required to explore the possible causal relationships between activity behaviours and spinal musculoskeletal health.

FIG

Article summary

- The study employed rigorous methods and validated approaches to investigate thoracic spine functional mobility
- Thoracic spine mobility differed across self-reported sitting and physical activity behaviours, with reduced thoracic mobility observed for those sitting >7 hours per day and greatest ranges seen for those involved in >150 minutes physical activity per week
- Thoracic functional mobility varied based on the duration of behaviours (sitting and physical activity) and nature of physical activity

INTRODUCTION

Background/rationale

Sedentary lifestyles are an undesirable hallmark of modern society affecting a significant proportion of the population [1]. Prolonged sitting (a form of sedentary behaviour) has progressively become the norm with computerisation in the work place, transportation modernisation, and advances in domestic technology [2]. These developments are not only detrimental for physiological health and wellbeing with rising levels of obesity, diabetes, and cardiovascular disease [3], but also musculoskeletal health and well-being with recent research finding an association between prolonged sitting (>8 hours a day) and increased neck-shoulder [4-7] and low back pain [8]. It is therefore reasonable to suppose that sedentary behaviours may induce musculoskeletal changes within the relatively stiff thoracic spine; contributing towards the dysfunction in the adjacent spinal regions. The term ”regional interdependence” describes a relationship whereby seemingly unrelated impairments in one anatomical region are associated with the development or persistence of pain in another [9]. Contributing to 33% and 21% of the movement occurring during neck flexion and rotation respectively [10], it is not surprising that the thoracic spine may contribute to the development of pain in surrounding the neck. Empirical evidence supports this theory, where thoracic movement dysfunction has been linked to pathologies in the neck [11] shoulder [12] and elbow [13]. Furthermore, there is a considerable body of compelling evidence to support the use of physiotherapy treatment techniques targeting the thoracic spine in clinical presentations of neck and shoulder pain [14-16]. Notwithstanding the paucity of literature exploring the influence of sedentary behaviours on the thoracic spine, one large cross sectional study (n=1886) did report a relatively high prevalence of thoracic spine pain, alongside neck and back pain in sedentary workers (36-41%), most notably in individuals with postural constraints, such as drivers and individuals unable to change tasks regularly [17]. However, the relationship between sedentary behaviour and

thoracic mobility, a proxy for spinal musculoskeletal health, contributing 80% of axial spinal trunk rotation [18] has not yet been established.

Arguably those who are physically active may present with greater mobility of their thoracic region where exercise promotes joint and soft tissue mobility, countering the deleterious adaptive shortening of muscles and joint stiffness through static postures [19]. However, it remains unclear what physical activity is comprised of in terms of; 'length of activity', 'type of activity', and 'how often' the activity is performed. Physical activity has been previously defined as "more than 150 minutes of moderate to intense physical activity per week" [20]. However a focus on physical exertion seems inadequate when considering musculoskeletal health [21], and arguably biomechanical factors such as mobility and types of activity should also be considered, where some physical activity have been sub classified as linear (straight-line e.g. running) or dynamic (rotational e.g. tennis) in nature.

With sedentary lifestyles becoming increasingly the norm and evidence that sitting for just 1 hour leads to increased spinal stiffness [22] it is now important to further investigate the relationship between sedentary behaviours, physical activity and thoracic spine mobility. Therefore, the aim of this study was to investigate the effect of prolonged sitting and physical activity on thoracic spine mobility.

<u>Objectives</u>

1. Investigate the influence of sedentary behaviour on thoracic spine mobility
2. Investigate the influence of physical activity on thoracic spine mobility
3. To evaluate whether a relationship exists between duration of sitting and physical activity and thoracic mobility

METHODS

Design and setting

A single assessor blinded prospective observational study was conducted between April and June 2016 within a University setting; designed and reported in line with STROBE guidelines [23].

Recruitment

Participants were recruited via email from the staff and student body of a large UK University using posters and email advertisement. Interested and eligible participants were provided with a participant information sheet, had their questions answered, and were asked to provide written informed consent. Screening against eligibility criteria was performed at the point of recruitment by a research assistant (KT).

The XXXXXXXXXXXXXXXXXXXXXXXXXX Ethics Committee granted ethical approval and the study was conducted according to the Declaration of Helsinki with participants able to withdraw at any point.

Participants

Participants comprised a convenience sample of healthy asymptomatic volunteers from within a UK university population. Eligibility criteria included young adults 18-30 years, who fulfilled one of the following criteria based on Dunstan et al., [24] for sitting duration and NICE Guidelines [25] for duration of moderate intensity physical activity [26]. The sample size was based on a minimum of 30 per group to be able to detect a minimum clinically important difference (10-degrees) in thoracic spinal rotation movement between the groups, based on power 0.8 and at 5% significance level [27].

1. Individuals who participate in >150 minutes of physical activity per week and sit <4 hours per day (physically active)
2. Individuals who participate in <150 minutes of physical activity per week and sit >7 hours per day (sitters)

3. Individuals who spend between 4-7 hours sitting daily and <150 minutes of physical activity per week (low activity).

Exclusion criteria included a current or previous neuromusculoskeletal spine condition, rheumatoid arthritis, current or chronic respiratory condition, pregnancy, current hip or knee pathology, unable to adopt heel sit position, not fulfilling one of the criteria listed above.

Variables: Demographic data and outcome assessment

Procedure

Piloting to determine the feasibility of the protocol was performed prior to the main study. For the main study, one researcher (KT) recruited, screened and took all baseline measures to characterise the sample [age, gender, body mass index (BMI), exercise type/duration, sitting duration]. The primary measure of interest, thoracic spine mobility, was recorded by a blinded assessor (GB) with the participant an a heel-sit position [28, 29] (Figures 1 and 2). Following familiarisation and 3 practice attempts from a position of full right to left rotation to ensure stability of measures [27], the end range position of the 4th rotation was measured 3 times using an Acumar digital inclinometer placed over the C7-T1 interspinous space [27, 29]. The mean of the 3 measures for full right and left rotation were recorded and retained for data analysis [27].

Insert Figure 1 and 2

Outcome measure

The Acumar digital inclinometer (Acumar, Model ACU 360, Lafayette Instrument Company, Indiana, USA) was used to measure thoracic rotation. The heel-sit position was chosen to minimise concurrent movement occurring in the relatively mobile lumbar spine, a limitation of sitting where rotation comprises motion from both regions [28]. Reliability (ICC $_{2,1}$ [95% confidence interval], 0.88

[0.78, 0.93]) and strong criterion (r=0.88) and concurrent validity (r=0.98) against a combined imaging and motion analysis approach has previously been established [28, 29].

Bias

A number of measures were put in place to minimise the influence of bias, including standardisation of procedures, assessor blinding, partial blinding of participants in that they were not made aware of planned comparison between groups and piloting of all procedures in advance of the main study.

Statistical methods

Data were transferred to SPSS (version 22, IBM, New York, NY) and checked to ensure their integrity by two researchers. Descriptive and inferential statistical analyses included a summary of participant characteristics using means, standard deviations and one-way analysis of variance (ANOVA). Further inferential analyses included an analysis of co-variance (ANCOVA) to determine main effects including Bonferroni correction (with pairwise comparisons) to evaluate between group differences in thoracic spine mobility with gender as a covariate (as groups were imbalanced with respect to gender). Pearson product correlational analyses were used to evaluate relationships between thoracic mobility and self-report measures of sitting duration, days active, and physical activity. Strength of associations were based on established criteria where: 0.00-0.25 implies a weak association, 0.26-0.50 a low association, 0.51-0.75 a moderate association and 0.76-1.00 a strong association [30]. For all analyses statistical significance was set at $p<0.05$.

RESULTS

Participants, descriptive data and outcome data

A total of 92 participants were recruited. Baseline characteristics, self-reported behaviours for physical activity (exercise duration and types of exercise), and sitting duration are presented in

Table 1. Groups were comparable with respect to age and BMI (p>0.05), but not for gender with more women were recruited to the low activity and sitter group.

Table 1: Participant characteristics

	Sitters n=30	Physically active n=32	Low activity n=30
Age in years, mean (SD)	22.73 (2.92)	22.03 (2.65)	20.93 (2.49)
Gender (Women %)	63.3[$]	47.0[$]	76.7[$]
BMI, mean (SD)	22.90 (2.47)	23.12 (2.92)	22.60 (2.36)
Thoracic rotation degrees mean (SD) 95% Confidence interval	64.74 (8.93) 62.37, 67.14	74.96 (8.26) 72.61, 77.31	68.44 (4.36) 66.02, 70.86
Exercise duration (minutes)			
0-30	7	-	3
30-60	4	-	6
60-90	15	-	5
90-150	4	-	16
150-180	-	4	-
180-210	-	12	-
210-240	-	5	-
240+	-	11	-
Types of exercise (frequency)			
Gym cardio	6	10	1
Gym weights	5	3	9
Running	10	6	-
Cycling	3	1	3
Dance/gymnastics	-	3	1
Football	-	4	2
Netball/basketball	-	1	1
Tennis	-	3	2
Rowing	-	1	-
Martial arts	1	-	-
Other	3	-	11
None	2	-	-
Sitting duration (hours)			
0-2	-	1	-
2-4	-	5	6
4-6	-	11	17
6-7	-	15	7
7-8	9	-	-
8-9	9	-	-
9-10	6	-	-
10+	6	-	-

[$] Statistically different p<0.001

Main results

Thoracic spine mobility (mean, SD and 95% CI) for the sitters, physically active and low activity groups were 64.74±6.33 (62.37,67.14°), 75.12±8.26 (72.61, 77.31°), 68.28±4.36 (66.02, 70.86°) respectively (Figure 3).

A one-way ANCOVA was conducted having checked data met the assumptions to compare thoracic mobility between groups, whilst controlling for gender. There was a significant difference between groups [F (2,88)=18.66 P<0.001] with the post hoc analyses confirming differences between the low activity and physically active groups (p<0.001), the physically active group and sitters (p<0.001), although not between the low activity and sitters. Thoracic spine mobility (mean, SD and 95% CI) was 64.75±1.20 (95%CI 62.37-67.14°), 74.96±1.18 (95%CI 72.61-77.31°), 68.44±1.22 (95%CI 66.02-70.86°) for the sitters, physically active and low activity group respectively.

Insert Figure 3

Other analyses: Correlational analysis

Across the whole sample, a moderate positive *c*orrelation was found between thoracic mobility and exercise duration (r=0.67, p<0.001), a low negative correlation between sitting duration (r=-0.29, p<0.001) and low positive correlation between number of days exercised (r=0.45, p<0.001).

DISCUSSION

Key results

This is the first rigorous observational study to investigate sedentary behaviour, physical activity and thoracic spine mobility in young adults. Whilst no causal relationship can be inferred from this study, findings provide preliminary evidence to posit a beneficial effect of physical activity and the deleterious effects of sitting on thoracic mobility, a proxy for spinal musculoskeletal health.

Interpretation

The low activity group contained the highest percentage of women, with more than half the group involved in 90-150 minutes of physical activity and 4-6 hours sitting duration a week. Failing to meet the national guidelines for exercise [31] does appear to impact thoracic mobility, compared to those who are fulfilling the recommendations of >150 minutes physical activity per week [25] and sit for less than 4 hours per day [24]. In contrast, the findings from the physically active group endorse the Public Health England [31] recommendation that exercise is beneficial for musculoskeletal health, with those involved in physical activity having significantly greater thoracic mobility than those who are more sedentary. There is persuasive evidence from this study of a relationship between prolonged sitting and thoracic mobility, with >10° less mobility for the sitters compared to those who were physically active. Moreover, with sitters having approximately 4° less mobility than those in the low activity group, our findings also support the need further investigation of not only increased levels of physical activity, but also reduced sitting duration for optimal spinal musculoskeletal health. Although the majority of individuals in the low activity group sit between 4-7 hours a day (comparable to the findings of the physical activity group), it appears that some physical activity, albeit less than the guidelines is beneficial to mitigate the 'detrimental' effects of sitting; with those in the low activity group having >6° less thoracic mobility than those in the physically activity group.

These findings lend support for those young adults who comply with national guidelines on physical activity having better musculoskeletal health. Findings also support the need to further investigate types of physical activity, where consideration is made specifically to biomechanical as well as physiological parameters of physical activity. With evidence of associations between thoracic mobility and exercise duration (positive), number of days exercised (positive) and sitting duration (negative), further research is now required to investigate the potentially causal relationship of reduced thoracic mobility and musculoskeletal complaints such as neck, thoracic and low back pain.

Strengths and limitations

Reported in line with STROBE and employing rigorous methods, including assessor blinding, we have established differences in thoracic mobility in a large population of young adults. Whilst self-reported measures of physical activity and sitting duration potentially lead to under- or over-estimation of sitting and physical activity behaviours, they are able to capture information relating to activities which are not compatible or insensitive to accelerometry such as water based activity or cycling and stair climbing respectively [32].

Although not examined here, patterns of sitting are a potentially important consideration in future studies, where breaks have been shown to be beneficial on pro-inflammatory markers; linked to development of neck-shoulder pain [7]. Moreover, future studies could also usefully evaluate other sitting parameters where constrained or poor postures, ergonomic parameters e.g. keyboard position, may place greater loads on musculoskeletal tissues [17, 33-35].

Generalisability

To enable generalisability to different populations further studies are required with different age groups and individuals from a range of socio-demographic backgrounds. However it is likely that this population comprising young adults are an at 'risk' group for developing musculoskeletal complaints, with many likely to work in occupations where a substantial periods of time will be sitting [7]. Moreover this population represent a group where there is potential to influence thoracic mobility, with spinal degenerative changes often developing at and beyond the third decade [36] and therefore likely less responsive to physical therapy interventions targeting stiff joints and muscles.

CONCLUSION

This study provides evidence of reduced thoracic mobility in individuals who spend >7 hours a day sitting and <150 minutes of physical activity a week. With observed associations between thoracic mobility and exercise and sitting duration, further research is now required to explore the possible causal relationship between physical activity behaviours on spinal musculoskeletal health and subsequently their relationship to spinal complaints.

Contribution statement: NH was the chief investigator leading the study design, analyses and dissemination. KT and GB conducted data collection and preliminary analyses. All authors (NH, GB, KT, DF, AR) contributed to analysis and interpretation of results, conclusions and dissemination. NH drafted the initial manuscript. All authors have read, contributed to and agreed on the final manuscript.

Competing Interests Statement: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work.

Funding: None

Data sharing: Raw data is held by the lead author at the University of Birmingham in accordance with guidelines. Data is available by contacting the lead author at n.heneghan@bham.ac.uk

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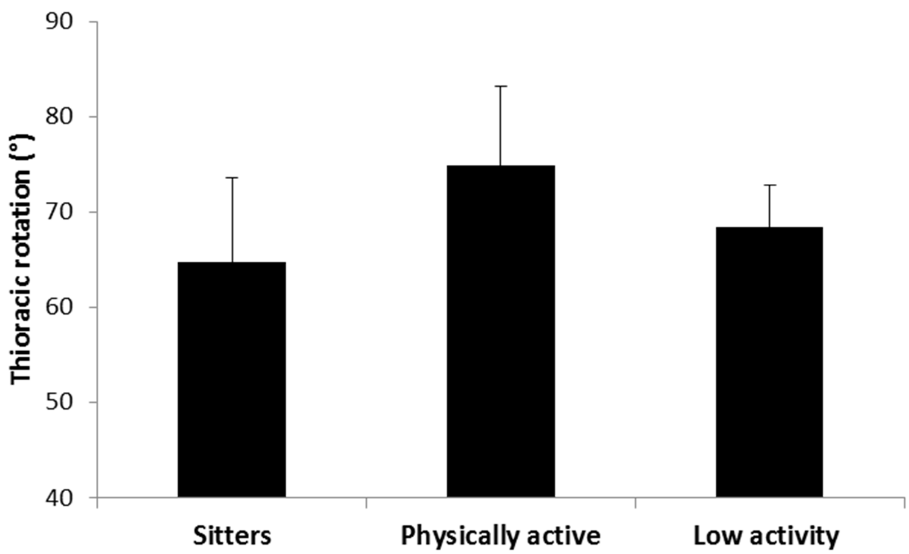
Figure 3. Thoracic mobility measured from all participants classified as either low activity, physically active or sitters



STROBE Statement—Checklist of items that should be included in reports of ***case-control studies***

	Item No	Page number	Recommendation
Title and abstract	1	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		3	(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
			Introduction
Background/rationale	2	5	Explain the scientific background and rationale for the investigation being reported
Objectives	3	6	State specific objectives, including any prespecified hypotheses
			Methods
Study design	4	7	Present key elements of study design early in the paper
Setting	5	7	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	7	(*a*) Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls
		7	(*b*) For matched studies, give matching criteria and the number of controls per case
Variables	7	8	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8*	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	9	Describe any efforts to address potential sources of bias
Study size	10	7	Explain how the study size was arrived at
Quantitative variables	11	8	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	9	(*a*) Describe all statistical methods, including those used to control for confounding
			(*b*) Describe any methods used to examine subgroups and interactions
			(*c*) Explain how missing data were addressed
			(*d*) If applicable, explain how matching of cases and controls was addressed
			(*e*) Describe any sensitivity analyses
			Results
Participants	13*	9	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
			(b) Give reasons for non-participation at each stage
			(c) Consider use of a flow diagram
Descriptive data	14*	10	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
			(b) Indicate number of participants with missing data for each variable of interest
Outcome data	15*	10	Report numbers in each exposure category, or summary measures of

			exposure
Main results	16	11	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
			(*b*) Report category boundaries when continuous variables were categorized
			(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period

Other analyses	17	7		Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion				
Key results	18	7	11	Summarise key results with reference to study objectives
Limitations	19	9	13	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	8	12	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21	9	13	Discuss the generalisability (external validity) of the study results
Other information				
Funding	22	10	14	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

BMJ Open

What is the effect of prolonged sitting and physical activity on thoracic spinal mobility? An observational study of young adults in a UK university setting

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-019371.R1
Article Type:	Research
Date Submitted by the Author:	02-Feb-2018
Complete List of Authors:	Heneghan, Nicola; University of Birmingham, Centre of Precision Rehabilitation for Spinal Pain, School of Sport, Exercise and Rehabilitation Sciences Baker, Gemma; Sandwell and West Birmingham Hospitals NHS Trust, Physiotherapy Thomas, Kimberley ; Heart of England NHS Foundation Trust, Physiotherapy, Solihull Hospital Falla, Deborah; University of Birmingham, Centre of Precision Rehabilitation for Spinal Pain, School of Sport, Exercise and Rehabilitation Sciences Rushton, Alison; University of Birmingham, Centre of Precision Rehabilitation for Spinal Pain, School of Sport, Exercise and Rehabilitation Sciences
Primary Subject Heading:	Rehabilitation medicine
Secondary Subject Heading:	Sports and exercise medicine, Evidence based practice
Keywords:	physical activity, spine mobility, spinal pain, sedentary behaviour, thoracic spine

TITLE

What is the effect of prolonged sitting and physical activity on thoracic spinal mobility? An observational study of young adults in a UK university setting

Authors

Heneghan NR, Baker G, Thomas K, Falla D, Rushton A

Affiliations

Dr Nicola Heneghan
Lecturer Physiotherapy
Centre of Precision Rehabilitation for Spinal Pain
School of Sport, Exercise and Rehabilitation Sciences
University of Birmingham
Birmingham, West Midlands
UK

Miss Gemma Baker
Physiotherapist
Sandwell and West Birmingham Trust
Birmingham, West Midlands
UK

Miss Kimberley Thomas
Physiotherapist
Solihull Hospital
Heart of England NHS Foundation Trust
Birmingham, West Midlands
UK

Professor Deborah Falla
Professor in Rehabilitation Science and Physiotherapy

Centre of Precision Rehabilitation for Spinal Pain

School of Sport, Exercise and Rehabilitation Sciences

University of Birmingham

Birmingham, West Midlands

UK

Dr Alison Rushton

Reader in Musculoskeletal Rehabilitation Sciences

Centre of Precision Rehabilitation for Spinal Pain

School of Sport, Exercise and Rehabilitation Sciences

University of Birmingham

Birmingham, West Midlands

UK

Correspondence:

Nicola R Heneghan

Centre of Precision Rehabilitation for Spinal Pain (CPR Spine),

School of Sport, Exercise & Rehabilitation Sciences

University of Birmingham, Edgbaston,

Birmingham. B15 2TT. UK

Email: n.heneghan@bham.ac.uk

Tel: +44 121 415 8367

Keywords

Sedentary behaviour, physical activity, thoracic spine, spinal mobility, spinal pain

Word count

2517

ABSTRACT

Objective

Sedentary behaviour has long been associated with neck and low back pain, although relatively little is known about the thoracic spine. Contributing considerably to functional neck movement, understanding the effect of sedentary behaviour and physical activity on thoracic spinal mobility may guide clinical practice and inform research of novel interventions in spinal pain research.

Design

An assessor blinded prospective observational study designed and reported in accordance with STROBE.

Setting

UK university (June to September 2016)

Participants

A convenience sample (18-30 years) was recruited and, based on self-reported behaviours, were assigned to one of three groups: Group 1, sitters: sitting >7 hours/day + physical activity < 150 minutes/week; Group 2, physically active: moderate exercise >150 minutes/week + sitting < 4 hours/day, and Group 3, low activity: sitting 2-7 hours/day + physical activity <150 minutes/week.

Outcome Measures

Thoracic mobility was assessed in the heel-sit position using Acumar digital goniometer. Descriptive and inferential analyses were used including analysis of variance (ANOVA) and covariance (ANCOVA) for between group differences and Spearman's rank correlation for analysis of associations.

Results

The sample (n=92) comprised: Group 1, n=30, Group 2, n=32 and Group 3, n=30 and groups comparable with respect to age and BMI.

Thoracic spine mobility (mean [SD]) was: Group 1, sitters: 64.75[1.20], Group 2, physically active: 74.96[1.18] and Group 3, low activity: 68.44[1.22]. Significant differences in thoracic mobility were detected between the sitters and both low activity and physically active groups (p<0.001), with an overall effect size of 0.31. Correlations between thoracic rotation and exercise duration (r=0.67, p<0.001), sitting duration (r=-0.29, p<0.001) and days exercised (r=0.45, p<0.001) were observed.

Conclusions

Findings evidence reduced thoracic mobility in individuals who spend >7 hours/day sitting and <150 minutes/week of physical activity. Further research is now required to explore possible causal relationships between activity behaviours and spinal musculoskeletal health.

FIG

Article summary

- The study employed rigorous methods and validated approaches to investigate thoracic spine functional mobility
- The inclusion of accelerometry would have been useful to verify self-reported behaviours
- Whilst the study sample size was based on *a priori* power calculation of the primary outcome, a validated measure of thoracic mobility, individual group sample size was insufficient to support further post hoc analysis

INTRODUCTION

Background/rationale

Sedentary lifestyles are an undesirable hallmark of modern society affecting a significant proportion of the population [1]. Prolonged sitting (a form of sedentary behaviour) has progressively become the norm with computerisation in the work place, transportation modernisation, and advances in domestic technology [2]. These developments are not only detrimental for physiological health and wellbeing with rising levels of obesity, diabetes, and cardiovascular disease [3], but also musculoskeletal health and well-being with recent research finding an association between prolonged sitting (>8 hours a day) and increased neck-shoulder [4-7] and low back pain [8]. It is therefore reasonable to suppose that sedentary behaviours may induce musculoskeletal changes within the relatively stiff thoracic spine; contributing towards the dysfunction in the adjacent spinal regions. The term ”regional interdependence” describes a relationship whereby seemingly unrelated impairments in one anatomical region are associated with the development or persistence of pain in another [9]. Contributing to 33% and 21% of the movement occurring during neck flexion and rotation respectively [10], it is not surprising that the thoracic spine may contribute to the development of pain in surrounding the neck. Empirical evidence supports this theory, where thoracic movement dysfunction has been linked to pathologies in the neck [11] shoulder [12] and elbow [13]. Furthermore, there is a considerable body of compelling evidence to support the use of physiotherapy treatment techniques targeting the thoracic spine in clinical presentations of neck and shoulder pain [14-16]. Notwithstanding the paucity of literature exploring the influence of sedentary behaviours on the thoracic spine, one large cross sectional study (n=1886) did report a relatively high prevalence of thoracic spine pain, alongside neck and back pain in sedentary workers (36-41%), most notably in individuals with postural constraints, such as drivers and individuals unable to change tasks regularly [17]. However, the relationship between sedentary behaviour and

thoracic mobility, a proxy for spinal musculoskeletal health, contributing 80% of axial spinal trunk rotation [18] has not yet been established.

Arguably those who are physically active may present with greater mobility of their thoracic region where exercise promotes joint and soft tissue mobility, countering the deleterious adaptive shortening of muscles and joint stiffness through static postures [19]. However, it remains unclear what physical activity is comprised of in terms of; 'length of activity', 'type of activity', and 'how often' the activity is performed. Physical activity has been previously defined as "more than 150 minutes of moderate to intense physical activity per week" [20]. However a focus on physical exertion seems inadequate when considering musculoskeletal health [21], and arguably biomechanical factors such as mobility and types of activity should also be considered, where some physical activity have been sub classified as linear (straight-line e.g. running) or dynamic (rotational e.g. tennis) in nature.

With sedentary lifestyles becoming increasingly the norm and evidence that sitting for just 1 hour leads to increased spinal stiffness [22] it is now important to further investigate the relationship between sedentary behaviours, physical activity and thoracic spine mobility. Therefore, the aim of this study was to investigate the influence of prolonged sitting and physical activity on thoracic spine mobility.

Objectives

1. Investigate the influence of sedentary behaviour on thoracic spine mobility
2. Investigate the influence of physical activity on thoracic spine mobility
3. To evaluate whether a relationship exists between duration of sitting and physical activity and thoracic mobility

METHODS

Design and setting

A single assessor blinded prospective observational study was conducted between April and June 2016 within a University setting; designed and reported in line with STROBE guidelines [23].

Recruitment

Participants were recruited via email from the staff and student body of a large UK University using posters and email advertisement. Interested and eligible participants were provided with a participant information sheet, had their questions answered, and were asked to provide written informed consent. Screening against eligibility criteria was performed at the point of recruitment by a research assistant (KT).

The XXXXXXXXXXXXXXXXXXXXXXXXXX Ethics Committee granted ethical approval and the study was conducted according to the Declaration of Helsinki with participants able to withdraw at any point.

Participants

Participants comprised a convenience sample of healthy asymptomatic volunteers from within a UK university population. Eligibility criteria included young adults 18-30 years, who fulfilled one of the following criteria based on Dunstan et al., [24] for sitting duration and NICE Guidelines [25] for duration of moderate intensity physical activity [26]. The sample size was based on a minimum of 30 per group to be able to detect a minimum clinically important difference (10-degrees) in thoracic spinal rotation movement between the groups, based on power 0.8 and at 5% significance level [27].

Group 1, sitters: Individuals who participate in <150 minutes of physical activity per week and sit >7 hours per day

Group 2, physically active: Individuals who participate in >150 minutes of physical activity per week and sit <4 hours per day

Group 3, low activity: Individuals who spend between 4-7 hours sitting daily and <150 minutes of physical activity per week

Exclusion criteria included a current or previous neuromusculoskeletal spine condition, rheumatoid arthritis, current or chronic respiratory condition, pregnancy, current hip or knee pathology, unable to adopt heel sit position, not fulfilling one of the criteria listed above.

Procedure

Piloting to determine the feasibility of the protocol was performed prior to the main study. For the main study, one researcher (KT) recruited, screened and took all baseline measures to characterise the sample [age, gender, body mass index (BMI), exercise type/duration, sitting duration]. The primary measure of interest, thoracic spine mobility, was recorded by a blinded assessor (GB) with the participant an a heel-sit position [28, 29] (Figures 1 and 2). Following familiarisation and 3 practice attempts from a position of full right to left rotation to ensure stability of measures [27], the end range position of the 4th rotation was measured 3 times using an Acumar digital inclinometer placed over the C7-T1 interspinous space [27, 29]. The mean of the 3 measures for full right and left rotation were recorded and retained for data analysis [27].

Insert Figure 1 and 2

Outcome measure

The Acumar digital inclinometer (Acumar, Model ACU 360, Lafayette Instrument Company, Indiana, USA) was used to measure thoracic rotation. The heel-sit position was chosen to minimise concurrent movement occurring in the relatively mobile lumbar spine, a limitation of sitting where rotation comprises motion from both regions [28]. Reliability ($ICC_{2,1}$ [95% confidence interval], 0.88

[0.78, 0.93]) and strong criterion (r=0.88) and concurrent validity (r=0.98) against a combined imaging and motion analysis approach has previously been established [28, 29].

Bias

A number of measures were put in place to minimise the influence of bias, including use of a validated measurement approach [29], standardisation of procedures through training of assessor, assessor blinding, controlling for environmental variables, avoidance of physical activity prior to testing, partial blinding of participants in that they were not made aware of *a priori* planned comparison between groups and piloting of all procedures in advance of the main study.

Statistical methods

Data were transferred to SPSS (version 22, IBM, New York, NY) and checked to ensure their integrity by two researchers. Descriptive statistical analyses included a summary of participant characteristics (age, gender, BMI, types of exercise, duration of exercise and sitting) using means, standard deviations. Inferential analysis initially included one-way analysis of variance (ANOVA) to explore between group differences, and *post hoc* comparisons to explore between group differences. Effect size (eta squared) was calculated, and interpreted using Cohen's classification [30].

Further inferential analyses included an analysis of co-variance (ANCOVA) to determine main effects including Bonferroni correction (with pairwise comparisons) to evaluate between group differences in thoracic spine mobility with gender as a covariate (as groups were imbalanced with respect to gender). Spearman's rank correlation was used to evaluate relationships between thoracic mobility and self-reported measures of sitting duration, days active, and physical activity. For all analyses statistical significance was set at $p<0.05$.

RESULTS

Participants, descriptive data and outcome data

From 109 potentially eligible participants, a total of 92 participants meet the eligibility requirements and were recruited. Baseline characteristics, self-reported behaviours for physical activity (exercise duration and types of exercise), and sitting duration are presented in Table 1. Groups were comparable with respect to age and BMI (p>0.05), but not for gender with more women were recruited to the low activity and sitter group.

Table 1: Participant characteristics

	Group 1 Sitters n=30	**Group 2 Physically active n=32**	**Group 3 Low activity n=30**
Age in years, mean (SD)	22.73 (2.92)	22.03 (2.65)	20.93 (2.49)
Gender (Women %)	63.3$^{\$}$	47.0$^{\$}$	76.7$^{\$}$
BMI, mean (SD)	22.90 (2.47)	23.12 (2.92)	22.60 (2.36)
Thoracic rotation degrees mean (SD) 95% Confidence interval	64.74 (8.93) 62.37, 67.14	74.96 (8.26) 72.61, 77.31	68.44 (4.36) 66.02, 70.86
Exercise duration (minutes)			
0-30	7	-	3
30-60	4	-	6
60-90	15	-	5
90-150	4	-	16
150-180	-	4	-
180-210	-	12	-
210-240	-	5	-
240+	-	11	-
Types of exercise (frequency)			
Gym cardio	6	10	1
Gym weights	5	3	9
Running	10	6	-
Cycling	3	1	3
Dance/gymnastics	-	3	1
Football	-	4	2
Netball/basketball	-	1	1
Tennis	-	3	2
Rowing	-	1	-
Martial arts	1	-	-
Other	3	-	11
None	2	-	-
Sitting duration (hours)			
0-2	-	1	-
2-4	-	5	6

4-6	-	11	17
6-7	-	15	7
7-8	9	-	-
8-9	9	-	-
9-10	6	-	-
10+	6	-	-

[$] Statistically different p<0.001

Main results

Thoracic spine mobility (mean, SD and 95% CI) for the sitters, physically active and low activity groups were 64.74±6.33 (62.37, 67.14°), 75.12±8.26 (72.61, 77.31°), 68.28±4.36 (66.02, 70.86°) respectively (Figure 3).

Results from the ANOVA showed a statistically significant difference in thoracic mobility between groups [F (2,56)=20.19 P<0.001], with a large effect size of 0.31. *Post hoc* comparisons of group mean scores indicated significant differences between Group 3, low activity and Group 2, physically active (6.84-degrees, p<0.001), between Group 2, physically active and Group 1, sitters (10.38 degrees, p<0.001), although not between the Group 3, low activity and Group 1, sitters (3.54 degrees).

A one-way ANCOVA was conducted having checked data met the assumptions to compare thoracic mobility between groups, whilst controlling for gender. There was a significant difference between groups [F (2,88)=18.66 P<0.001] with the *post hoc* analyses confirming differences between Group 3, low activity and Group 2, physically active (p<0.001), and between Group 2, physically active and Group 1, sitters (p<0.001), although not between Group 3, low activity and Group 1, sitters .

Insert Figure 3

Other analyses: Correlational analysis

Across the whole sample, a moderate positive correlation was found between thoracic mobility and exercise duration (r=0.62, p<0.001), a low negative correlation between thoracic mobility and sitting duration (r=-0.25, p<0.05) and a low positive correlation between thoracic mobility and number of days exercised (r=0. 15, p<0.001).

DISCUSSION

Key results

This is the first rigorous observational study to investigate sedentary behaviour, physical activity and thoracic spine mobility in young adults. Whilst no causal relationship can be inferred from this study, findings including a large effect size, provide preliminary evidence to posit a beneficial effect of physical activity and the deleterious effects of sitting on thoracic mobility, a proxy for spinal musculoskeletal health.

Interpretation

The low activity group contained the highest percentage of women, with more than half the group involved in 90-150 minutes of physical activity and 4-6 hours sitting duration a week. Failing to meet the national guidelines for exercise [31] does appear to impact thoracic mobility, compared to those who are fulfilling the recommendations of >150 minutes of moderate physical activity per week [25] and sit for less than 4 hours per day [24]. In contrast, the findings from the physically active group endorse the Public Health England [31] recommendation that exercise is beneficial for musculoskeletal health, with those involved in moderate physical activity having significantly greater thoracic mobility than those who are more sedentary. There is persuasive evidence from this study of a relationship between prolonged sitting and thoracic mobility, with >10° less mobility for the sitters compared to those who were physically active. Moreover, with sitters having approximately 4° less mobility than those in the low activity group, our findings also support the need further investigation of not only increased levels of physical activity, but also reduced sitting duration for optimal spinal musculoskeletal health. Although the majority of individuals in the low activity group sit between 4-7 hours a day (comparable to the findings of the physical activity group), it appears that some physical activity, albeit less than the recommended guidelines is beneficial to offset the 'detrimental' effects of sitting; with those in the low activity group having >6° less thoracic mobility than those in the physically activity group.

These findings lend support for those young adults who comply with national guidelines on physical activity [25] having better musculoskeletal health. Findings also support the need to further investigate types of physical activity, where consideration is made specifically to biomechanical as well as physiological parameters of physical activity such as exercise intensity. With evidence of associations between thoracic mobility and exercise duration (positive), number of days exercised (positive) and sitting duration (negative), further research is now required to investigate the potentially causal relationship of reduced thoracic mobility leading to musculoskeletal complaints such as neck, thoracic and low back pain.

Strengths and limitations

Reported in line with STROBE and employing rigorous methods, including assessor blinding, we have established differences in thoracic mobility in a large population of young adults. Whilst self-reported measures of physical activity and sitting duration potentially lead to under- or over-estimation of sitting and physical activity behaviours, they are able to capture information relating to activities which are not compatible or insensitive to accelerometry such as water based activity or cycling and stair climbing respectively [32].

Although not examined here, patterns of sitting are a potentially important consideration in future studies, where breaks have been shown to be beneficial on pro-inflammatory markers; linked to development of neck-shoulder pain [7]. Moreover, future studies could also usefully evaluate other sitting parameters where constrained or poor postures, ergonomic parameters e.g. keyboard position, may place greater loads on musculoskeletal tissues [17, 33-35].

Generalisability

To enable generalisability to different populations further studies are required with different age groups and individuals from a range of socio-demographic backgrounds. However it is likely that this population comprising young adults are an at 'risk' group for developing future musculoskeletal complaints, with many likely to work in occupations where a substantial periods of time will be sitting [7]. Moreover this population represent a group where there is potential to influence thoracic mobility, with spinal degenerative changes often developing at and beyond the third decade [36] and therefore likely less responsive to physical therapy interventions targeting stiff joints and muscles.

CONCLUSION

This study provides evidence of reduced thoracic mobility in individuals who spend >7 hours a day sitting and <150 minutes of physical activity a week. With observed associations between thoracic mobility and exercise and sitting duration, further research is now required to explore the possible causal relationship between physical activity behaviours on spinal musculoskeletal health and subsequently their relationship to spinal complaints.

Figure 1. Starting position of the heel-sit position

Figure 2. Thoracic rotation moving and measurement being taken

Figure 3. Thoracic mobility measured from all participants classified as either low activity, physically active or sitters

Contribution statement: NH was the chief investigator leading the study design, analyses and dissemination. KT and GB conducted data collection and preliminary analyses. All authors (NH, GB, KT, DF, AR) contributed to analysis and interpretation of results, conclusions and dissemination. NH drafted the initial manuscript. All authors have read, contributed to and agreed on the final manuscript.

Competing Interests Statement: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted

work; no financial relationships with any organisations that might have an interest in the submitted work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work**.**

Funding: None

Data sharing: Raw data is held by the lead author at the University of Birmingham in accordance with guidelines. Data is available by contacting the lead author at n.heneghan@bham.ac.uk

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STROBE Statement—Checklist of items that should be included in reports of ***case-control studies***

	Item No	Page number	Recommendation
Title and abstract	1	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		3	(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction			
Background/rationale	2	5	Explain the scientific background and rationale for the investigation being reported
Objectives	3	6	State specific objectives, including any prespecified hypotheses
Methods			
Study design	4	7	Present key elements of study design early in the paper
Setting	5	7	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	7	(*a*) Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls
		7	(*b*) For matched studies, give matching criteria and the number of controls per case
Variables	7	8	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8*	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	9	Describe any efforts to address potential sources of bias
Study size	10	7	Explain how the study size was arrived at
Quantitative variables	11	8	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	9	(*a*) Describe all statistical methods, including those used to control for confounding
			(*b*) Describe any methods used to examine subgroups and interactions
			(*c*) Explain how missing data were addressed
			(*d*) If applicable, explain how matching of cases and controls was addressed
			(*e*) Describe any sensitivity analyses
Results			
Participants	13*	10	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
			(b) Give reasons for non-participation at each stage
			(c) Consider use of a flow diagram
Descriptive data	14*	10	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
			(b) Indicate number of participants with missing data for each variable of interest
Outcome data	15*	10	Report numbers in each exposure category, or summary measures of

			exposure
Main results	16	11	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
			(*b*) Report category boundaries when continuous variables were categorized
			(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period

Other analyses	17	7		Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion				
Key results	18	7	11	Summarise key results with reference to study objectives
Limitations	19	9	13	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	8	12	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21	9	13	Discuss the generalisability (external validity) of the study results
Other information				
Funding	22	10	14	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.

BMJ Open

What is the effect of prolonged sitting and physical activity on thoracic spinal mobility? An observational study of young adults in a UK university setting

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2017-019371.R2
Article Type:	Research
Date Submitted by the Author:	06-Apr-2018
Complete List of Authors:	Heneghan, Nicola; University of Birmingham, Centre of Precision Rehabilitation for Spinal Pain, School of Sport, Exercise and Rehabilitation Sciences Baker, Gemma; Sandwell and West Birmingham Hospitals NHS Trust, Physiotherapy Thomas, Kimberley ; Heart of England NHS Foundation Trust, Physiotherapy, Solihull Hospital Falla, Deborah; University of Birmingham, Centre of Precision Rehabilitation for Spinal Pain, School of Sport, Exercise and Rehabilitation Sciences Rushton, Alison; University of Birmingham, Centre of Precision Rehabilitation for Spinal Pain, School of Sport, Exercise and Rehabilitation Sciences
Primary Subject Heading:	Rehabilitation medicine
Secondary Subject Heading:	Sports and exercise medicine, Evidence based practice
Keywords:	physical activity, spine mobility, spinal pain, sedentary behaviour, thoracic spine

TITLE

What is the effect of prolonged sitting and physical activity on thoracic spinal mobility? An observational study of young adults in a UK university setting

Authors

Heneghan NR, Baker G, Thomas K, Falla D, Rushton A

Affiliations

Dr Nicola Heneghan — Lecturer Physiotherapy
Centre of Precision Rehabilitation for Spinal Pain
School of Sport, Exercise and Rehabilitation Sciences
University of Birmingham
Birmingham, West Midlands
UK

Miss Gemma Baker — Physiotherapist
Sandwell and West Birmingham Trust
Birmingham, West Midlands
UK

Miss Kimberley Thomas — Physiotherapist
Solihull Hospital
Heart of England NHS Foundation Trust
Birmingham, West Midlands
UK

Professor Deborah Falla — Professor in Rehabilitation Science and Physiotherapy

Centre of Precision Rehabilitation for Spinal Pain

School of Sport, Exercise and Rehabilitation Sciences

University of Birmingham

Birmingham, West Midlands

UK

Dr Alison Rushton Reader in Musculoskeletal Rehabilitation Sciences

Centre of Precision Rehabilitation for Spinal Pain

School of Sport, Exercise and Rehabilitation Sciences

University of Birmingham

Birmingham, West Midlands

UK

Correspondence:

Nicola R Heneghan

Centre of Precision Rehabilitation for Spinal Pain (CPR Spine),

School of Sport, Exercise & Rehabilitation Sciences

University of Birmingham, Edgbaston,

Birmingham. B15 2TT. UK

Email: n.heneghan@bham.ac.uk

Tel: +44 121 415 8367

Keywords

Sedentary behaviour, physical activity, thoracic spine, spinal mobility, spinal pain

Word count

2536

ABSTRACT

Objective

Sedentary behaviour has long been associated with neck and low back pain, although relatively little is known about the thoracic spine. Contributing around 33% of functional neck movement, understanding the effect of sedentary behaviour and physical activity on thoracic spinal mobility may guide clinical practice and inform research of novel interventions.

Design

An assessor blinded prospective observational study designed and reported in accordance with STROBE.

Setting

UK university (June to September 2016)

Participants

A convenience sample (18-30 years) was recruited and based on self-report behaviours were assigned to one of three groups: Group 1] sitters - sitting >7 hours/day + physical activity < 150 minutes/week, Group 2] physically active - moderate exercise >150 minutes/week + sitting < 4 hours/day, and Group 3] low activity - sitting 2-7 hours/day + physical activity <150 minutes/week.

Outcome Measures

Thoracic mobility was assessed in the heel-sit position using Acumar digital goniometer; a validated measure. Descriptive and inferential analyses included analysis of variance (ANOVA) and covariance (ANCOVA) for between group differences and Spearman's rank correlation for *post hoc* analysis of associations.

Results

The sample (n=92) comprised: Sitters n=30, Physically active n=32, and Low activity n=30. Groups were comparable with respect to age and BMI.

Thoracic spine mobility (mean [SD]) was; Group 1 sitters 64.75[1.20], Group 2 physically active 74.96[1.18] and Group 3 low activity 68.44[1.22]. Significant differences were detected between 1) sitters and low activity 2) sitters and physically active ($p<0.001$). There was an overall effect size of 0.31. Correlations between thoracic rotation and exercise duration ($r=0.67$, $p<0.001$), sitting duration ($r=-0.29$, $p<0.001$) and days exercised ($r=0.45$, $p<0.001$) were observed.

Conclusions

Findings evidence reduced thoracic mobility in individuals who spend >7 hours/day sitting and <150 minutes/week of physical activity. Further research is required to explore possible causal relationships between activity behaviours and spinal musculoskeletal health.

FIG

Article summary

- The study employed rigorous methods and validated approaches to investigate thoracic spine functional mobility
- The inclusion of accelerometry would have been useful to verify self-report behaviours
- Whilst the study sample size was based on *a priori* power calculation of the primary outcome, a validated measure of thoracic mobility, individual group sample size was insufficient to support further post hoc analysis

INTRODUCTION

Background/rationale

Sedentary lifestyles are an undesirable hallmark of modern society affecting a significant proportion of the population [1]. Prolonged sitting (a form of sedentary behaviour) has progressively become the norm with computerisation in the work place, transportation modernisation, and advances in domestic technology [2]. These developments are not only detrimental for physiological health and wellbeing with rising levels of obesity, diabetes, and cardiovascular disease [3], but also musculoskeletal health and well-being with recent research finding an association between prolonged sitting (>8 hours a day) and increased neck-shoulder [4-7] and low back pain [8]. It is therefore reasonable to suppose that sedentary behaviours may induce musculoskeletal changes within the relatively stiff thoracic spine; contributing towards the dysfunction in the adjacent spinal regions. The term ”regional interdependence” describes a relationship whereby seemingly unrelated impairments in one anatomical region are associated with the development or persistence of pain in another [9]. Contributing to 33% and 21% of the movement occurring during neck flexion and rotation respectively [10], it is not surprising that the thoracic spine may contribute to the development of pain in surrounding the neck. Empirical evidence supports this theory, where thoracic movement dysfunction has been linked to pathologies in the neck [11] shoulder [12] and elbow [13]. Furthermore, there is a considerable body of compelling evidence to support the use of physiotherapy treatment techniques targeting the thoracic spine in clinical presentations of neck and shoulder pain [14-16]. Notwithstanding the paucity of literature exploring the influence of sedentary behaviours on the thoracic spine, one large cross sectional study (n=1886) did report a relatively high prevalence of thoracic spine pain, alongside neck and back pain in sedentary workers (36-41%), most notably in individuals with postural constraints, such as drivers and individuals unable to change tasks regularly [17]. However, the relationship between sedentary behaviour and

thoracic mobility, a proxy for spinal musculoskeletal health, contributing 80% of axial spinal trunk rotation [18] has not yet been established.

Arguably those who are physically active may present with greater mobility of their thoracic region where exercise promotes joint and soft tissue mobility, countering the deleterious adaptive shortening of muscles and joint stiffness through static postures [19]. However, it remains unclear what physical activity is comprised of in terms of; 'length of activity', 'type of activity', and 'how often' the activity is performed. Physical activity has been previously defined as "more than 150 minutes of moderate to intense physical activity per week" [20]. However a focus on physical exertion seems inadequate when considering musculoskeletal health [21], and arguably biomechanical factors such as mobility and types of activity should also be considered, where some physical activity have been sub classified as linear (straight-line e.g. running) or dynamic (rotational e.g. tennis) in nature.

With sedentary lifestyles becoming increasingly the norm and evidence that sitting for just 1 hour leads to increased spinal stiffness [22] it is now important to further investigate the relationship between sedentary behaviours, physical activity and thoracic spine mobility. Therefore, the aim of this study was to investigate the influence of prolonged sitting and physical activity on thoracic spine mobility.

Objectives

1. Investigate the influence of sedentary behaviour on thoracic spine mobility
2. Investigate the influence of physical activity on thoracic spine mobility
3. To evaluate whether a relationship exists between duration of sitting and physical activity and thoracic mobility

METHODS

Design and setting

A single assessor blinded prospective observational study was conducted between April and June 2016 within a University setting; designed and reported in line with STROBE guidelines [23].

Recruitment

Participants were recruited via email from the staff and student body of a large UK University using posters and email advertisement. Interested and eligible participants were provided with a participant information sheet, had their questions answered, and were asked to provide written informed consent. Screening against eligibility criteria was performed at the point of recruitment by a research assistant (KT).

The School of Sport, Exercise and Rehabilitation Sciences Ethics Committee granted ethical approval and the study was conducted according to the Declaration of Helsinki with participants able to withdraw at any point.

Participants

Participants comprised a convenience sample of healthy asymptomatic volunteers from within a UK university population. Eligibility criteria included young adults 18-30 years, who fulfilled one of the following criteria based on Dunstan et al., [24] for sitting duration and NICE Guidelines [25] for duration of moderate intensity physical activity [26]. The sample size was based on a minimum of 30 per group to be able to detect a minimum clinically important difference (10-degrees) in thoracic spinal rotation movement between the groups, based on power 0.8 and at 5% significance level [27].

1. Individuals who participate in >150 minutes of physical activity per week and sit <4 hours per day (physically active)
2. Individuals who participate in <150 minutes of physical activity per week and sit >7 hours per day (sitters)

3. Individuals who spend between 4-7 hours sitting daily and <150 minutes of physical activity per week (low activity).

Exclusion criteria included a current or previous neuromusculoskeletal spine condition, rheumatoid arthritis, current or chronic respiratory condition, pregnancy, current hip or knee pathology, unable to adopt heel sit position, not fulfilling one of the criteria listed above.

Variables: Demographic data and outcome assessment

Procedure

Piloting to determine the feasibility of the protocol was performed prior to the main study. For the main study, one researcher (KT) recruited, screened and took all baseline measures to characterise the sample [age, gender, body mass index (BMI), exercise type/duration, sitting duration]. The primary measure of interest, thoracic spine mobility, was recorded by a blinded assessor (GB) with the participant an a heel-sit position [28, 29] . Following familiarisation and 3 practice attempts from a position of full right to left rotation to ensure stability of measures [27], the end range position of the 4th rotation was measured 3 times using an Acumar digital inclinometer placed over the C7-T1 interspinous space [27, 29]. The mean of the 3 measures for full right and left rotation were recorded and retained for data analysis [27].

Outcome measure

The Acumar digital inclinometer (Acumar, Model ACU 360, Lafayette Instrument Company, Indiana, USA) was used to measure thoracic rotation. The heel-sit position was chosen to minimise concurrent movement occurring in the relatively mobile lumbar spine, a limitation of sitting where rotation comprises motion from both regions [28]. Reliability ($ICC_{2,1}$ [95% confidence interval], 0.88 [0.78, 0.93]) and strong criterion (r=0.88) and concurrent validity (r=0.98) against a combined imaging and motion analysis approach has previously been established [28, 29].

Bias

A number of measures were put in place to minimise the influence of bias, including use of a validated measurement approach[29], standardisation of procedures through training of assessor, assessor blinding, controlling for environmental variables, avoidance of physical activity prior to testing, partial blinding of participants in that they were not made aware of *a priori* planned comparison between groups and piloting of all procedures in advance of the main study.

Statistical methods

Data were transferred to SPSS (version 22, IBM, New York, NY) and checked to ensure their integrity by two researchers. Descriptive statistical analyses included a summary of participant characteristics (age, gender, BMI, types of exercise, duration of exercise and sitting) using means, standard deviations. Inferential analysis initially included one-way analysis of variance (ANOVA) to explore between group differences, and *post hoc* comparisons to explore between group differences. Effect size (eta squared) was calculated, and interpreted using Cohen's classification [30].

Further inferential analyses included an analysis of co-variance (ANCOVA) to determine main effects including Bonferroni correction (with pairwise comparisons) to evaluate between group differences in thoracic spine mobility with gender as a covariate (as groups were imbalanced with respect to gender). Spearman's rank correlation correlational analyses were used to evaluate relationships between thoracic mobility and self-report measures of sitting duration, days active, and physical activity. For all analyses statistical significance was set at $p<0.05$.

Patient involvement

The study was conceived from our working with patients with spinal complaints over many years and their views used to inform the design and methods used. Study findings have been disseminated to patients and participants via conference presentations including the Centre of Precision Rehabilitation for Spinal Pain, Patient and Public Involvement Group.

RESULTS

Participants, descriptive data and outcome data

A total of 92 participants were recruited. Baseline characteristics, self-reported behaviours for physical activity (exercise duration and types of exercise), and sitting duration are presented in Table 1. Groups were comparable with respect to age and BMI ($p>0.05$), but not for gender with more women were recruited to the low activity and sitter group.

Table 1: Participant characteristics

	Sitters n=30	Physically active n=32	Low activity n=30
Age in years, mean (SD)	22.73 (2.92)	22.03 (2.65)	20.93 (2.49)
Gender (Women %)	63.3$	47.0$	76.7$
BMI, mean (SD)	22.90 (2.47)	23.12 (2.92)	22.60 (2.36)
Thoracic rotation degrees mean (SD) 95% Confidence interval	64.74 (8.93) 62.37, 67.14	74.96 (8.26) 72.61, 77.31	68.44 (4.36) 66.02, 70.86
Exercise duration (minutes)			
0-30	7	-	3
30-60	4	-	6
60-90	15	-	5
90-150	4	-	16
150-180	-	4	-
180-210	-	12	-
210-240	-	5	-
240+	-	11	-
Types of exercise (frequency)			
Gym cardio	6	10	1
Gym weights	5	3	9
Running	10	6	-
Cycling	3	1	3
Dance/gymnastics	-	3	1
Football	-	4	2
Netball/basketball	-	1	1
Tennis	-	3	2
Rowing	-	1	-
Martial arts	1	-	-
Other	3	-	11
None	2	-	-
Sitting duration (hours)			
0-2	-	1	-
2-4	-	5	6
4-6	-	11	17
6-7	-	15	7
7-8	9	-	-
8-9	9	-	-
9-10	6	-	-
10+	6	-	-

$ Statistically different p<0.001

Main results

Thoracic spine mobility (mean, SD and 95% CI) for the sitters, physically active and low activity groups were 64.74±6.33 (62.37,67.14°), 75.12±8.26 (72.61, 77.31°), 68.28±4.36 (66.02, 70.86°) respectively (Figure 1).

Results from the ANOVA showed a statistically significant difference in thoracic mobility between groups [F (2,56)=20.19 P<0.001], with a large effect size of 0.31. *Post hoc* comparisons of group mean scores indicated significant differences between the low activity and physically active groups (6.84-degrees, p<0.001), the physically active group and sitters (10.38 degrees, p<0.001), although not between the low activity and sitters (3.54 degrees).

A one-way ANCOVA was conducted having checked data met the assumptions to compare thoracic mobility between groups, whilst controlling for gender. There was a significant difference between groups [F (2,88)=18.66 P<0.001] with the *post hoc* analyses confirming differences between the low activity and physically active groups (p<0.001), the physically active group and sitters (p<0.001), although not between the low activity and sitters.

Insert Figure 1

Other analyses: Correlational analysis

Across the whole sample, a moderate positive correlation was found between thoracic mobility and exercise duration (r=0.62, p<0.001), a low negative correlation between sitting duration (r=-0.25, p<0.05) and low positive correlation between number of days exercised (r=0. 15, p<0.001).

DISCUSSION

Key results

This is the first rigorous observational study to investigate sedentary behaviour, physical activity and thoracic spine mobility in young adults. Whilst no causal relationship can be inferred from this study, findings including a large effect size, provide preliminary evidence to posit a beneficial effect of physical activity and the deleterious effects of sitting on thoracic mobility, a proxy for spinal musculoskeletal health.

Interpretation

The low activity group contained the highest percentage of women, with more than half the group involved in 90-150 minutes of physical activity and 4-6 hours sitting duration a week. Failing to meet the national guidelines for exercise [31] does appear to impact thoracic mobility, compared to those who are fulfilling the recommendations of >150 minutes of moderate physical activity per week [25] and sit for less than 4 hours per day [24]. In contrast, the findings from the physically active group endorse the Public Health England [31] recommendation that exercise is beneficial for musculoskeletal health, with those involved in moderate physical activity having significantly greater thoracic mobility than those who are more sedentary. There is persuasive evidence from this study of a relationship between prolonged sitting and thoracic mobility, with >10° less mobility for the sitters compared to those who were physically active. Moreover, with sitters having approximately 4° less mobility than those in the low activity group, our findings also support the need further investigation of not only increased levels of physical activity, but also reduced sitting duration for optimal spinal musculoskeletal health. Although the majority of individuals in the low activity group sit between 4-7 hours a day (comparable to the findings of the physical activity group), it appears that some physical activity, albeit less than the recommended guidelines is beneficial to offset the 'detrimental' effects of sitting; with those in the low activity group having >6° less thoracic mobility than those in the physically activity group.

These findings lend support for those young adults who comply with national guidelines on physical activity [25] having better musculoskeletal health. Findings also support the need to further investigate types of physical activity, where consideration is made specifically to biomechanical as well as physiological parameters of physical activity such as exercise intensity. With evidence of associations between thoracic mobility and exercise duration (positive), number of days exercised (positive) and sitting duration (negative), further research is now required to investigate the potentially causal relationship of reduced thoracic mobility leading to musculoskeletal complaints such as neck, thoracic and low back pain.

Strengths and limitations

Reported in line with STROBE and employing rigorous methods, including assessor blinding, we have established differences in thoracic mobility in a large population of young adults. Whilst self-reported measures of physical activity and sitting duration potentially lead to under- or over-estimation of sitting and physical activity behaviours, they are able to capture information relating to activities which are not compatible or insensitive to accelerometry such as water based activity or cycling and stair climbing respectively [32].

Although not examined here, patterns of sitting are a potentially important consideration in future studies, where breaks have been shown to be beneficial on pro-inflammatory markers; linked to development of neck-shoulder pain [7]. Moreover, future studies could also usefully evaluate other sitting parameters where constrained or poor postures, ergonomic parameters e.g. keyboard position, may place greater loads on musculoskeletal tissues [17, 33-35].

Generalisability

To enable generalisability to different populations further studies are required with different age groups and individuals from a range of socio-demographic backgrounds. However it is likely that this population comprising young adults are an at 'risk' group for developing future musculoskeletal complaints, with many likely to work in occupations where a substantial periods of time will be sitting [7]. Moreover this population represent a group where there is potential to influence thoracic mobility, with spinal degenerative changes often developing at and beyond the third decade [36] and therefore likely less responsive to physical therapy interventions targeting stiff joints and muscles.

CONCLUSION

This study provides evidence of reduced thoracic mobility in individuals who spend >7 hours a day sitting and <150 minutes of physical activity a week. With observed associations between thoracic mobility and exercise and sitting duration, further research is now required to explore the possible causal relationship between physical activity behaviours on spinal musculoskeletal health and subsequently their relationship to spinal complaints.

LEGEND

Figure 1: Thoracic rotational mobility across groups: sitters, physically active and low activity

Contribution statement: NH was the chief investigator leading the study design, analyses and dissemination. KT and GB conducted data collection and preliminary analyses. All authors (NH, GB, KT, DF, AR) contributed to analysis and interpretation of results, conclusions and dissemination. NH drafted the initial manuscript. All authors have read, contributed to and agreed on the final manuscript.

Competing Interests Statement: All authors have completed the ICMJE uniform disclosure form at www.icmje.org/coi_disclosure.pdf and declare: no support from any organisation for the submitted work; no financial relationships with any organisations that might have an interest in the submitted

work in the previous three years; no other relationships or activities that could appear to have influenced the submitted work**.**

Funding: None

Data sharing: Raw data is held by the lead author at the University of Birmingham in accordance with guidelines. Data is available by contacting the lead author at n.heneghan@bham.ac.uk

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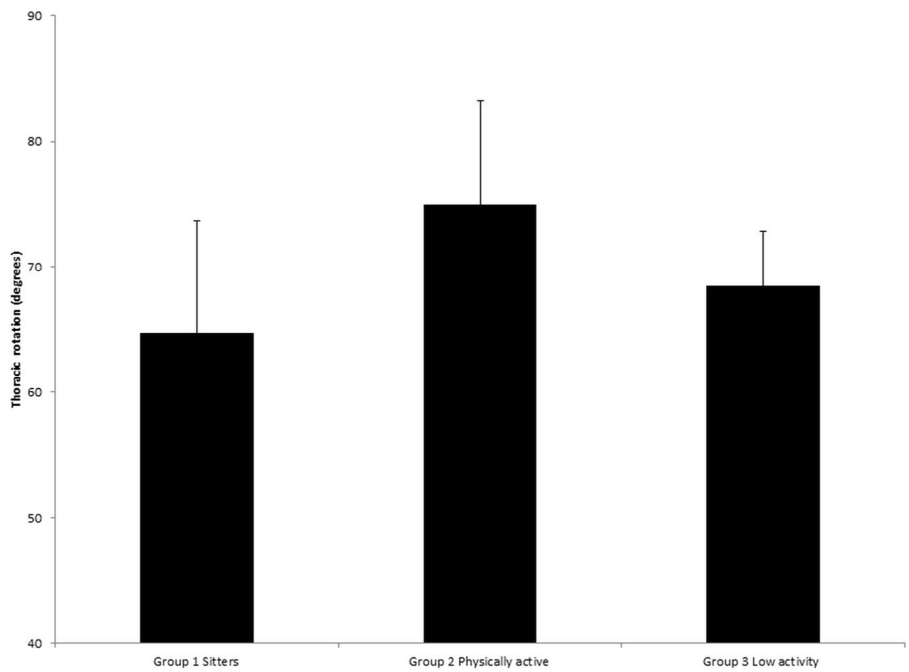

Figure 1: Thoracic rotational mobility across groups: sitters, physically active and low activity

119x90mm (300 x 300 DPI)

STROBE Statement—Checklist of items that should be included in reports of ***case-control studies***

	Item No	Page number	Recommendation
Title and abstract	1	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract
		3	(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found
Introduction			
Background/rationale	2	5	Explain the scientific background and rationale for the investigation being reported
Objectives	3	6	State specific objectives, including any prespecified hypotheses
Methods			
Study design	4	7	Present key elements of study design early in the paper
Setting	5	7	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection
Participants	6	7	(*a*) Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls
		7	(*b*) For matched studies, give matching criteria and the number of controls per case
Variables	7	8	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable
Data sources/ measurement	8*	8	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group
Bias	9	9	Describe any efforts to address potential sources of bias
Study size	10	7	Explain how the study size was arrived at
Quantitative variables	11	8	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why
Statistical methods	12	9	(*a*) Describe all statistical methods, including those used to control for confounding
			(*b*) Describe any methods used to examine subgroups and interactions
			(*c*) Explain how missing data were addressed
			(*d*) If applicable, explain how matching of cases and controls was addressed
			(*e*) Describe any sensitivity analyses
Results			
Participants	13*	11	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed
			(b) Give reasons for non-participation at each stage
			(c) Consider use of a flow diagram
Descriptive data	14*	11	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders
			(b) Indicate number of participants with missing data for each variable of interest
Outcome data	15*	11	Report numbers in each exposure category, or summary measures of

			exposure
Main results	16	11/12	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included
			(*b*) Report category boundaries when continuous variables were categorized
			(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period

Other analyses	17	7		Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses
Discussion				
Key results	18	7	12	Summarise key results with reference to study objectives
Limitations	19	9	14	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias
Interpretation	20	8	13	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence
Generalisability	21	9	14	Discuss the generalisability (external validity) of the study results
Other information				
Funding	22	10	15	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based

*Give information separately for cases and controls.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at http://www.strobe-statement.org.