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Influence of a dynamic seating habit on lumbar motor control in schoolchildren

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Abstract.

BACKGROUND: Adequate motor control is considered important for spinal stability and the prevention of low back pain in adulthood and in childhood.

OBJECTIVE: Given that the sitting position can affect proprioception, this study aimed to evaluate the influence of using at school a triangular and dynamic cushion on schoolchildren's trunk motor control.

METHODS: Thirty 8-year-old schoolchildren were randomized into a control group (n = 15) and a "cushion group" (n = 15), in which the children used the cushion for one year and a half. At the end of this period, a 3D-analysis was used to assess lumbar spine proprioception by means of a trunk repositioning task performed blindfolded in a seated position in two conditions (on a stable and on an unstable surface).

RESULTS: The schoolchildren in the cushion group performed better at the trunk repositioning task ($p = 0.02$) and hold their lumbar lordosis ($p = 0.03$) better than the control children, in both conditions (stable and unstable).

CONCLUSIONS: This preliminary study suggests that daily use of a triangular dynamic cushion has a beneficial impact on children's lumbar proprioception. Further studies are needed to confirm these results and investigate the effectiveness of its use to prevent low back pain in adulthood.

Keywords: Ergonomics, schoolchildren, sitting position, lumbar spine, reposition sense, proprioception

1. Introduction

Trunk proprioception is considered important for spinal stability and the prevention of injury [1] and particularly of low back pain [2,3]. However, the neural control strategy to stabilize the spine is complex. Actually, it is not sufficient to select the appropriate muscles to activate, but it is also necessary to decide on the appropriate activation level and to control and readjust movement all the time [4]. That function relies on the visual, vestibular, and extensive muscular and articular proprioceptive systems [5,6]. In particular, muscles spindles have a major role in proprioception, providing static and dynamic proprioceptive sensory input to the motor control system [4,5,7]. Given that proprioception is the function of afferent integration and tuning of muscular and articular receptors, it is obvious that it can be affected by changes in body posture [5] and thus also in the sitting position. In fact, "slouched" or flexed posture affects the reflexive activity of the proprioceptive structures and viscoelastic properties of spinal

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tissues so that lumbar motor control can be degraded in the long term [1]. Moreover, in this posture, the lumbar neutral position is lost [8]; as a result, articular stress increases and muscles spindles perform minimally, whereas joint receptors are very active at extreme joints angles [4]. Consequently, it is usually suggested to keep a more erect position as often as possible [8]. Unfortunately, maintaining an
erect posture when sitting on traditional furniture requires a high level of muscular activity [9,10] which, after a prolonged period, may lead to fatigue and affect trunk muscle function and proprioception [5]. A position with a 130o trunk - thighs angle is often recommended in order to preserve the physiological lumbar lordosis [8,11,12] and modulate the intensity of spine muscle activation [13,14]. On the other hand, the muscular inactivity observed in a prolonged static sitting position may induce hypotonia [15] and affect trunk proprioception [1]. Therefore, sitting on a triangular (to open the trunk – thighs angle) and dynamic (to reduce the static effect of the sitting position]cushion is considered to be a solution [16].
To the best of our knowledge, no study has yet investigated the link between schoolchildren's sitting position habit and lumbar proprioception. However, from as early as the first year of elementary school, pupils spend about a thousand hours a year sitting, most of the time, upon unsuitable furniture and in an inadequate body posture [17,18] that could result in motor control dysfunction.
Considering the scant literature on the topic, the aim of this study was to investigate the effectiveness of the long-term use of a triangular dynamic cushion put on traditional school furniture on schoolchildren's proprioception.

2. Materials and methods

Eight-year-old schoolchildren coming from the same school were invited to participate in the present study; with the informed consent of both parents and children. The inclusion criteria were that the children had to have been born in 2008, had to be in second elementary school and did not suffer from any known skeletal deformations or neurological problems. At school, all children sat on similar furniture (chair, desk). In addition, 15 participants had to sit throughout the school day on a triangular dynamic air-inflated cushion (Movin'Sit(c)!!!: 7 × 25 × 30 cm) (Fig. 1) for one year and a half to constitute the "cushion group", while the other 15 children who never used the cushion constituted the control group.
All participants attended a one-hour assessment session conducted in the Laboratory of Human Motion Analysis (LAMH) of the University of Liège, Belgium. This session aimed to assess lumbar proprioception by means of a repositioning task performed in a sitting position. The protocol was identical to the one used
by Hidalgo et al. [19]. This test consisted of measuring the repositioning error in a trunk forward bending task in two conditions: on a traditional seat (stable) and on a circular air-filled cushion placed on the stool (unstable condition). The height of the stool was adjusted, for each child and in each condition, to create a 130^{o} angle between the trunk and thighs, allowing the maintenance of lumbar physiological curvature by anterior pelvic tilt in the starting position [20]. To minimize proprioceptive feedback from the limbs [21], participants were positioned in a standardized position: both feet were placed on a mark and both upper limbs were crossed in front of the chest with the hands on the contralateral shoulder. As described by Hidalgo et al. [19], after a 5-second period in the erect *starting position* (measure 1), participants were asked to bend forward while maintaining the spine physiological position until a 30^{o} trunk flexion target position (measured with a goniometer and objectified by a chair contact on chest) and to hold that *target position* (measure 2) for 5 seconds to memorize it before returning to the starting position. After that preparation phase, the chair was removed and participants were instructed to move to the target position as precisely as possible while keeping the spine straight and return to the starting position 10 times (measure 3 = mean of the 10 real flexed positions) at their own pace (spontaneous speed). The whole procedure was performed with the eyes blindfolded in both conditions (on the stable and unstable surfaces). To avoid bias due to a training phe¬nomenon [22], the order of assessment of both condi¬tions was randomized and spaced by a 5-minute free-motion period.
A three-dimensional optoelectronic system (CodamotionTM , Charnwood Dynamics, Rothley, UK) was used to measure the repositioning error during the trunk forward bending task. We tracked the 3D position of the child's trunk, pelvis and legs with 13 markers and four Codamotion CX1 units. The acqui¬sition rate was 100 Hz. We placed

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five markers along the spine, four markers on the pelvis and four mark¬ers on both legs (Fig. 2). The marker placements al¬lowed us to measure different angles (o). Therefore, the repositioning error was first analysed regarding the global trunk flexion (a), while specific motor control was evaluated in dorsal (b) and lumbar (c) spine cur¬vature, pelvis tilt (d) and hip flexion (e) (Fig. 3). These angles were measured at different moments: the initial erect position (measure 1), the flexed target position (measure 2) and during the bending forward task, at the end of each trunk flexion of the 10 trials (measure 3). Repositioning error was defined as the absolute alge¬braic difference between the mean value of the 10 tri¬als (measure 3) and the flexed target position (measure 2).

Fig. 1. *Illustration of a child sitting on the cushion Movin'Sit© at school.*

Fig. 2. *Placement of 3D-markers (a = C7/D1; b = top of the dorsal curvature; c = D12/L1; d = top of the lumbar curvature; e = L5/S1; f–g = PSIS; h–i = ASIS; j = trochanter; k = joint space of the knee; l = malleolus; m = metacarpal bone V).*

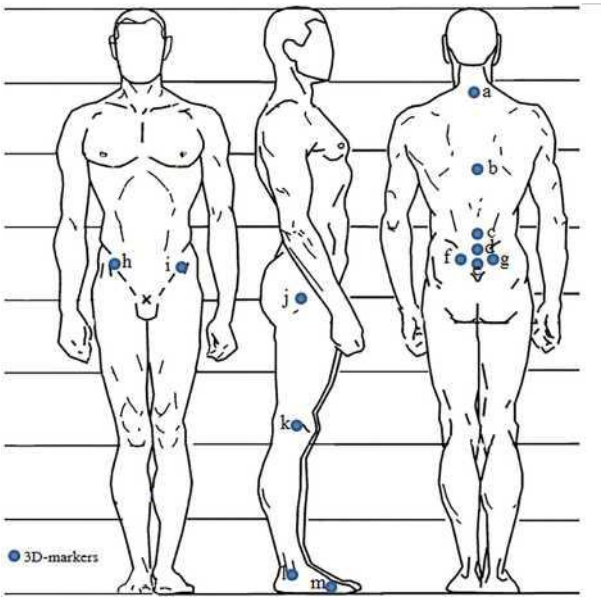

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Table 1. *Anthropometric characteristics of the control and experimental groups (mean ± SD)*

	Control group (n = 15)	Cushion group (n = 15)	p
Age (years)	7.8 ± 0.41	7.7 ± 0.75	0.93
Height (cm)	128.9 ± 5.86	129.7 ± 6.44	0.94
Weight (Kg)	27.0 ± 5.23	29.6 ± 8.81	0.67

2.1. Statistical analysis

The minimum sample size was estimated using power-based sample size calculations for the global trunk repositioning error. Based on a preliminary study and an estimated baseline trunk repositioning error of 10° and standard deviation of 4°, the minimum sample size was estimated at 26 participants to detect a 50% difference in the experimental group when $\alpha < 0.05$ and the power is 95%.
The statistical analysis was carried out using the statistical software "R" (version 3.3.0). Basic descriptive statistics and frequency tables were used to calculate the means, standard deviations, extreme values and percentages. Normal distribution of the data was verified and the Student t-test for independent and for paired samples was respectively used to compare the starting (measure 1) and target (measure 2) positions in both groups and to analyse the movements from the first position to the second. A two-way repeated measure ANOVA was used to compare the children's repositioning errors in both groups in both conditions (stable and unstable). Significant results were determined as $p < 0.05$.

3. Results

Thirty 8-year-old schoolchildren (age: 7.8 ± 0.4 years; height: 129.3 cm ± 6.15; weight: 28.3 ± 7.01) were included in this study and performed the repositioning test in both conditions. Their anthropometric characteristics are presented in Table 1; these did not significantly differ between groups *($p > 0.05$)*.
Table 2 illustrates the body posture at the starting (measure 1) and the target (measure 2) positions. No differences between groups were observed regarding each static position. In addition, when the children realized a global trunk flexion of 30°, we can observe that the movement mainly corresponds to a pelvis tilt (p = 0.03), whereas dorsal and lumbar curvatures only change slightly *($p > 0.1$)*. Figure 4 illustrates the 10 trunk flexion trials of the repositioning test in one child from each group.

Table 2. *Between-group comparison of the angles at the starting (measure 1) and the target (measure 2) positions (m ± SD)*

Angle	Starting position (measure 1)			Target position (measure 2)			
	Control group (n = 15)	Cushion group (n = 15)	p	Control group (n = 15)	Cushion group (n = 15)	p	P between positions
Trunk flexion (◦)	-1.8 ± 13.1	0.9 ± 8.5	0.33	30.4 ± 12.2	30.5 ± 12.7	0.38	0.01*
Dorsal kyphosis (◦)	165.1 ±5.9	161.7 ± 8.6	0.09	166.2 ±7.8	162.5 ± 12.1	0.63	0.54
Lumbar lordosis (◦)	174.5 ± 13.3	179.5 ±9.5	0.09	175.3 ± 11.4	180.1 ± 11.6	0.12	0.49
Pelvis tilt (◦)	-1.7 ±0.6	1.2 ± 7.9	0.47	24.5 ± 10.4	23.5 ± 8.2	0.71	0.03*
Hip flexion (◦)	54.3 ± 16.2	53.5 ± 11.6	0.85	55.1 ± 9.91	51.9 ± 11.9	0.20	0.15

*$p < 0.05$.

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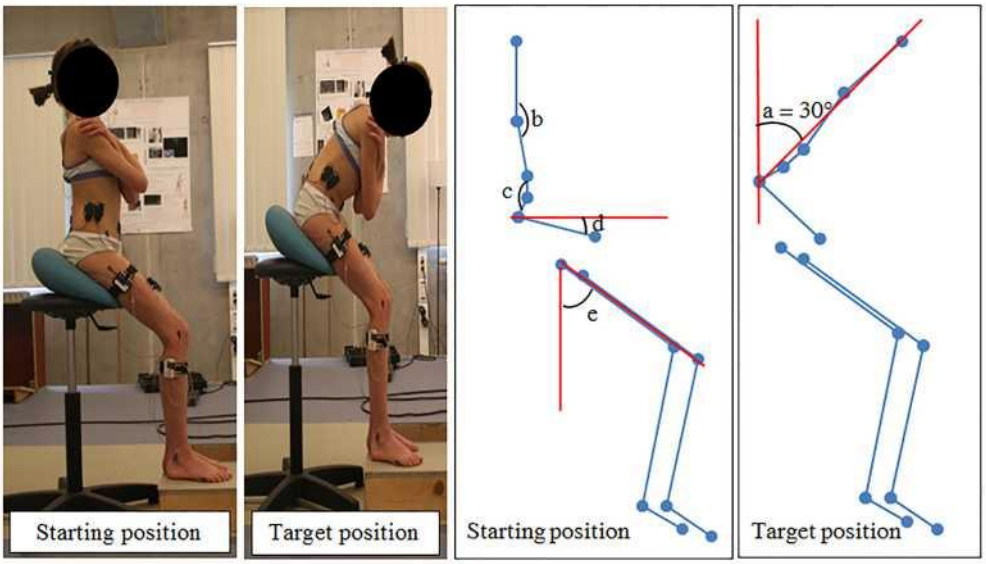
Fig. 3. *Illustration in one subject of the starting (measure 1) and target positions at 30° trunk flexion (measure 2) in the unstable condition and of the different measured angles (a = global trunk flexion; b = dorsal kyphosis; c = lumbar lordosis; d = pelvis tilt; e = hip flexion).*



Between-group comparisons showed that, globally, the cushion group performed significantly better in the tasks than the control group (Table 3), regardless of the conditions. Indeed, the cushion group had reduced repositioning errors for the global trunk flexion ($p < 0.02$) in both conditions. Specifically, this group held the lumbar lordosis better than the other group ($p = 0.03$). No significant difference appeared regarding the other parameters. On the other hand, it appears that children of both groups perform identically in both conditions (Table 3).

4. Discussion

Schoolchildren spend about a thousand hours a year in a sitting position. Considering that a poor sitting position may be one of the risk factors of trunk motor control dysfunction and injuries in school environments [23,24], the impact of the sitting position at the start of primary school on proprioception should be taken into consideration, especially as this is an important period during which children may get bad habits [25].

Several methods exist to evaluate lumbar motor control and proprioception [26]. The most common assessments of proprioception consist in the measurement of active and/or passive repositioning error (i.e. the difference between a target position and the position reached by the participant) using kinematic tools [2,22,26–28]. The 3D analyses conducted in the present study enabled us to measure very accurately the repositioning errors related to the global trunk flexion, but also the motor control of the spine curves. Actually, while most studies have evaluated only global segments, considering these as rigid and homogeneous [19], this study aims to evaluate in detail the body parts where movement really occurs.

Table 3. *Between-group comparison of the score of repositioning error and motor control tasks in both conditions (stable and unstable) (m ± SD)*

Angle	Condition	Control group (n = 15)	Cushion group (n = 15)	p between groups	p between conditions	p groups × conditions
Trunk flexion (°)	Stable	15.9 ± 10.9	7.3 ± 3.9	0.02*	0.83	0.79
	Unstable	12.7 ± 5.5	7.0 ± 5.2			
Dorsal kyphosis (°)	Stable	5.5 ± 5.6	6.4 ± 4.8	0.96	0.77	0.93

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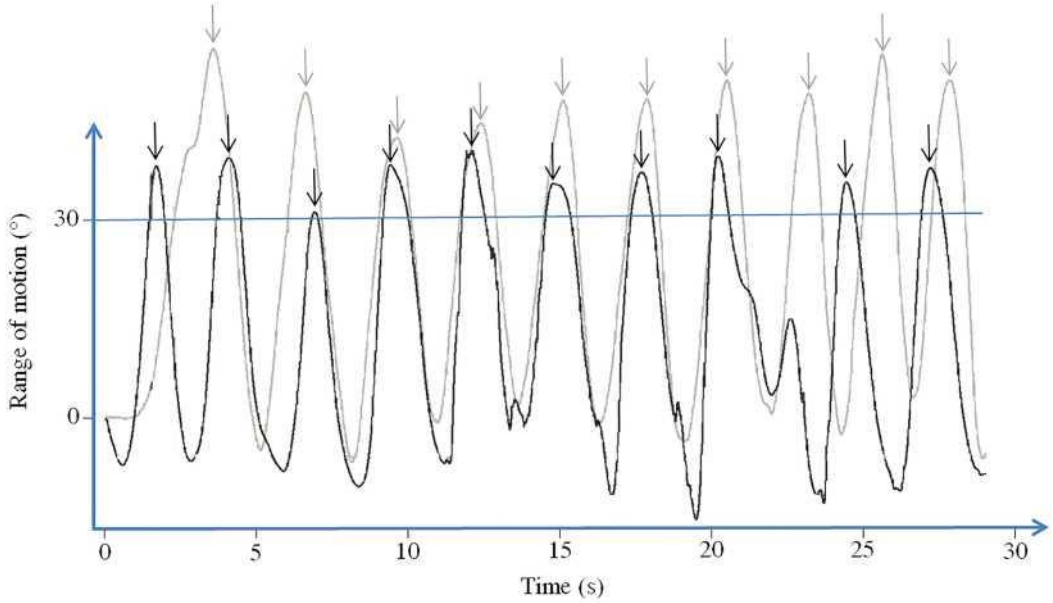
	Unstable	6.1 ± 7.9	7.3 ± 9.7			
Lumbar lordosis (◦)	Stable	10.8 ± 8.8	5.4 ± 4.6	0.03*	0.43	0.23
	Unstable	11.8 ± 3.1	5.7 ± 3.6			
Pelvis tilt (◦)	Stable	10.2 ± 10.7	8.3 ± 6.6	0.36	0.67	0.23
	Unstable	9.5 ± 10.0	9.5 ± 9.2			
Hip flexion (◦)	Stable	7.2 ± 6.0	8.9 ± 7.6	0.06	0.87	0.28
	Unstable	5.1 ± 8.2	7.6 ± 8.3			

*$p < 0.05$.

Fig. 4. *Illustration of the trunk flexion (°) time course (s) between the starting position (0°) and the target position (30°) in stable condition of one control (in grey) and one "cushion" (in black) child (arrow = time when the repositioning error was calculated).*



In accordance with Stillman [6], who described five inputs of proprioception (from cutaneous tissues, articulation, muscle, tendon and visual inferences), several instructions have to be respected during the task. Therefore, to minimise the proprioceptive feedback from the limbs [21] and visual inferences, the subjects were positioned in a standardized position and performed the tasks with their eyes blindfolded. In addition, since our study focuses on sitting on a triangular dynamic cushion and that posture affects proprioceptive feedback [5,29], the repositioning task was realized in a sitting position with a 130° trunk - thighs angle as provided by the cushion. A same position was already used in other studies to evaluate the proprioception in adulthood [19]. In addition, based on the fact that various artificial proprioceptive perturbations can affect the repositioning error sense of the lumbar spine in healthy individuals [19], the repositioning task were also done on an unstable surface. In this condition, the test might be more discriminant than on a stable surface and therefore more significant results might appear.

The comparison between the starting (measure 1) and the target (measure 2) positions confirmed that the trunk flexion movement mainly resulted from a pelvic tilt and that the children of both groups managed to keep the spine straight in a static position [14]. As concerns the repositioning error, the children's errors in this study differ from the literature. Actually, it appears that our 8-year-old children performed less well (error of ± 10° for the global trunk flexion) than adults (error of ± 4°) [19]. This result is logical given that children are still developing and, specifically, that trunk positioning accuracy improves significantly with age and particularly after the age of 9 [30,31]. However,

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the cushion group showed reduced repositioning error for the global trunk flexion in both conditions (stable and unstable). In addition, they managed to hold their lumbar lordosis better than the control subjects. Given that promoting and training lumbar proprioception seems important [1,32], the better performance of the cushion group might result from the fact that sitting daily on this cushion can be considered as a kind of proprioceptive training. Indeed, the inclination of the cushion induces a 130° trunk - thighs angle in order to preserve the neutral lordosis with little muscle activity [8,11,12,33]. In this posture, the reflexive activity proprioceptive structures and viscoelastic properties of spinal tissues are the most efficient [1,4]. In addition, the cushion is inflated by air and therefore induces a dynamic sitting position that stimulates small perturbations around the erect posture all the time. Muscles spindles performing better in this ROM of lumbar spine [4], and regular stimulation could also enhance their capacity for detection of static and/or dynamic changes in muscle length/position so that the lumbar control motor improves [5]. The fact that no significant difference appeared for the other trunk segments may be explained by the fact that the dynamic and tilted seat acts directly on the lumbo-pelvic kinematics more than on other trunk segments [32].

A second hypothesis was that the repositioning error was larger on an unstable surface but that children who have habit to sit on unstable surface perform anyway better than others. The between-group comparison indicated no differences between the assessment in the stable and unstable conditions, suggesting that the unstable surface does not influence children's repositioning abilities. However, other studies have reported that unstable surfaces increase repositioning errors [19]. This could be explained by the fact that the level of perturbation might have been different because the unstable surface was created differently, with an air-filled cushion on the seat (in our experimental conditions) as opposed to a stability ball used in other studies [19].

4.1. Limitations

Although we included a number of participants in accordance with the results of our power analysis, our results need to be confirmed with a larger sample. On the other hand, the children's performance was assessed only after the cushion group used the cushion for 18 months. A pre-test, before the cushion group began to use the cushion, would be interesting to ensure that both groups were initially identical in terms of repositioning error.
In addition, information about the individual physical activity habit of the participants (time/day spent in sport; type of sport; daily hours of inactivity), the time in a day when the children remain seated at school and especially on the cushion was not collected although they might have been relevant.
Until now, most studies have evaluated adult proprioception, whereas this study focused on young 8- year-old children. Given that trunk positioning accuracy improves significantly with age and particularly after 9 years [30,31], re-evaluating them after one year could be interesting. Further studies on the topic are necessary. Indeed, it would be relevant to conduct a long-term follow-up to investigate if seating posture and lumbar proprioception in schoolchildren are predictors of their seating posture, lumbar proprioception and the risk of low back pain in adulthood.

5. Conclusion

The preliminary study suggests that using a cushion combining a tilted seat and dynamism might have a beneficial impact on children's lumbar proprioception. Further studies are needed to evaluate the long-term effect of this type of seat on proprioception and if this could reduce low back pain in adulthood.

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Conflict of interest
None to report.

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References

[1] Dolan KJ, Green A. Lumbar spine reposition sense: the effect of a "slouched" posture. Man Ther. 2006; 11: 202-7.
[2] Sullivan PBO, Burnett A, Floyd AN, Ther MM, Gadsdon K, Ther MM, et al. Lumbar Repositioning Deficit in a Specific Low Back Pain Population. Spine (Phila Pa 1976). 2003; 28(10): 1074-9.
[3] O'Keeffe M, Dankaerts W, O'Sullivan P, O'Sullivan L, O'Sullivan K. Specific flexion-related low back pain and sitting: comparison of seated discomfort on two different chairs. Ergonomics. 2013; 56(4): 650-8.
[4] Brumagne S, Cordo P, Lysens R, Verschueren S, Swinnen S. The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. Spine (Phila Pa 1976). 2000; 25(8): 989-94.
[5] Alghadir A, Zafar H, Iqbal Z, Al-Eisa E. Effect of sitting postures and shoulder position on the cervicocephalic kinesthesia in healthy young males. Somatosens Mot Res. 2016; 33(2): 93-8.
[6] Stillman B. Making sense of proprioception: The meaning of proprioception, kinaesthesia and related terms. Physiotherapy. 2002; 88(11): 646-67.
[7] Winter JA, Allen TJ, Proske U. Muscle spindle signals combine with the sense of effort to indicate limb position. J Physiol. 2005; 568(3): 1035-46.
[8] O'Sullivan K, O'Dea P, Dankaerts W, O'Sullivan P, Clifford A, O'Sullivan L. Neutral lumbar spine sitting posture in pain- free subjects. Man Ther. Elsevier Ltd. 2010; 15(6): 557-61.
[9] Caneiro JP, O'Sullivan P, Burnett A, Barach A, O'Neil D, Tveit O, et al. The influence of different sitting postures on head/neck posture and muscle activity. Man Ther. 2010; 15: 54-60.
[10] Waongenngarm P, Rajaratnam BS, Janwantanakul P. Internal Oblique and Transversus Abdominis Muscle Fatigue Induced by Slumped Sitting Posture after 1 Hour of Sitting in Office Workers. Saf Heal Work. 2016; 7: 49-54.
[11] Mandal AC. The seated man (Homo Sedens) the seated work position. Theory and practice. Appl Ergon. 1981; 12: 19-26.
[12] O'Sullivan K, McCarthy R, White A, O'Sullivan L, Dankaerts W. Lumbar posture and trunk muscle activation during a typing task when sitting on a novel dynamic ergonomic chair. Ergonomics. 2012; 55(12): 1586-95.
[13] O'Sullivan K, McCarthy R, White A, O'Sullivan L, Dankaerts W. Can we reduce the effort of maintaining a neutral sitting posture? A pilot study. Man Ther. Elsevier Ltd. 2012; 17(6): 566-71.
[14] Annetts S, Coales P, Colville R, Mistry D, Moles K, Thomas B, et al. A pilot investigation into the effects of different office chairs on spinal angles. Eur Spine J. 2012; 21(Suppl 2): S165- 70.
[15] Baumgartner D, Zemp R, Stoop M, Naxera J, Elsig JP, Loren- zetti S. The spinal curvature of three different sitting positions analysed in an open MRI scanner. Scientific World Journal. 2012; 19: 400-6.
[16] Fettweis T, Onkelinx MN, Schwartz C, Demoulin C, Croisier JL, Vanderthommen M. Relevance of adding a triangular dynamic cushion on a traditional chair: A 3D-analysis of seated schoolchildren. Clin Biomech. Elsevier Ltd; 2017; in press.
[17] Cardon G, De Clercq D, De Bourdeaudhuij I, Breithecker D. Sitting habits in elementary schoolchildren: a traditional versus a "Moving school". Patient Educ Couns. 2004; 54(2): 13342.
[18] Troussier B. Comparative study of two different kinds of school furniture among children. Ergonomics. 1999; 42(3): 516-26.
[19] Hidalgo B, Gobert F, Bragard D, Detrembleur C. Effects of proprioceptive disruption on lumbar spine repositioning error in a trunk forward bending task. J Back Musculoskeletic Re- habil. 2013; 26(4): 381-7.
[20] Mandal AC. The correct height of school furniture. Physiotherapy. 1984; 70: 48-53.
[21] Pal P, Milosavljevic S, Sole G, Johnson G. Hip and lumbar continuous motion characteristics during flexion and return in young healthy males. Eur Spine J. 2007; 16: 741-747.
[22] Petersen C, Zimmermann C, Cope S, Bulow M, Ewers- Panveno E. A new measurement method for spine reposition sense. J Neuroengenering Rehabil. 2008; 5: 1-9.
[23] Burton AK, Eriksen HR. Chapter 2. European guidelines for prevention in low back pain? Eur Spine J. November 2004; 15: S136-168.
[24] Balagué F, Troussier B, Salminen JJ. Non-specific low back pain in children and adolescents: risk factors. Eur Spine J. 1999; 1; 8(6): 429-38.
[25] Cardon G, De Bourdeaudhuij I, De Clercq D. Knowledge and perceptions about back education among elementary school students, teachers, and parents in Belgium. J Sch Health. 2002; 72: 100-6.
[26] Lehman G. Biomechanical assessment of lumbar spinal function. How low back pain sufferers differ from normal. Implication for outcomes measures research. Part I: kinematic assessment of lumbar function. J Manipulative Physiol Ther.

Published in : Journal of Back and Musculoskeletal Rehabilitation -1 (2017) 1–7
DOI 10.3233/BMR-169763
Status : Postprint (Author's version)

2004; 27: 57-62.

[27] Feipel V, Parent C, Dugailly P, Brassine E, Salvia P, Rooze M. Development of kinematics tests for the evaluation of lumbar proprioception and equilibration. Clin Biomech. 2003; 18: 612-618.

[28] Gill K, Callaghan M. The measurement of lumbar proprioception in individuals with and without low back pain. Spine (Phila Pa 1976). 1998; 23(3): 371-7.

[29] Preuss R, Grenier S, Mcgill S. The effect of test position on lumbar spine position sense. J Orthop Sports Phys Ther. 2003; 33(2): 73-8.

[30] Kagerer FA, Clark JE. Development of interactions between sensorimoto representations in school-aged children. Hum Mov. 2014; 34: 164-77.

[31] Ashton-Miller J, McGlashen K, Schultz A. Trunk positioning accuracy in children 7–18 years old. J Orthop Res. 1992; 10(2): 217-25.

[32] Sullivan PO, Dankaerts W, Burnett A, Straker L, Bargon G, Moloney N, et al. Lumbopelvic Kinematics and Trunk Muscle Activity on Stable and Unstable Surfaces. J Orthop Sports Phys Ther. 2006; 36(1): 19-25.

[33] Wu CS, Miyamoto H, Noro K. Research on pelvic angle variation when using a pelvic support. Ergonomics. 1998; 41(3): 317-27.