Accelerometer Based Body Movement Quantification in Classroom Lectures: Seated Activity Comparison Between Body Regions

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Abstract: Sitting behavior research rarely consider non-ambulatory movement in separate body regions. This study used accelerometers, a sedentary cut off criterion, and measurement variables to evaluate movement accumulation in trunk, waist, and foot regions of students in a 42-minute classroom session. Findings show that all three sites were unique in stationary and movement measures (P≤0.012). Trunk and waist spent almost entire lesson period in stationary state (98%) whereas foot spent larger proportion in movement (9%). In addition, longest stationary period in trunk and waist regions exceeded the 30-minute threshold of prolonged sitting by a margin of 1 to 2 minutes as opposed to the foot. Altogether, trunk and waist recorded negligible seated activity and foot recorded sporadic and frequent movement. Based on health connection of body regions movement while sitting, we believe that some movement may be better than no movement at all. Since trunk and wait were inactive during the lesson period, strategies could be established to encourage intermittent movement in static body regions and facilitation of movement in already active regions. However, further investigation is needed to better understand dependencies of localized body activity on students' wellbeing in prolonged sessions of classroom lessons.

1 INTRODUCTION

Prolong sitting (PS) is typically defined as bouts of uninterrupted sitting for 30 minutes or longer (Léger, Cardoso, Dion, & Albert, 2022). It can interfere with cognitive abilities (Triglav et al., 2019), aggravate cardiometabolic risks (Honda et al., 2016), impact glucose metabolism (Saunders, Chaput, & Tremblay, 2014), induce chronic low back (Bontrup et al., 2019), elevate blood pressures, fatigue, and musculoskeletal symptoms in spine and lower limbs (Daneshmandi, Choobineh, Ghaem, & Karimi, 2017), distress vascular function in lower limbs (Paterson et al., 2020), (Credeur et al., 2019). It was shown that mere 10 consecutive minutes of continuous sitting was sufficient to impair leg microvascular function (Vranish et al., 2018). Among many groups of adult population, young university students were found to engage in PS behaviours against general everyday movement recommendations (Garn & Simonton, 2023). Due to increased sitting times, students gained 2.7 kg in transitioning from college to the university second-year (Deforche, Van Dyck, Deliens, & De Bourdeaudhuij, 2015), possible reason of which could be the increased sedentary activities in the universities. Academics require students to spend larger portion of their day in PS sessions in the laboratories, cafeteria, or library of university campuses (Keating et al., 2020). In classrooms alone, students are seated for lectures lasting up to 3 hours (Bligh, 2000) which is long enough to expose this group of young adults to the health risks of PS (Goncalves et al., 2022). Research shows that uninterrupted classroom sitting of 10 minutes could progressively lead to discomfort and sleepiness in students (Hosteng, Reichter, Simmering, & Carr, 2019).

Short breaks between lessons offer an opportunity to get and move but most students remain in their seats socializing, doing assignments, eating, or just relaxing (Cowgill et al., 2021). Standup-based approaches (Smith, Fagan, LeSarge, & Prapavessis, 2017) such as activity microbreaks (Lynch, O'Donoghue, & Peiris, 2022) or standing desks (Jerome, Janz, Baquero, & Carr, 2017) have been proposed but their implementation is limited by students' beliefs, impediments to infrastructure, or

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classroom tradition (Pachu, Strachan, McMillan, Ripat, & Webber, 2020). Seat-based movement devices such as specialized sitting platforms (Tanoue et al., 2016) and rubber balls (Dickin, Surowiec, & Wang, 2017) may also be impractical due to classroom layout and affordability. Keeping in view these shortcomings, the question of allowing movement in PS sessions may be settled by appreciating the notion of in-chair movements (ICMs) ("In-Chair Movements of Healthy People during Prolonged Sitting," 2014), dynamic sitting (DS) (van der Berg et al., 2019), and fidgeting (Fryer et al., 2022). Even in ordinary chairs, ICMs and DS allow seated movement to balance static sitting posture and fidgety movements compensate for a sustained seated idleness (Ricciardi, Maggi, & Nocera, 2019). Seated movement has been investigated in workplace environments (Ricciardi et al., 2019) but evidence on its incidence in students attending classroom sessions is yet to be explored.

The PS threshold of 30 minutes discriminates between sitting and ambulation (Altenburg et al., 2021), but it does not give a full report on non-ambulatory movement of different body regions. Lecture-attending students may accumulate varying frequency of seated movement in trunk, waist, and foot regions until the end of the lecture session. For instance, postural transitions due to erection and slouching of torso along sagittal plane (Cho, Cho, & Park, 2020) can produce spells of vertical movement in trunk region. Similarly, sustained pressure causing displacement of buttocks on chair's seat-pan (Arippa, Nguyen, Pau, & Harris-Adamson, 2022) can also cause perpendicular movement in waist region. Toe and heel tapping, foot position change, or sporadic fidgeting (Senaratne, Ellis, Oviatt, & Melvin, 2020) may also be anticipated as repetitive up-down movement in the foot region.

As trunk, waist, and foot regions are positioned at different degrees of freedom in a classroom chair, each may accumulate episodes (or bouts) of varying movement until the end of lecture session. Based on this understanding, the aim is to quantify stationary and movement states across trunk, waist, and foot regions and evaluate whether substantial differences in movement exists between them. Specifically, we are interested in finding times spent by each region in stationary and movement bouts, and also identifying which regions exceed the stationary threshold of 30 minutes of PS during the lecture session.

We build our analysis on a movement-intensity cut-point and variables of stationary and movement measures (Boerema, van Velsen, Vollenbroek, & Hermens, 2020) to analyse if a particular region was more active than others. A comparative overview of movement in trunk, waist, and foot would enable the identification of relatively least and most active regions in lecture attending classroom students. The outcomes could encourage students/researchers to allocate focus of seated movement on stationary/active regions rather than the whole body, as well as set a direction for further research in this field.

2 METHODOLOGY

2.1 Participants and Instruments

The goal of this study is to evaluate stationary and movement states in trunk, waist, and foot regions in seated classroom students.

Participants were lecture attending students enrolled in a degree course of Movement Sciences at the University of Naples Parthenope Italy. Online questionnaires were used for recruitment and submission of personal consent to process the data. All participants provided additional verbal consent to wear accelerometers. The protocol was approved by ethics committee reference number 0032042, "University of Campania L. Vanvitelli".

The sample included 15 able bodied participants (6 Females, 5 Males, 4 undeclared, Age: 23.5±2.88, BMI: 23.9±2.38 Three accelerometers were tied to the anterior trunk, right waist, and right ankle on each participant for seated body region movement measurement and evaluation during the lesson period. Trunk-unit was positioned roughly over the sternum with the fastening belt following a line connecting the right and left axilla. Waist-unit was positioned laterally on the right-side superior to the iliac crest. Foot-unit was placed slightly superior to right ankle just above the lateral malleolus. Hands were not used as site of movement measurement as accelerometer placement on wrists could obstruct the ongoing lesson tasks such as note-taking, typing, etc. All accelerometers were placed on clothing and each participant was free to opt out of the experiment any time. Recordings were considered valid only if sitting during the lesson was not interrupted by stand-up or removal of the device. Accelerometer model wGT3x (Actigraph Pensacola, FL-USA), initialized at 30 Hz (Brønd & Arvidsson, 2016), epoch-length of 10 sec was used for recordings. Movement data were downloaded and processed using Actilife Software Version 6.13.4. All chairs had a reclinable back rest with a fixed seat pan.

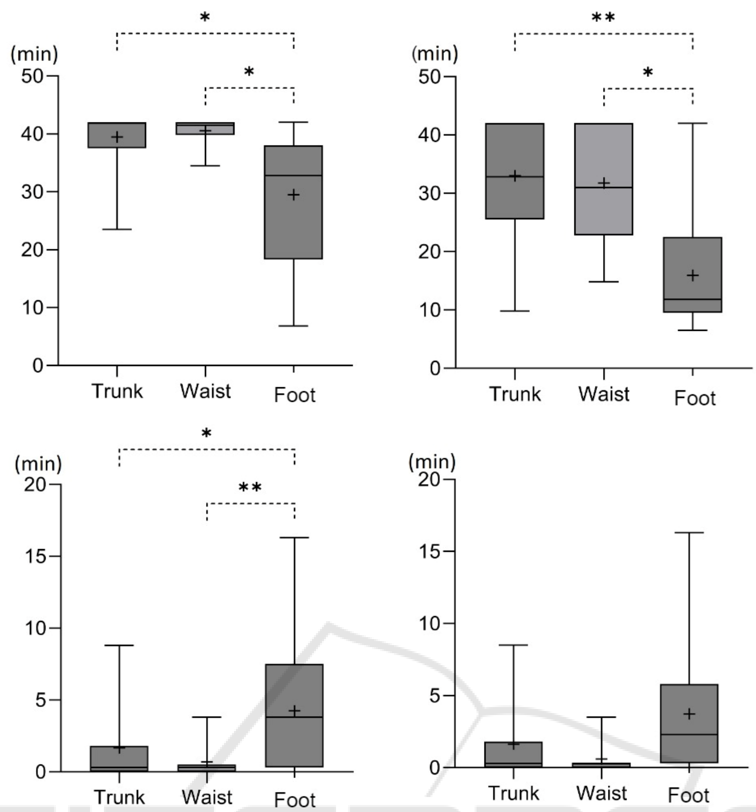

Figure 1: Box plots showing post-hoc pairwise comparison and differences in movement measures. Top left: Differences of time in stationary bouts was significant between trunk-foot and waist-foot pairs. Top right: Differences in longest stationary bout were significant between trunk-foot and waist-foot pair. Bottom left: Variation of time in movement breaks was significant between trunk-foot and waist-foot pairs. Bottom right: Insignificant differences in longest movement break were noted between all three pairs. P-value interpretation. P = 0.123 (ns), 0.0332 (*), 0.002 (**), 0.0002 (***). The (+) symbol shows the position of mean relative to the median. The vertical axis shows time in minutes.

2.2 Data Reduction and Variable Definitions

All data was downloaded and reduced for further analysis after the session. The length of lecture and accelerometer wear time (WT) were aligned to 42 minutes since most valid accelerometer recordings were consistent with this length. Epochs were upscaled to 15 seconds so that 4 epochs were contained in a single minute. A minute was either stationary or a movement minute, depending on the level of counts above or below the reference cut point of 100 counts per minute (cpm) (Altenburg et al., 2021). Consequently, a stationary bout was defined as time accumulated in consecutive stationary minutes (Honda et al., 2016) whereas a movement bout (or break) was defined as time collected in consecutive movement minutes (Dalene et al., 2022). The minimum length of stationary and movement bouts/breaks was set to 5 minutes which could extend up to the total WT. Only vertical movement counts were assigned to stationary and movement variables in order to avoid complex computations. The choice of variables was based on relevance to health outcomes of PS (Boerema et al., 2020). For each body region, two variables were derived to evaluate stationary bouts.

i. Time in stationary bouts (TSB)
ii. Longest stationary bout (LSB)

TSB refers to the total time spent in stationary bouts by a region whereas LSB corresponds to the single longest bout of uninterrupted stationary state. Period of interruption between two stationary bouts was called a movement break. For each region, two variables of movement breaks were evaluated.

i. Time in movement breaks (TMB)
ii. Longest movement break (LMB)

TMB refers to the total time spent by all episodes of movement and LMB corresponds to the single longest episode of movement among all.

Table 1: Overall and pairwise comparisons of movement measures. TSB, Time in stationary bouts; LSB, Longest stationary bout; TMB, Time in movement breaks; LMB, Longest movement break.

Movement variable	Overall comparison P-value [F]	Pairwise comparisons Remarks on median difference P-value [rank sum difference]		
		trunk-waist	trunk-foot	waist-foot
TSB	0.0029 [11.69]	0.3 min more in trunk >0.9999 [-2]	9 min more in trunk 0.0318 [14]	8.7 min more in waist 0.0100 [16]
LSB	0.0010 [13.73]	1.8 min more in trunk >0.9999 [3]	21 min more in trunk 0.0030 [18]	19.2 min more in waist 0.0180 [15]
TMB	0.0009 [14.04]	No difference >0.9999 [3]	3.5 min more in foot 0.0411 [-13]	3.5 min more in foot 0.007 [-16.5]
LMB	0.0126 [8.750]	No difference >0.9999 [2.5]	3.5 min more in foot 0.2037 [-10]	2 min more in foot 0.6700 [-12.5]

2.3 Statistical Analysis

Each variable was tested for normality using Shapiro-Wilk test in each region. Their average was matched cross all regions using Freidman tests (F and P-value) and post-hoc (Dunn's) pair-wise comparison between every two regions. In addition to medians and 95% confidence interval (C.I), percentages in proportion to WT for each variable were compared across regions. Statistical descriptors were plotted in Box & Whiskers. Significance level 'alpha' was set to $\alpha = 0.05$. All calculations and plots were obtained from GraphPad Prism v. 2.2.

3 RESULTS

All four variables in all regions were not distributed normally ($P<0.01$). Average TSB in trunk and waist was 41.8 min and 41.5 min, respectively. Similarly, average LSB in trunk and waist was 32.8 min and 31 min, respectively. Average TMB and LMB in both trunk and waist was 0.3 min. In foot region, average TSB and LSB were 32.8 min and 11.8 min, respectively. Average TMB and LMB in foot was 3.8 min and 2.3 minute, respectively.

Both trunk and waist regions spent >98% of lesson time in stationary state and <1% in episodic movement. Comparatively, foot spent about 78% of lesson time in stationary bouts and 9% in intermittent movement. Average longest uninterrupted stationary period in trunk and waist regions constituted at least 73% of the lesson time. The same in foot, however, spanned only 28% of the lesson time. The average longest episode of movement in trunk and waist stretched 0.7% of lesson time. In foot the spanned about 5.5% of lesson time.

Global difference of average minutes in all four stationary and movement variables was significant across trunk, waist, and foot region ($P\leq0.013$). Pairwise comparisons show that the longest uninterrupted stationary bout in trunk and waist was 19 to 21 min longer than that in the foot ($P<0.01$). Both these regions spent on average 8 to 9 min more in stationary bouts ($P<0.03$), and 3.5 min less in movement breaks ($P<0.042$) compared to the foot. All other differences were not significant ($P>0.2$). Detailed global and pairwise comparisons are shown in figure and table 1.

4 DISCUSSION

The goal of this study was to find regions of least and most movement among trunk, waist, and foot using accelerometers and variable measures of sitting behaviour in lecture attending students. Second, we analysed which regions were stationary up to the point of crossing the 30 min threshold of PS. Trunk and waist were similar in all four measures of stationary and movement patterns. Both trunk and waist spent almost entire lecture session in a stationary state. The longest uninterrupted stationary period was also recorded in trunk and waist region. Its length exceeded the 30-minute threshold of uninterrupted PS by a margin of 1 to 2 minutes. Foot, however, was equally different from trunk as much as it was from the waist. It remained well within the bounds of PS threshold by sufficiently distributing its movement rather than staying at a complete rest. Conclusively, trunk and waist were altogether in a stationary state and foot recorded relatively higher movement activity.

This relative pattern of movement distribution in different body regions could be attributed to simple underlying causes. Whether students intentionally did not move the upper portion of their bodies or the sitting situation itself is responsible, it makes sense to assume that both waist and trunk are solidly attached to the base and back of the chair. The fixed mechanical system in used classroom chairs might have inhibited the trunk and pelvic movements in the waist region (Tanoue et al., 2016). Foot-floor contact and hand placement on a desk (in lesson tasks such as taking notes) creates a stabilizing effect on the upper body could possibly have inhibited movement in hips and buttocks (Nüesch, Kreppke, Mündermann, & Donath, 2018). In contrast, relatively higher movement was recorded in the foot possibly due to a higher degree of motion in legs while sitting. Students were not engaged in any meaningful task (Ricciardi et al., 2019) during the lesson period, larger movement in foot region possibly accumulated due to leg fidgeting, vertical thigh activity, or heel/toe taps, etc (Esseiva, Caon, Mugellini, Khaled, & Aminian, 2018). Several unexplained personal or environmental factors could also have contributed to this pattern of stationarity and movement distribution in the three regions.

Although this study did not measure the consequences of stationary and moving body regions on student's health, associations of foot region movement have been previously found with energy expenditure. Gluteal femoral muscular contractions in foot movement significantly increased energy expenditure in individuals sitting in standard chairs (Koepp, Moore, & Levine, 2017). Generally, lower limb movement has been linked to positive impact on an individual's leg vascular health (Morishima et al., 2016), executive functions (Fryer et al., 2022), resting energy expenditure (Koepp, Moore, & Levine, 2016). Some associations have also been reported between seated movement behavior and BMI, waist circumference and the metabolic syndrome (van der Berg et al., 2019). Nevertheless, prevalence of higher movement in foot region may be better than no movement at all. It is merely a speculation but small amount of leg fidgeting in prolonged sitting classroom sessions may provide some preventive benefits.

To our knowledge, this study was the first in measuring accumulated stationary and movement times using accelerometers and standard classroom chairs. Accelerometers were a suitable choice for detecting body region movement regardless of their placement on body sites (Senaratne et al., 2020). They can reliably measure limb movement (Fortune, Lugade, & Kaufman, 2014) and foot activity in seated posture when placed at the ankle position (Chalkley, Ranji, Westling, Chockalingam, & Witchel, 2017). While compliant sitting surfaces have a more significant effect in eliciting trunk, waist, and foot movement (Wang, Weiss, Haggerty, & Heath, 2014), the larger activity found in foot was not hurdled by horizontal static seat surface of used classroom chair. It is imperative that people often participate in involuntary and spontaneous seated body movements such as moving on chair in varying contexts (Ricciardi et al., 2019). This applies to students attending a lesson presentation as well who, based on the findings, can proceed to move stationary regions of their bodies or remove any barriers interfering in movement of already active regions. Since most students choose to stay seated even in their free time, foot movement in classroom chairs could evolve as a habit that can extend anywhere, at any time, and for those who may find stand up or walking breaks challenging (Pettit-Mee, Ready, Padilla, & Kanaley, 2021). From an epidemiological view, small seated movement in chairs could be medically important in the long run (Koepp et al., 2016) since many students could adapt this as a habit beyond classrooms in their life (Nüesch et al., 2018).

Population of students attentive to long lesson presentations are undesirably exposed to the risks associated with extended periods of sitting. Traditional movement interventions are not only challenging to implement but they also lack in evoking non-ambulatory seated movement of different body regions. In order to encourage specific seated movement behaviors, this study emphasized on detecting and comparing accumulated movement between three distinct body regions. As it is common for classroom lectures to exceed the 30-minute threshold of continuous sitting, we were able to discern regions that had the tendency to exceed that threshold. Based on the knowledge of least and most active regions, future research could be extended towards development of suitable interventions that enhance activity in vulnerable body regions and aid in prevention of likely negative health impacts.

Finally, there were some limitations that should be carefully considered prior to further investigation. For instance, cut-off criterion can decisively alter the measurements of selected variables. Attention should be paid to its selection as it has potential to offset the resulting movement outcomes. Moreover, calculations in this study were performed using only vertical component of movement. It is possible to have a diverse understanding of seated movement patterns if multidimensional approach is opted. In addition, mutual relationship between the movement variables was also not taken into account. Recruiting hybrid variables could enable assessment of temporal patterns of movement progression. Unfortunately, we faced sample size, lesson time, and some other unexplained protocol restrictions. A more comprehensive study design can also replenish the gaps due to varied epoch length, sensor typology, and sample heterogeneity. The direct connection of seated body movement to localized energy expenditures also warrants a further examination.

5 CONCLUSIONS

This study evaluated stationary and movement periods in body regions of seated students attentive to lecture presentation. Using accelerometers placed at three body sites, a cut off criterion, and a set of measurement variables, we found that foot region accumulated most movement as compared to trunk and waist until the end of lesson. Trunk and waist also exceeded the 30-minute threshold of prolonged sitting as opposed to foot which engaged in unassisted episodic movement. Realizing that body trunk and waist are more stationary than foot, students and interventionists can encourage diverse movement strategies in upper body regions in standard classroom chairs. To make a more detailed assessment of stationary and movement states and their associated health connection, we recommend a rigorous examination on alternative detection modalities, compliant sitting surfaces, variable inter-relationship, temporal dynamics, and localized energy costs of seated activity.

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