Research article

The effects of standing tutorial meetings on physical activity behavior in undergraduates: A randomized controlled trial

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A R T I C L E   I N F O

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A B S T R A C T

This study explored the effects of using standing desks in tutorial meetings on the physical activity behavior (PAB) of undergraduate students. Standing desks have been introduced to minimize the detrimental health effects of prolonged sedentary behavior (SB). The effectiveness of using standing desks has not been explored among undergraduate students - a population showing high SB. Ninety-six undergraduate students were randomly assigned to a sitting or standing tutorial group that ran for nine weeks, and their PAB was monitored using the activPAL3 triaxial activity monitor. To check for potential compensatory or other covarying behaviors, the students’ PAB was monitored on tutorial and non-tutorial days. PAB monitoring was conducted in week 4–5, and a follow-up measurement was conducted in week 9 to examine longer-term effects. In week 4–5, the stand group (n = 41) showed less SB (β = -0.092, SE = 0.044, 95% CI: -0.179, 0.006) and more moderate-to-vigorous physical activity (β = 0.320, SE = 0.160, 95% CI: 0.004, 0.635) compared to the sit group (n = 36). On tutorial days, the stand group showed more light physical activity (LPA) than the sit group (p < .001, d = 1.04). In week 9, there was an exam on the last day of that week. Nonetheless, the stand group (n = 37) showed less SB (p < .001, d = 0.378) and more LPA (p = .008, d = 0.725), while breaking up prolonged SB more frequently (p = .007, d = 0.696) on the tutorial day compared to the sit group (n = 32). Overall, undergraduates attending standing tutorial meetings showed less SB and more LPA than those attending conventional, seated tutorial meetings. Standing tutorial meetings can contribute to a more active lifestyle for undergraduates.

1. Introduction

Sedentary behavior (SB) is the act of sitting, reclining, or lying, while being awake and expending energy at 1.5 metabolic equivalents (METs) or less [1]. A large body of evidence has shown that prolonged SB leads to an increased risk of cardiometabolic diseases, all-cause mortality, depression, anxiety, and stress [2,3]. In an effort to reduce SB, standing desks have been introduced to schools [4–6] and workplaces [7,8]. Despite high acceptability and feasibility of using standing desks in university environments [9], the effectiveness of standing desk interventions at reducing SB has yet to be explored among, for instance, undergraduates. Endeavors to reduce SB are especially important for this population as they are among those with the highest amount of SB [10]. In the current study, we aim to investigate the effects of a standing desk intervention on the physical activity behavior (PAB) of undergraduates, specifically by introducing standing tutorial meetings.

Standing desk interventions have generally been effective at reducing SB in other contexts. Reported in a meta-analysis, SB in office workers can be reduced up to 77 min per 8-hour workday [8]. Although systematic reviews of standing desk interventions in school...
environments show inconsistent results, trends can be discerned that standing desk interventions decrease SB and increase standing time [4, 6]. Addressing the inconsistency in results, Sherry and colleagues’ highlight in their review that many studies carry out activity monitoring within a specific timeframe of the school day, which may not reflect the students’ PAB outside of school [6]. This caveat is important, as there may be significant behavioral changes outside the intervention environment (i.e., the school or classroom). For example, the activity-stat hypothesis states that with any changes in physical activity, there will be compensatory behaviors to maintain the overall level of energy expenditure around a set point over time [11]. Some studies find support for this hypothesis, reporting that overweight and obese adults who underwent moderate physical activity training compensate by being less active outside the training [12,13]. Others did not find support for this hypothesis, observing no compensatory behaviors in obese [14,15] and lean adults [16]. With regards to standing desk interventions, Mansoubi and colleagues found support for the activity-stat hypothesis, where despite an overall reduction in SB and increment of standing and stepping time, office workers compensated by being more sedentary during nonworking hours [17]. Changes in physical activity can also lead to co-variation, where a positive change in one behavior leads to improvements in another behavior [18]. Interestingly, co-variation was observed by Mansoubi and colleagues as well, as moderate-to-vigorous physical activity increased during working hours in the early weeks of the intervention [17].

Considering the possibilities of compensatory or covarying behaviors, it is important to take a holistic activity monitoring approach when studying the effectiveness of introducing standing desks to undergraduates. In the current study, undergraduates were randomly assigned to either a sitting or standing tutorial group that ran for nine weeks. Chaput et al. advise that all movement behaviors in a 24-hour day should be monitored [19]. Therefore, in this study, all PAB that would constitute a 24-day was monitored using the activPAL3™ (PAL Technologies Ltd., Glasgow, UK) triaxial activity monitor. Gomersall et al. further advise that, to detect possible compensatory behaviors, activity monitoring should last longer than a day, with measurements taken at least four weeks after the introduction of an intervention [20]. In this study, the participants’ week-long PAB was monitored in week 4–5 and week 9 from the start of the intervention. Between-group comparisons of PAB were made on each type of day (tutorial days and non-tutorial days). We expected that on tutorial days, the participants attending the standing tutorial meetings would have less SB and more

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**Fig. 1.** Flow diagram depicting progress of participants through the study [21].
LPA because of the imposed standing intervention. On non-tutorial days, PAB was monitored for possible compensatory or covarying behaviors.

2. Methods

2.1. Participants

From 135 first-year Biomedical Sciences undergraduates who expressed interest to participate, 96 were randomly recruited and allocated to either a sitting or stand group (48 in each) by an independent administrative staff member. As this study is part of a larger study to explore the effects of standing tutorial meetings on learning, the sample size of 96 was determined based on an a-priori power analysis of another measure [22]. Each tutorial group consisted of 12 participants, leading to four sitting and four standing tutorial groups. After detailed briefing, written and verbal consent was obtained from each participant. Participant attrition is reported in Fig. 1. Ethical approval was obtained from the Netherlands Association for Medical Education (NVMO) Ethical Review Board, file number: 1030.

2.2. Design and setting

In this exploratory randomized controlled trial, we compared the PAB between participants attending either sitting or standing tutorial meetings. The tutorial meetings were part of the course Human Genetics, Reproduction and Prenatal Development (course code: BBS1005) within the first-year Bachelor of Biomedical Sciences at Maastricht University. The study ran from April 10 to June 8 of 2018 (9 weeks), with 13 tutorial meetings held on Tuesday and Friday mornings, at 8:30–10:30 or 11:00–13:00. Both time slots had an equal number of sitting and standing tutorial groups. PAB measurements were performed during one week in week 4–5 (starting from May 2, after attending six tutorial meetings) and week 9 (starting from June 2, after attending 12 tutorial meetings). It was not possible to conduct a pretest because before the start of the study, the participants had to attend exams for a previous course. Therefore, a posttest-only design was applied.

The four tutorial classrooms were adjacent to one another, with standardized classroom settings. The only difference was the sitting/standing arrangements. Each classroom had five 160 × 80 cm desks that were electronically adjustable to a height of 70 to 130 cm (see Fig. 2a and b).

For week 4–5, a 2 × 2 factorial design was used, with group (sitting/standing) as the between-groups independent variable and type of day (tutorial/non-tutorial days) as the within-groups (repeated-measures) independent variable. Week 4–5 was a regular week where the participants attended two 2-hour tutorial meetings, beside other educational commitments (a 2-hour skills training, a 1-hour lecture on Tuesday, and a 2.5-hour lecture on Friday).

For week 9, the academic schedule appeared very different from week 4–5 because an exam was scheduled on the last day of the week. Therefore, a 2 × 4 factorial design was used, with group (sitting/standing) and type of day (regular day, tutorial day, pre-exam days, and exam day) as the independent variables. In week 9, the participants attended one 2-hour tutorial meeting on Tuesday. Other educational commitments included a 2-hour lecture on Monday (regular day) and Tuesday (tutorial day). There were no other contact hours on Wednesday and Thursday (pre-exam days). A 3-hour exam (instead of their regular tutorial) was scheduled on Friday. All participants were seated during the lectures and exam.

2.3. Materials

The activPAL3™ (PAL Technologies Ltd., Glasgow, UK) triaxial activity monitor was used to identify limb position and acceleration to classify lying, sitting, standing, and stepping [23]. The activPAL3™ is a valid and reliable device for measuring PAB in adults [24], recommended for field-based monitoring of free-living activities [25], without affecting one’s daily behavior [26,27]. As a supplementary check for the activPAL3™ data, the participants were also requested to complete a daily diary, based on the short format of the International Physical Activity Questionnaire [28]. At the start of the study, the participants were given a demographics questionnaire covering age, height, weight, sex, and self-rated health and fitness on a scale of 1 to 5, with 1 being very poor and 5 being very good.

2.4. Procedure

At the start of the course, the participants were briefed, and each gave their informed consent and completed the demographics questionnaire. Before starting each tutorial meeting, the participants adjusted the desks’ height for an ergonomically comfortable posture, with their elbows approximately 90° to the desk. On May 1 and June 1, the participants were requested to attach the waterproof activPAL3™ on the middle-anterior of their thighs, with the activPAL3™ programmed to activate at midnight (May 2 and June 2). During both weeks, the participants wore the activPAL3™ for seven continuous 24-hour days. To simultaneously measure the PAB of all participants, the participants were given written and video instructions to attach the activPAL3™ on their own. A previous study reported acceptable accuracy from self-attachment under such instructions [29].

2.5. Physical activity behavior (PAB) variables

PALbatch (Version 8.10.9.43) was used to download and process the activPAL3™ data [23]. Although we report in our protocol [22] that we would use the Maastricht Study’s activPAL algorithm to identify wake and sleep time, we decided to use activPAL3™’s proprietary CREA algorithm that was released in 2019 [30]. Similar to activPAL3™’s default data-processing algorithm, the CREA algorithm classifies events (PAB) based on limb position and acceleration. The added feature is that the CREA algorithm is able to identify lying, transportation, non-wear, and upright correction. Recording for each day started at midnight, with a valid day defined by the PALbatch software as having at most only four continuous hours of zero movement (non-wear). Non-valid days were
automatically removed from the dataset. The following variables were of interest:

- Sedentary behavior (SB) – represented by the “sitting” variable extracted by the algorithm.
- Moderate-to-vigorous intensity physical activity (MVPA) – defined as activity that expends 3.0 METs or more [31]. MVPA is represented by steps of \( \geq 100 \) steps/minute, calibrated based on \( \geq 3.0 \) METs [32].
- Light intensity physical activity (LPA) - operationally defined as the activities between the thresholds of SB and MVPA, comprising of standing and steps of \(< 100 \) steps/minute.
- Lying - consisting of primary (e.g., nighttime sleep) and secondary lying (e.g., daytime naps) time on each calendar day.
- Active SB ratio - a gauge of how often the participants engaged in continuous bouts of SB lasting 30 min or less over the entire duration of their SB. The active SB ratio is shown in Eq. (2.1). Detrimental effects of overall SB are expected to be lower with higher active SB ratios.

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\text{Active SB ratio} = \frac{\text{total duration of SB bouts lasting } \leq 30 \text{ minutes}}{\text{total duration of SB}} \quad (2.1)
\]

2.6. Data analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows (version 25.0, Armonk, NY, US). The demographical information of the sample was summarized using means (M), standard deviations (SD), and sample size (n). The PAB variables are expressed as hours:minutes (hh:mm). Two-sided \( p \)-values \( \leq 0.05 \) were considered statistically significant. Demographical information was compared between groups using Mann-Whitney U tests for continuous variables (age, height, weight, and body mass index) and chi-square tests for categorical variables (timing of tutorial meeting, sex, perceived health, and perceived fitness).

In a preliminary analysis, the lying time of those in the earlier (8:30 to 10:30) tutorial meetings were compared against those in the later (11:00 to 13:00) tutorial meetings. When a significant difference was found, meaning that participants with different tutorial times had different waking hours to perform the various other PAB, then lying duration was added to the models as a covariate.

Furthermore, previous research found that PAB during weekends was significantly different compared to weekdays, thereby potentially confounding the effects of the standing tutorial meetings [33]. In the current study, Friedman’s ANOVA was used to check whether PAB during weekends was significantly different from weekdays across both groups; when this was found to be the case, weekends were excluded from further analyses to separate the weekend effects from the effects of the standing tutorial meetings. The results of these preliminary analyses have been reported in the Appendix.

PAB was analyzed separately in week 4–5 and week 9 due to the differences in academic schedule. For week 4–5, a 2 (sitting/stand group) x 2 (tutorial/non-tutorial day) factorial design was used. Tutorial days were averaged across Tuesday and Friday, while non-tutorial days were averaged across Monday, Wednesday, and Thursday. In week 9, a 2 (sitting/stand group) x 4 (type of day) factorial design was used. The type of days was regular day (Monday), tutorial day (Tuesday), pre-exam days (averaged across Wednesday and Thursday), and exam day (Friday). Because of the unique academic schedule (pre-exam days that had no contact hours and exam day that had a 3-hour exam), we expect for PAB to be different across the days. This difference has been reported in the Appendix, where PAB on pre-exam days and exam day were each found to be different than the regular day and tutorial day for both stand and sit groups. Therefore, unlike week 4–5, four types of days were used for week 9.

As PAB-output was confined to a 24-hour day, PAB duration was quantified as counts (1 min = 1 count). To compare the duration of SB, LPA, MVPA, and lying between groups and type of day, generalized linear mixed models (GLMM) with Poisson distribution and log link functions were used to account for the repeated-measures and count data. For active SB ratio, which is a continuous variable, a marginal model was used instead. For all five PAB variables, the fixed part of models contained the main effects of group (standing or sitting; categorical) and type of day (categorical), plus their interactions. An unstructured covariance type was selected for the repeated measures within a participant. No other random effects or random intercepts were included in the models. Estimated means, standard error, and \( p \)-values of the \( F \)-ratio test were reported for each model. Significant interactions were followed up using simple-effect analyses, with Bonferroni correction for the purpose of comparison, the absolute value of Cohen’s \( d \) was calculated using the mean of difference scores divided by the standard deviation of difference scores.

3. Results

3.1. Participant characteristics

No significant differences were found between groups for age, height, weight, body mass index, timing of tutorial meeting, sex, self-rated physical health, and self-rated physical fitness (all \( p \)'s \( > 0.05 \)). Overall, the participants appeared to be healthy, with body mass index corresponding to a normal range [34], and a generally positive self-rating of physical health and fitness (detailed in Table 1).

According to the Royal Netherlands Meteorological Institute [35], week 4–5 (first week of May 2018) started out cool, with an average temperature ranging 11.6 °C – 12.5 °C. In the second half of the week the average temperature rose to 18.1 °C - 20.7 °C. Week 4–5 was sunny, with no precipitation. Week 9 (first week of June 2018) started with 23 mm of rain on the first day. However, the rest of the week remained dry, except for June 8, when there was 2 mm of rain. Week 9 saw average temperatures ranging from 16.7 °C to 21.1 °C.

Table 1

| Self-reported participant characteristics assuming full attendance (n = 87). | Sit group, M ± SD | Stand group, M ± SD | Overall, M ± SD |
| --- | --- | --- | --- |
| **Age** | 19.9 ± 1.4 | 19.9 ± 1.4 | 19.9 ± 1.4 |
| **Height (m)** | 1.7 ± 0.1 | 1.7 ± 0.1 | 1.7 ± 0.1 |
| **Weight (kg)** | 67.8 ± 12.3 | 66.3 ± 13.5 | 67.1 ± 12.9 |
| **Body mass index** | 22.3 ± 2.7 | 22.0 ± 3.0 | 22.2 ± 2.8 |
| **Timing of tutorial meeting** | 8:30–10:30 | 22 | 22 | 44 |
| | 11:00–13:00 | 22 | 21 | 43 |
| **Sex** | **Women** | 27 | 26 | 53 |
| | **Men** | 17 | 17 | 34 |
| **Self-rated physical health** | **Very poor** | 0 | 0 | 0 |
| | **Poor** | 1 | 1 | 2 |
| | **Average** | 17 | 13 | 30 |
| | **Good** | 23 | 23 | 46 |
| | **Very good** | 3 | 6 | 9 |
| **Self-rated physical fitness** | **Very poor** | 1 | 1 | 2 |
| | **Poor** | 5 | 2 | 7 |
| | **Average** | 23 | 17 | 40 |
| | **Good** | 11 | 18 | 29 |
| | **Very good** | 4 | 5 | 9 |

*Notes. M = mean; SD = standard deviation; n = sample size.*
3.2. PAB in week 4–5

By the start of week 4–5, the participants had attended a total of six tutorial meetings (12 h). Throughout week 4–5, the participants attended two more tutorial meetings (i.e., four more hours). As detailed by the F-ratio tests in Table 2, the standing tutorial meetings had a significant effect on SB and MVPA. The stand group showed significantly less SB (β = −0.092, SE = 0.044, 95% CI: −0.179, −0.006) and more MVPA (β = 0.320, SE = 0.160, 95% CI: 0.004, 0.635) than the sit group. As shown in Fig. 3, this effect was significant for both tutorial and non-tutorial days.

The standing tutorial meetings had an effect on LPA as well. For LPA, there was a significant interaction between the group and type of day (β = 0.186, SE = 0.061, 95% CI: 0.066, 0.307). Simple-effect analyses reveal that the stand group showed significantly more LPA than the sit group on tutorial days only (p < .001, d = 1.04), due to the standing desk intervention imposed onto them. This LPA difference between the stand and sit group on tutorial days was only approximately 1.5 h despite the 2-hour standing tutorial meeting, suggesting that the stand group did compensate by performing less LPA outside of the standing tutorial meetings. On non-tutorial days, both groups performed similar amounts of LPA (p = .133, d = 0.35).

3.3. PAB in week 9

By the start of week 9, the participants had attended a total of 12 tutorial meetings (24 h); they attended one final 2-hour tutorial meeting in week 9. During week 9, the standing desk intervention’s effect was not immediately clear, as main effects of group were not significant for all PAB (all ps > 0.05, shown in Table 3). However, there were significant interactions between group and the type of day for SB, active SB ratio, LPA, and MVPA. Simple-effect analyses showed that the groups differed in SB, active SB ratio, and LPA on their tutorial day, with the stand group showing significantly less SB (β < .001, d = 0.378), a higher active SB ratio meaning that they broke up their SB more frequently (β = .007, d = 0.696), and more LPA (β = .008, d = 0.725). Although there was a significant interaction between group and type of day for MVPA, the groups did not differ when MVPA was compared per day (all ps > 0.05).

4. Discussion

This study explored the effects of standing tutorial meetings (13 tutorial meetings, two hours each, across nine weeks) on undergraduates’ PAB. Standing tutorial meetings were found to be effective at reducing SB and increasing LPA. In week 4–5, the standing tutorial meetings had a significant effect on the undergraduates’ PAB, with the stand group showing significantly less SB and more MVPA than the sit group, both on tutorial and non-tutorial days. The interaction between group and type of day was significant for LPA, showing that the stand group showed more LPA than the sit group on tutorial days only.

In week 9, there were several significant interactions between the groups and the type of day. On tutorial days, the stand group showed less SB, higher active SB ratio, and more LPA compared to the sit group. On tutorial days of week 4–5, the stand group showed approximately 55 min less SB and 1.5 h more LPA than the sit group. This finding is encouraging because extant literature has shown that replacing just 30 min of SB with 30 min of LPA per day is associated with 14% reduced risk of mortality [36]. With tutorial meetings scheduled for two hours, one may argue that there was partial support for the activity-stat hypothesis [11], as the PAB changes (55 min less SB and 1.5 h more LPA) suggest that outside the tutorial meetings, there were modest compensatory behaviors. Yet, the activity-stat hypothesis was not fully supported for two reasons. First, the 2-hour standing intervention was not fully replaced by two hours more of SB and two hours less of LPA outside the tutorial meetings. These modest signs of compensation are outweighed by the overall lower SB and higher LPA across the entire tutorial day. Second, on non-tutorial days in week 4–5, no compensatory behaviors were found for the stand group. No group differences were found for LPA, illustrating that the stand group showed just as much LPA as the sit group on non-tutorial days, without compensating for their higher LPA from tutorial days. Interestingly, the stand group still showed less SB compared to the sit group on non-tutorial days, suggesting that there were carry-over effects of the standing intervention that encouraged the undergraduates to be less sedentary even when standing was not imposed onto them. The stand group showed approximately 55 min less SB on tutorial days, and 42 min less SB on non-tutorial days, compared to the sit group. These findings are clinically relevant when compared to previous meta-analyses that report SB-reducing interventions produced clinically significant reductions of 42 to 91 min less SB per day [37,38]. Furthermore, the current study showed that the effects of standing tutorial meetings carry over to non-tutorial days, while previous studies have shown that SB-reducing interventions have the potential to last up to 12 months [38]. Therefore, introducing standing tutorial meetings can be a worthwhile investment for universities to effectively reduce SB among undergraduates.

Moreover, in week 4–5, the stand group had approximately 9 min more MVPA than the sit group – both on days with and without tutorial meetings. We suspect that by introducing LPA or reducing SB, the undergraduates were activated to engage in more MVPA, showing co-variation that is deemed desirable in the research field of Multiple Health Behavior [18]. However, MVPA was not different between the sit and stand groups in week 9. This finding resonates with previous studies that reported an increase of MVPA in office workers at the start of their standing desk intervention [17], and a higher step count in elementary school children [39]; yet, these co-variation effects disappear with time, signaling at the possibility of novelty effects. Similar to these two studies, the effects of standing tutorial meetings may have had novelty effects, leading MVPA to covary with lower SB and the higher LPA brought about by the standing tutorial meetings.

In week 9, the stand group showed 96 min less SB, 57 min more LPA, and a higher active SB ratio compared to the sit group on the tutorial day. Unlike week 4–5, there were no significant group differences on non-tutorial days, suggesting that the carryover effects from the standing tutorial meetings seen in week 4–5 had dissipated by week 9. A second explanation may be that the exam scheduled on the last day of week 9 may have diluted the effects of the standing tutorial meetings. Although not the primary intervention of this study, the exam appears to have an effect on the undergraduates’ PAB. Two days before the exam, the undergraduates in both groups spent more time lying down.
both groups, similar to the findings by Wunsch et al., who reported that students compared to their tutorial and exam days, shown in Table 3. During these two days, the undergraduates’ LPA and MVPA also dropped in both groups, similar to the findings by Wunsch et al., who reported that students compared to their tutorial and exam days, shown in Table 3. During these two days, the undergraduates’ LPA and MVPA also dropped in both groups, similar to the findings by Wunsch et al., who reported that

Considering the success of the current study’s intervention at reducing SB, our recommendation for future research is to explore the dose-response effect of standing interventions and the underlying motivational factors to minimize compensatory behaviors while maximizing the effectiveness and lasting effects of the SB-reducing intervention. Referring to the diluted results found in week 9, we highlight the importance of taking into account the undergraduates’ academic schedule, which has been reported in a previous study to be associated

### Table 3

For week 9, the estimated means (standard error) for each PAB.

| Group      | SB (hh:mm) (00:20) | Active SB ratio | LPA (hh:mm) (00:18) | MVPA (hh:mm) (00:06) | Lying (hh:mm) (00:05) |
|------------|---------------------|-----------------|----------------------|----------------------|----------------------|
| Sit group  |                     |                 |                      |                      |                      |
| Regular    | 08:29 (00:20)       | .465            | 04:00 (00:18)        | 00:33 (00:06)        | 10:39 (00:05)        |
| Tutorial   | 09:08 (00:20)       | .341            | 03:34 (00:15)        | 00:22 (00:03)        | 10:24 (00:03)        |
| Pre-exam   | 09:14 (00:20)       | .454            | 03:08 (00:14)        | 00:16 (00:03)        | 12:02 (00:37)        |
| Exam       | 07:11 (00:23)       | .431            | 03:59 (00:17)        | 00:47 (00:06)        | 10:21 (00:31)        |
| Stand group|                     |                 |                      |                      |                      |
| Regular    | 08:36 (00:19)       | .402            | 03:56 (00:17)        | 00:25 (00:05)        | 10:14 (00:33)        |
| Contact    | 07:32 (00:17)       | .458            | 04:31 (00:16)        | 00:28 (00:03)        | 09:35 (00:34)        |
| Tutorial   | 09:02 (00:18)       | .444            | 03:16 (00:14)        | 00:12 (00:02)        | 11:05 (00:35)        |
| Pre-exam   | 07:57 (00:22)       | .462            | 04:19 (00:16)        | 00:45 (00:05)        | 09:42 (00:28)        |

Notes.

* Lying effects were controlled for within the model. SB = sedentary behavior; LPA = light physical activity; MVPA = moderate-to-vigorous physical activity; hh:mm = hours:minutes; PAB = physical activity behavior.
with their PAB [42]. In the current study, we only focused on PAB, in other words, the energy output. It is also possible that compensatory behaviors show at the level of the energy input, by changing one’s food intake [20,43]; this presents another interesting avenue for future research. Finally, further research is needed to explain the short-term co-variation effect of standing desk interventions on MVPA, which may have important societal implications for health promotion.

5. Conclusions

Standing tutorial meetings are effective at reducing SB and increasing LPA in undergraduates. Although there were modest compensatory behaviors, there was also a carry-over effect where the stand group showed less SB on non-tutorial days. Although these findings were diluted during the exam week (i.e., no carry-over effects), the stand group still showed less SB, broke up their SB more frequently, and showed more LPA on the tutorial day. The findings of this study, coupled with students reporting that they prefer the option to stand in class [44], call for educational institutions and policy makers to provide students with the option to engage in LPA during class hours. We conclude that standing tutorial meetings can contribute to a more active lifestyle for undergraduates.

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Author contributions

Study design, H.Q.C., R.H.J.E., and H.H.C.M.S.; Data collection, data management, data analysis, and writing of the report, H.Q.C.; Supervision, statistical planning, statistical analysis, reporting of results: P.W.M. V.G., R.H.M.D.G., M.G.A.O.E., R.H.J.E., and H.H.C.M.S. All authors have read and agreed to the published version of the manuscript.

Availability of data and materials

All data collected were stored securely and only the primary researcher has access (via password and key) to the data. All personal information was encrypted with a code, to which the primary researcher only has the key. The encrypted data were stored separately from the main study data. After the data collection phase, all data were completely anonymized. Data generated from this study will be available on Dataverse.nl or on reasonable request via the corresponding author.

Declaration of Competing Interest

The authors declare no conflict of interest.

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Appendix

Preliminary Analyses

Across all participants in week 4–5, there were significant differences between each day for:

- LPA, $\chi^2(6) = 20.1, p = .003$. Pairwise comparisons show that the participants had more LPA on Sunday compared to Friday (Bonferroni corrected $p = .002$)
- MVPA, $\chi^2(6) = 15.7, p = .016$. Pairwise comparisons show that the participants had more MVPA on Sunday compared to Friday (Bonferroni corrected $p = .018$)
- Lying, $\chi^2(6) = 21.5, p = .001$. Pairwise comparisons show that the participants lied down more on Sunday compared to Tuesday (Bonferroni corrected $p = .005$) and Friday (Bonferroni corrected $p = .020$)

Across all participants in week 9, there were significant differences between each day for:

- SB, $\chi^2(6) = 23.4, p = .001$. Pairwise comparisons show that participants had more SB on Sunday (compared to Monday, Bonferroni corrected $p = .026$), Tuesday, Bonferroni corrected $p = .050$, Wednesday, Bonferroni corrected $p = .004$, and Thursday Bonferroni corrected $p = .003$)
- LPA, $\chi^2(6) = 50.9, p < .001$. Pairwise comparisons show that participants had more LPA on Saturday (compared to Wednesday, Bonferroni corrected $p = .004$ and Thursday, Bonferroni corrected $p = .026$)
- MVPA, $\chi^2(6) = 96.9, p < .001$. Pairwise comparisons show that participants had more SB on Saturday (compared to Tuesday, Bonferroni corrected $p = .022$ and Friday, Bonferroni corrected $p < .001$) and Sunday (compared to Friday, Bonferroni corrected $p < .001$)
- Lying, $\chi^2(6) = 19.0, p = .004$. Pairwise comparisons show that participants lied down more on Sunday (compared to Friday, Bonferroni corrected $p < .001$)

Significant PAB differences between days always involved a weekend day, suggesting that activities during weekends were very different from activities on weekdays. Therefore, weekend days were removed from further analyses. The only remaining PAB differences between days were in week 9. The participants had less LPA and MVPA on Wednesday and Thursday (compared to Monday and Tuesday), supporting the clustering of these two days into one type of day, that is “pre-exam days”. Furthermore, the participants had more MVPA on Friday (compared to Monday, Wednesday, and Thursday). The participants also had more MVPA on Friday compared to Wednesday, but less compared to Thursday. This also support the classification of Friday as one type of day, that is the “exam day”.

Participants who were in the earlier (8:30 to 10:30) tutorials spent significantly less time lying on a tutorial day, (Friday of Week 4–5, approximately 88 min less, t (71) = 2.167, $p = .033$) than those in the later (11:00 to 13:00) tutorials. This meant that the waking hours were different for participants in earlier and later tutorials. Therefore, lying time was added to the GLMM analyses as a covariate.

The daily diaries were meant as a check for the activPAL3 data. However, this purpose was not met as 49 (63%) and 57 (83%) participants in week 4–5 and week 9, respectively, had incomplete diaries.

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