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Validation of a smart chair and corresponding smartphone app as an objective measure of desk-based sitting

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Abstract

Objectives: This study evaluated the validity of a smart chair and corresponding smartphone app (chair&app) to measure sitting time and sitting interruptions against camera-derived observation and activPAL.

Methods: Belgian deskbound university employees (n = 28, 17 women, mean age 30 ± 7.5 years, mean BMI $22.1 \pm 2.0 \, kg/m^2$) were provided with the chair&app in three conditions: a controlled condition (following a prescribed protocol), a free-living condition (conducting usual office work for 2 hours), and an extended free-living condition (conducting usual office work for three consecutive days). Total sitting time and the number of sitting interruptions were compared between the chair&app and criterion measures (camera observation and activPAL). Criterion validity was assessed using mean differences (95% CI) and intra-class correlation coefficients (ICC; 95% CI).

Results: In the controlled condition, mean sitting time and number of sitting interruptions differed between chair&app and camera observation by 2.7 (−2.4, 7.9) minutes and −8.0 (−10.4, −5.6) interruptions, respectively. For the free-living condition, there was good agreement between chair&app and camera observation for both sitting time (ICC: 0.74; 0.28, 0.93) and sitting interruptions (ICC: 0.68; 0.10, 0.91). For the extended free-living condition, there was excellent agreement between chair&app and activPAL for sitting time (ICC: 0.89; 0.49, 0.97). Meanwhile, there was poor agreement between chair&app and activPAL for sitting interruptions (ICC: 0.38; −0.04, 0.70).

Conclusions: Chair&app generally provided reliable measures of desk-based sitting. Consequently, chair&app might be useful as a self-monitoring tool in the workplace context. Further research is needed to explore its usefulness in reducing adults' desk-based sitting.

KEYWORDS

measurement, sedentary behavior, smartphone, validation, workplace

1 | INTRODUCTION

High levels of sedentary behavior (SB: sitting or reclining with low energy expenditure while awake[1]) have been linked to deleterious health outcomes, largely independent of the level of physical activity.[2] SB is widespread throughout the day. SB is particularly ubiquitous at the workplace. In fact, it was found that office workers spend up to 71% of working hours performing sedentary tasks.[3] Modern occupations involve high volumes of desk-based sitting. Accordingly,

workplace SB can be considered a potential occupational health risk.[4]

Adults are often unaware of their prolonged SB. Devices that monitor SB can be useful tools to increase awareness of prolonged sitting. As adults spend large amounts of time at work, the workplace offers an ideal avenue to deliver adults with feedback on their prolonged sitting. As such, personalized feedback can be derived from self-monitoring tools.

Research on self-monitoring tools has been proliferated recently. A recent scoping review evaluated self-monitoring tools that were developed to capture either physical activity or sedentary time.[5] A large number of devices were identified that self-monitor physical activity (eg, pedometers), while only few self-monitoring devices are developed to capture sedentary time. Even fewer of these self-monitoring devices have been scientifically tested on their validity.[5]

To fill this gap, this study evaluated a novel, promising and unobtrusive objective self-monitoring instrument designed to capture desk-based sitting. This self-monitoring instrument has been developed to provide the user feedback on desk-based sitting. The instrument consists of a measurement instrument (ie, a smart chair) and a corresponding feedback tool (ie, a smartphone app). The smart chair is an office chair that is able to detect sitting by pressure sensors located in the seat.[6] The smartphone app provides users with real-time feedback on their sitting pattern.

This study evaluated the validity of a smart chair and corresponding smartphone app to assess desk-based sitting against objective criterion measures (ie, camera-derived observation and activPAL). An evaluation of the validity of this self-monitoring instrument constitutes the first step to determine its usefulness as a feedback tool in future intervention studies.

2 | METHODS

2.1 | Smart chair and app

This study evaluated the validity of the Axia Smart Active® (ASA) smart chair and smartphone app (BMA Ergonomics, Zwolle, the Netherlands). This smart chair is a regular office chair that is equipped with pressure sensors located in the seat surface and backrest. The pressure sensors detect whether the user is sitting on the chair. This information with respect to sitting is stored in the chair and can be transferred to a smartphone app (ASA app) through a Bluetooth connection. The ASA app delivers real-time numerical and graphical feedback on the user's sitting pattern. Numerical feedback includes the user's total sitting time as well as the number of sitting interruptions. Graphical feedback includes the graphical representation of the user's sitting pattern. Screenshots of the smartphone app can be found in the article supplement (Figure S1).

The ASA smart chair and app were evaluated in three conditions: a controlled condition, a free-living condition, and an extended free-living condition. The specific procedure in each condition is described below. The study protocol was approved by the Social and Societal Ethics Committee of KU Leuven, Belgium (reference no. G-2015 11 388).

2.2 | Participants

Participants consisted of deskbound office workers that were recruited from the University of Leuven, (KU Leuven) Belgium. Two groups of university office workers were recruited. One group participated in both the controlled and free-living condition, while the other group participated in the extended free-living condition. All participants provided written informed consent.

2.2.1 | Controlled and free-living condition

For the controlled and free-living condition, a convenience sample of 10 healthy office workers was recruited via email and word of mouth. The office workers worked in the same building on a Faculty of the KU Leuven, Belgium.

2.2.2 | Extended free-living condition

For the extended free-living condition, a convenience sample of 18 university office workers was recruited by email. The office workers worked in different buildings of a Faculty of the KU Leuven, Belgium. Office workers were considered eligible if they were able to work in their office for three consecutive workdays including a minimum of four work hours on each workday.

2.3 | Procedure

Prior to measurements, participants self-reported their age, gender, height, and weight on a structured questionnaire. To determine the sensitivity and short-term validity of the ASA smart chair and app, one group of office workers completed both the controlled and free-living condition. Further elaboration on the validity was conducted in a separate, larger and comparable group of office workers. This group completed the extended free-living condition.

2.3.1 | Controlled condition

In the controlled condition, participants used the ASA smart chair and app following a prescribed protocol under standardized settings. Participants completed this protocol outside their office/work environment. The prescribed protocol corresponds to the example of Ryde et al.[7] The protocol consisted of 1 minute bouts of sitting interspersed with sitting

interruptions (standing) of differing durations. The interruptions had a minimum duration of 10 seconds and a maximum duration of 60 seconds. The protocol included a build-up phase (10, 15, 20, 30, 40, 50, and 60 seconds) and a declining phase (60, 50, 40, 30, 20, 15, and 10 seconds). Subsequently, the protocol consisted of four 5 minute sitting bouts interrupted by 1 minute of standing. This protocol tested the sensitivity of the pressure sensors (located in chair seat) to detect sitting interruptions. During this condition, participants were monitored using camera observation.

2.3.2 | Free-living condition

During the free-living condition, participants used the ASA smart chair and app in their office for 2 hours. Participants were instructed to perform their usual work activities. Similar to the controlled condition, participants were recorded by camera observation. The camera was positioned to record chair-based sitting.

To prevent a confounding "order effect," the order in which participants started with the controlled or free-living condition was counterbalanced across participants.

2.3.3 | Extended free-living condition

During the extended free-living condition, participants used the ASA smart chair and app in their office for three consecutive workdays.

Prior to the three workdays, there was a familiarization day. During this familiarization day, participants were provided with the ASA smart chair, ASA app, and an activPAL device. Participants received information regarding the ASA smart chair, the ASA smartphone app, and the activPAL monitor. Specifically, participants were instructed (a) on the correct (ergonomic) adjustment of the ASA smart chair, (b) on the different features of the ASA app, and (c) on the correct attachment and wear time (ie, working hours) of the activPAL device. After the instructions, participants were able to familiarize with the ASA smart chair and app during the rest of the day. The following three workdays were considered measurement days.

2.4 | Measures

2.4.1 | Smart chair and app

Controlled, free-living, and extended free-living condition
The ASA smart chair and app recorded sitting time as well as the number of sitting interruptions during all three conditions. After the completion of measurements, screenshots of the ASA app were collected. These screenshots displayed time spent sitting and the number of sitting interruptions (Figure S1).

2.4.2 | Criterion measures

Controlled and free-living condition
During both the controlled and free-living condition, the criterion measure was camera-derived observation. Camera data were time stamped and binary coded ($0 =$ sitting and $1 =$ standing/moving) to obtain time spent sitting and the number of sitting interruptions.

Extended free-living condition
During the extended free-living condition, the criterion measure was an activPAL inclinometer (activPAL3c, PAL Technologies Ltd., UK). ActivPAL is a small ($53 \times 35 \times 7$ mm) and light (15 g) tri-axial activity monitor. It is a widely used assessment method in SB research and has been validated previously (ie, correlation (r^2) of .94 between activPAL and direct observation).[8]

Participants attached the activPAL on the midline of their right thigh using hypoallergenic tape. The activPAL device provides accurate measures of time spent sitting, standing, and stepping based on inclination of the thigh. The collected activPAL data were processed using proprietary activPAL3 software (version 7.2.32). The activPAL3 software provides time-stamped events of sitting (including interruptions), standing, and stepping. More specifically, the software provides 10-second epochs of sitting, standing, or stepping. In this study, activPAL data of time spent sitting and the number of sitting interruptions were retrieved to be used in the analyses.

The activPAL device was worn during working hours. Participants held a diary in which they reported their working hours (ie, begin and end of workday), lunchtime, and periods of >20 minutes in which they were absent from their office. In order to retrieve desk-based sitting, diary information was used to remove activPAL data that have been recorded outside the office. Data from the three measurement days were averaged to retrieve the mean sitting time and the mean number of sitting interruptions throughout the 3-day measurement period.

2.5 | Statistical analyses

Study groups were compared using independent samples t tests (for age and BMI) and chi-square test (for gender). Mean sitting time and number of sitting interruptions were calculated for each device. Criterion validity of the ASA smart chair and app was evaluated using absolute agreements and intra-class correlation.

Agreements between the data collected by the ASA app and the criterion measures were assessed by calculating mean differences (ASA app-criterion measure), mean absolute error (MAE: Σ(ASA app-criterion measure)/n), and root of mean square error (RMSE: $\sqrt{\Sigma(\text{ASAapp} - \text{criterionmeasure})^2/n}$). Mean differences and MAE indicated whether the ASA app over-/

underestimated sitting time and number of sitting interruptions. RMSE indicated the standard deviation of the difference between the ASA app and the criterion measures. In addition, the agreement between the ASA app and the criterion measures was evaluated using Bland-Altman plots with 95% limits of agreement using Krouwer's method.[9] Furthermore, intra-class correlation was evaluated by 2-way mixed-model intra-class correlation coefficients (ICC) including 95% confidence intervals (CI). Validity was considered poor, moderate, good, or excellent when ICCs were ≤0.39, 0.4-0.59, 0.6-79, or >0.8, respectively.[10] Statistical analyses were performed using IBM SPSS Statistics version 21 (IBM Corp., Armonk, NY, USA).

3 | RESULTS

3.1 | Participants

Participants (n = 10; six women) in the controlled and free-living condition had a mean age of 28 ± 5.6 years and a mean BMI of 22.0 ± 2.4 kg/m^2. Participants (n = 18; eleven women) in the extended free-living condition had a mean age of 31 ± 8.3 years and a mean BMI of 22.1 ± 1.8 kg/m^2. Both groups did not differ on gender ($\chi^2 = 0.003$; $P = 0.954$), age ($F = 0.078$; $P = 0.378$), or BMI ($F = 2.003$; $P = 0.905$).

3.2 | Validity

Agreements between the ASA app and the criterion measures in each of the conditions are presented in Table 1.

3.2.1 | Controlled condition

The mean difference in sitting time and number of sitting interruptions between the ASA app (mean ± SD; 37.6 ± 7.3 minutes and 10.0 ± 3.3 interruptions) and camera-derived observation (34.9 ± 0.3 minutes and 18.0 ± 0.0 interruptions)

was 2.7 (95% CI: −2.4, 7.9; RMSE: 5.8) minutes and −8.0. (−10.4, −5.6; RMSE: 9.0) interruptions, respectively. The ASA smart chair and app were found to record sitting interruptions of at least 40 seconds.

3.2.2 | Free-living condition

The mean difference in sitting time and number of sitting interruptions between ASA app (112.6 ± 7.0 minutes and 3.1 ± 2.1 interruptions) and camera-derived observation (110.1 ± 6.6 minutes and 4.5 ± 3.1 interruptions) was 2.5 (−0.76, 5.73; RMSE: 4.6) minutes and −1.4 (−2.71, −0.09; RMSE: 2.7) interruptions, respectively. There was good agreement between the ASA app and camera-derived observation for both sitting time (ICC: 0.74, 95% CI: 0.28, 0.93) and the number of sitting interruptions (ICC: 0.68, 95% CI: 0.10, 0.91).

3.2.3 | Extended free-living condition

The mean difference in sitting time and number of sitting interruptions between ASA app (272.9 ± 73.0 minutes and 8.4 ± 4.6 interruptions) and activPAL (295.6 ± 66.6 minutes and 11.8 ± 5.8 interruptions) was −22.6 (−35.4, −9.9; RMSE:33.7) minutes and −3.4 (−6.2, −0.7; RMSE: 4.9) interruptions, respectively. For sitting time, there was excellent agreement between the ASA app and activPAL (ICC: 0.89, 95% CI: 0.49, 0.97). For the number of sitting interruptions, a poor agreement was found between ASA app and activPAL (ICC: 0.38, 95% CI: −0.04, 0.70).

Bland-Altman plots of sitting time and sitting interruptions for both the free-living and extended free-living conditions are shown in Figure 1. For both the free-living (Figure 1A,B) and extended free-living conditions (Figure 1C,D), the limits of agreement of sitting time and sitting interruptions were narrow. These narrow limits of agreement point out the

TABLE 1 Agreement between the Axia Smart Active app and criterion measures (camera observation and activPAL)

	Sitting time (min)			Number of sitting interruptions (n)		
	MAE[c] (95% CI)	RMSE[d]	ICC[e] (95% CI)	MAE (95% CI)	RMSE	ICC (95% CI)
Controlled condition[a]						
ASA app	0.27 (−0.24, 0.79)	0.58	0.03 (−0.54, 0.61)	−0.80 (−1.04, −0.56)	0.90	0.00 (−0.06, 0.19)
FL condition[a]						
ASA app	0.25 (−0.08, 0.57)	0.45	0.74 (0.28, 0.93)	−0.14 (−0.27, −0.01)	0.29	0.68 (0.10, 0.91)
Extended FL condition[b]						
ASA app	−1.26 (−1.96, −0.55)	1.87	0.89 (0.49, 0.97)	−0.19 (−0.34, −0.04)	0.27	0.38 (−0.04, 0.70)

ASA: Axia Smart Active; CI: confidence interval; FL: free-living; ICC: intra-class correlation; MAE: mean absolute error; RMSE: root mean square error.

[a]Criterion measure of both the controlled and free-living conditions was camera observation.

[b]Criterion measure of the extended free-living condition was activPAL.

[c]Mean difference between the two measures was calculated as Σ(ASA app-criterion measure)/n.

[d]Root of mean square error was calculated as $\sqrt{\Sigma(\text{ASAapp} - \text{criterion measure})^2/n}$.

[e]ICC calculated using two-way mixed-effects model with absolute agreement.

accuracy of the ASA smart chair in assessing sitting time as well as sitting interruptions.

4 | DISCUSSION

This study examined the validity of a smart chair and corresponding smartphone app as a measure of desk-based sitting. Overall, the results indicated that the smart chair and corresponding smartphone app were able to provide reliable measures of desk-based sitting. Good and excellent agreements between the smart chair and app and the criterion measures were found in the free-living and extended

free-living conditions. However, it should be noted that, in the extended free-living condition, there was poor agreement between the smart chair and app and activPAL regarding the number of sitting interruptions. This finding may be due to differences in recording sensitivity between the smart chair and activPAL. In fact, as tested in the controlled condition, the smart chair and app were found to record interruptions of a minimum of 40 seconds. This indicates that shorter sitting interruptions of 30 seconds or less might not be displayed on the smartphone app. Meanwhile, activPAL is more sensitive as it records sitting interruptions of as little as 10 seconds. This difference in sensitivity may explain the poor agreement between the smart chair and app and activPAL.
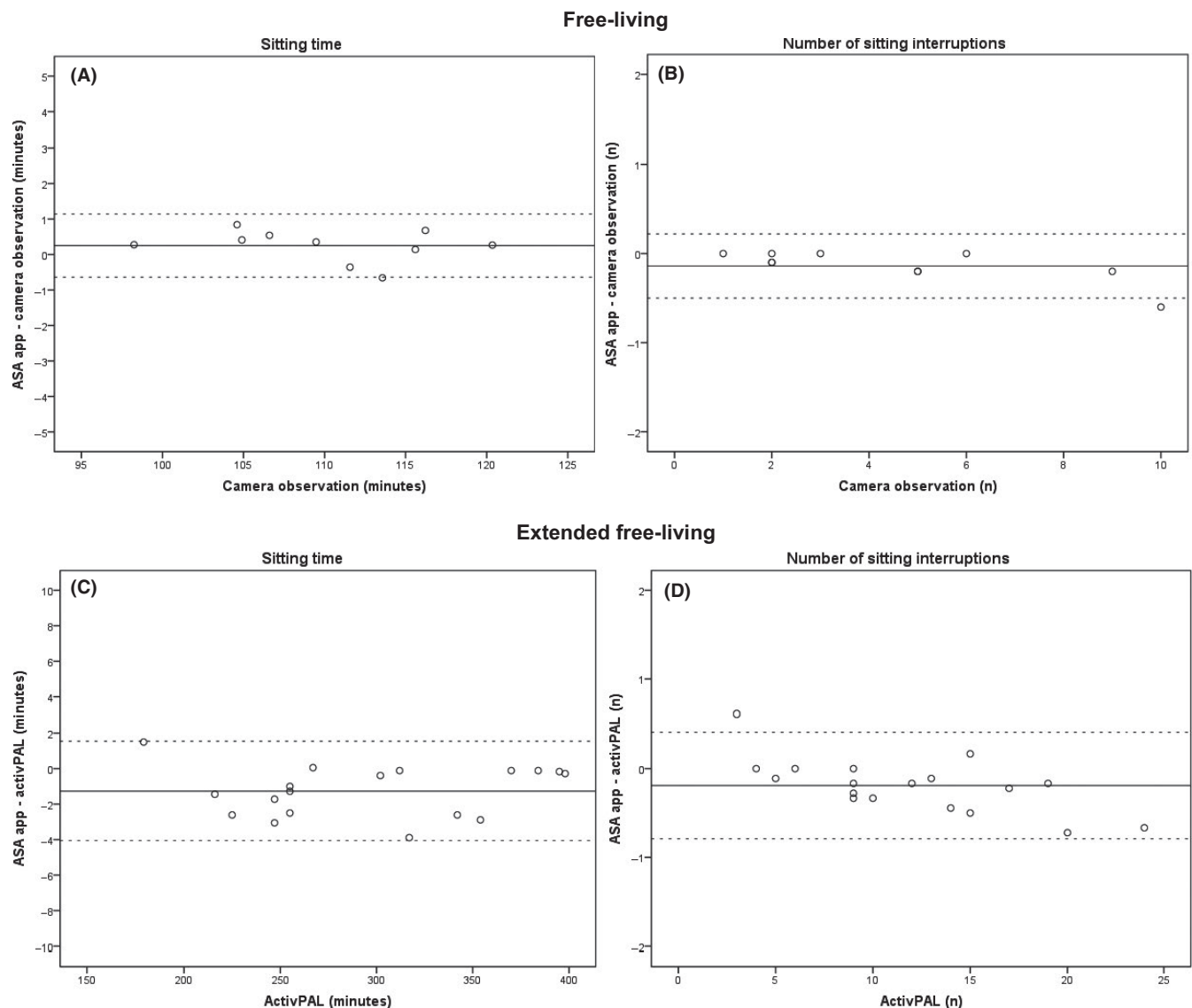
FIGURE 1 Bland-Altman plots of sitting time and the number of sitting interruptions between the Axia Smart Active (ASA) app and criterion measures (camera observation and activPAL). (A-B), Sitting time and number of sitting interruptions recorded during the free-living condition; (C-D), sitting time and number of sitting interruptions recorded during the extended free-living condition. The mean absolute difference between the ASA app and the criterion measure (y axes) is plotted against the criterion measure (x axes). Solid lines represent the mean differences. Dotted lines represent the upper (mean difference +1.96 SD) and lower (mean difference −1.96 SD) limits of agreement

The self-monitoring tool used in this study consisted of a measurement instrument (smart chair) and a feedback tool (smartphone app). The measurement instrument (smart chair) has similarities with the sitting pad that was developed in 2011.[7] The sitting pad consists of a cushion that contains a pressure sensor to detect sitting time and sitting interruptions. Ryde et al evaluated the validity of the sitting pad and found excellent levels of agreement between the sitting pad and camera-derived observation (ICC of 0.999 and 0.997 for sitting time and sitting interruptions, respectively).[7] These levels of agreement are higher than the levels of agreements reported in this study. This dissimilarity may not only result from the difference in sensitivity between the smart chair and the sitting pad but may also be due to the difference in protocol of the free-living condition. The sitting pad was evaluated in a relatively short free-living condition of up to 60 minutes, while the smart chair was evaluated using an extended free-living condition of three workdays. It should also be noted that the smart chair has a distinct advantage over the sitting pad. Unlike the sitting pad, the smart chair has the ability to transfer the collected sitting data to a smartphone device. As such, users can access data on their sitting pattern by means of a smartphone app. This feedback constitutes an added value as users of the smart chair may act upon the real-time feedback on their sitting pattern.[5]

The feedback tool (smartphone app) has the potential to elicit behavior change. Smartphone technology offers great potential to initiate behavior change as smartphones have become omnipresent in modern societies. As such, smartphone technology could be used to make people aware of their prolonged SB.[11,12] The current smartphone-based self-monitoring tool captures desk-based sitting. Previous objective data indicated that office workers spend up to two third (67%) of the workday seated at their desk.[13] Accordingly, desk-based sitting contributes substantially to the total sitting time accumulated during the workday. The current smartphone-based self-monitoring tool may be useful to make office workers aware of the prolonged character of desk-based sitting.

The main strengths of this study include the novelty of the objective measure (ie, the combination of smart chair and smartphone app) and the use of two different criterion measures (ie, camera-derived observation and activPAL). Nevertheless, the following limitations need to be considered. The first limitation refers to the measurement device. The smart chair and smartphone app provide personalized feedback, specifically, on desk-based sitting. Prolonged sitting away from the office (desk) is not captured. However, most modern occupations require high volumes of desk-based sitting.[13] For this specific setting, the smart chair and corresponding app would be useful feedback instruments. Another limitation refers to the study sample. The sample consisted of a small, homogenous group of desk-based university office workers. Therefore, the generalizability of our findings to desk-based office workers in other contexts (eg, call center) should be tested further.

The current smartphone-based self-monitoring tool is a commercially available consumer device. In general, there are two types of devices that are being used to self-monitor SB. These types include research devices (ie, research-grade devices) and commercially available consumer devices (ie, consumer-level devices). Consumer-level devices have the potential to be used as intervention tools in scientific studies. In particular, smartphone apps have great potential as they represent accessible, convenient, and user-friendly self-monitoring tools. However, consumer-level devices need to be validated against extensively validated research-grade devices before they can be used in intervention studies. This study examined the validity of a consumer-level smartphone-based self-monitoring tool and thus constitutes the first step in establishing its usefulness as an intervention tool in future intervention studies.

In this study, desk-based sitting refers to the duration and pattern of sitting. Besides the duration and pattern of sitting, it is also important to acknowledge the posture while seated. Ergonomically incorrect sitting postures (eg, insufficient low back support) can eventually lead to musculoskeletal discomfort.[14] In this respect, a previous version of the smart chair was developed to provide users with tactile feedback on their posture.[15] Specifically, the users received a vibration signal when seated in an ergonomically incorrect posture. Tactile feedback has been found to improve measures of musculoskeletal discomfort.[6] Future research needs to confirm this initial evidence of the potential of tactile feedback on improving sitting postures.

5 | CONCLUSION

Overall, the smart chair and corresponding smartphone app were able to provide reliable measures of desk-based sitting. However, the smartphone app appeared not to display short sitting interruptions (<30 seconds). Nevertheless, users of this self-monitoring tool receive real-time feedback on their desk-based sitting pattern. This context-specific feedback may be useful in the delivery of workplace behavioral interventions. Further research is needed to further determine the usefulness of the self-monitoring tool in reducing adults' desk-based sitting.

DISCLOSURES

Approval of research protocol: The Social and Societal Ethics Committee of KU Leuven approved the study protocol (reference no. G-2015 11 388). _Informed consent:_ All participants provided written informed consent. _Registry and the registration no. of the study/trial:_ N/A _Animal studies:_ N/A.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest.

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

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