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The effect of a dynamic chair on seated energy expenditure

Aoife Synnott^a , Wim Dankaerts^b, Jan Seghers^c, Helen Purtill^d and Kieran O'Sullivan^{a,e}

^aDepartment of Clinical Therapies, University of Limerick, Limerick, Ireland; ^bDepartment of Rehabilitation Sciences, University of Leuven, Leuven, Belgium; ^cDepartment of Kinesiology, University of Leuven, Leuven, Belgium; ^dDepartment of Mathematics and Statistics, University of Limerick, Ireland; ^eAspetar Sports Spine Centre, Doha, Qatar

ABSTRACT

Dynamic sitting approaches have been advocated to increase seated energy expenditure with the view of lessening the sedentary nature of the task. This study compared energy expenditure (EE) and overall body discomfort on a novel dynamic chair with a standard office chair. Fifteen pain-free participants completed a DVD viewing task on both chairs in a randomised order. Energy expenditure and discomfort were collected simultaneously. Linear mixed models were used to analyse steady-state EE recorded on each of the chairs. Differences in discomfort were analysed using Wilcoxon Signed Rank Tests. Sitting on the novel dynamic chair significantly ($p = 0.005$) increased energy expenditure compared to a standard office chair. The discomfort experienced was mild overall, but was significantly greater on the dynamic chair ($p = 0.004$). Whilst the EE was seen to be significantly higher on the dynamic chair, the MET values are still below 1.5 METS. Thus, the use of a dynamic chair does not seem to be the most effective measure to prevent sedentary behaviour.

Practitioner Summary: Sitting on a dynamic chair increased energy expenditure compared to sitting on a standard office chair among pain-free participants. Whilst the EE was seen to be significantly higher on the dynamic chair, the MET values are still below 1.5 METS (low level EE).

ARTICLE HISTORY

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KEYWORDS

Sitting; sedentary; energy expenditure; office ergonomics

1. Introduction

Modern society has continually demonstrated regular advances in the communication, transportation and home-entertainment systems that form an integral part of our daily lives, consequently altering the physical, economic and social environments in which we now live (Choi et al. 2010; Owen et al. 2010). In turn, the demands for the present population to be physically active have significantly reduced, while conscious and subconscious participation in sedentary behaviours have only continued to grow (Parry and Straker 2013).

Sedentary behaviours are characterised by periods of prolonged sitting or reclining in the absence of Physical Activity (PA), typified by their association with low energy expenditure values (<1.5 METS) (Parry and Straker 2013; van Uffelen et al. 2010). As engagement in sedentary behaviours could potentially displace time spent in higher PA intensities, the deleterious biological consequences associated with chronic uninterrupted periods of muscular inactivity during prolonged sedentary activities have received considerable attention in recent years (Hamilton et al. 2008; Owen et al. 2010).

Research has shown that prolonged sitting has significant metabolic effects, leading to increased cardiovascular risk and premature mortality (Grunseit et al. 2013; Hamilton et al. 2008). Time spent in sedentary behaviours is now regarded as an independent risk factor for premature mortality, which cannot be compensated for with participation in leisure time PA (Biswas et al. 2015; Wilmot et al. 2012).

The contemporary workplace typically represents a sedentary community, in which office-based workers spend more than half of their working day seated (Dunstan et al. 2012; Pronk et al. 2012). As employed adults represent more than 50% of the world's population, with most adults spending one-third of their adult life at work (Alkhajah et al. 2012), the occupational environment is seen as a key area for both prevention and intervention of health conditions related to physical inactivity (Alkhajah et al. 2012).

Public health policy denotes the creation of PA opportunities at work as a priority, emphasising sitting as the primary outcome for future workplace action (Dunstan et al. 2013; Grunseit et al. 2013). The use of sit-to-stand desks and micro-breaks has been proposed as strategies to attenuate time spent sitting at work (Pronk et al. 2012).

Table 1. Demographic data presented as mean (standard deviation) or median (range)[#].

Measure	Mean (\pm SD)
Age (years)	24 (18–55) [#]
Height (cm)	176.4 (\pm 2.6)
Mass (kg)	68.6 (\pm 4.6)
Body Mass Index (kg/m ²)	23.7 (\pm 0.54)

Note: # indicates median range.

While such interventions demonstrated promising results in the short term (Pronk et al. 2012), poor methodological quality (Dunstan et al. 2013), poor long-term compliance (Pronk et al. 2012), employer concerns regarding employee productivity (Tudor-Locke et al. 2014) and installation costs have prevented the wide spread implementation of such interventions in the workplace (Chau et al. 2010).

Dynamic chairs which increase the effort required to maintain balance in sitting represent a potential alternative to the aforementioned costly and productivity-compromising interventions which aim to address the negative effects of prolonged sitting at work. Increasing variation in posture for constrained work is believed to be of benefit to both health and work performance (Straker and Erik Mathiassen 2010). The novel 'Back App' chair (*manufacturer: backapp.eu*) combines the features of a forward-inclined saddle chair with the principles of dynamic sitting (O'Keeffe et al. 2013) where the seated person may have to increase the effort associated with sitting due to the unstable base (O'Keeffe et al. 2013). The degree of seated motion can be adjusted using a ball located at the base of the chair. For instance, by adjusting the ball at the base of the chair to different colour zones, it can function as a relatively static chair (green zone), a dynamic chair (black zone) or a more unstable training chair (red zone) (O'Keeffe et al. 2013). Therefore, it can vary muscular effort, with a potential impact on energy expenditure (EE), though this has not yet been examined (O'Sullivan et al. 2012b).

Therefore, the aim of this experimental study was to examine whether the dynamic sitting environment of the 'Back App' chair increases the associated EE during sitting. The study aims to see if the dynamic chair significantly increased the METS attained to above that of 1.5 METS, as seen in implemented physical activity technical measures in the workplace in previously conducted research, e.g. using a deskbike VDU workstation (Botter et al. 2016).

2. Methods

2.1. Study design

A single session, repeated measures, crossover study design was used, in line with previous, similar studies (Curran et al. 2014; O'Keeffe et al. 2013; O'Sullivan et al. 2012b). All participants completed the same protocol on

a single day of their choice. The order of testing and chair type for alternate one-hour testing periods was randomly decided by tossing a coin. The primary dependent variable was EE, and the independent variable was chair type. Ethical approval was obtained from the local university Research Ethics Committee (Ethical approval number 2014_06_38_EHS), and written informed consent was obtained from all participants.

2.2. Participants

Fifteen (6F, 9M) pain-free participants were recruited from the local university community, comprised all of university undergraduate and postgraduate students of whom had no prior experience of sitting in a dynamic chair. Participants were aged >18 years, were not pregnant, had no low back pain (LBP) in the last two years, no previous spinal surgery, no neurological symptoms such as pins and needles or numbness, no specific spine disorder/tumour/fracture (van Deursen et al. 1999), no visual impairment and could speak/understand English. Subject demographics were obtained prior to testing and can be seen in Table 1.

2.3. Instrumentation

2.3.1. Energy expenditure

Breath-by-breath ventilation was measured using the Jaeger Oxycon Mobile[®] (VIASYS Healthcare GmbH, Leibnizstr, Germany). The Oxycon Mobile[®] is an automated, portable metabolic gas analysis system that has been validated as a measure of PA intensity compared to the Douglas Bag method (Rosdahl et al. 2010). It consists of a lightweight (approx 950 g), battery-operated ergospirometry system attached to the individual using a vest. Data are examined breath by breath and expired gas is collected through a facemask. This information is transferred to and stored in the host computer in real time. The data are presented for every 30 s of recording. In line with the manufacturer's recommendations, the power and calibration unit (PCa unit) was switched on and connected to the Sensorbox unit (SBx unit) for at least 15 min prior to use. Subsequently, the flow sensor was calibrated using the inbuilt automated 'Auto-Cal' procedure as per the manufacturer's instructions. Gas calibration was performed prior to each experiment using a reference gas of known composition.

2.3.2. Chairs

The dynamic, forward-inclined saddle chair (Figure 1) was adjusted to allow hip flexion of 55° with feet placed on the footplate for all participants, in line with previous research (O'Sullivan et al. 2012a, 2012b). The ball underneath the



Figure 1. Dynamic Chair.



Figure 2. Standard Office Chair.

chair was adjusted to allow a moderate degree of instability (black zone), in line with previous research (O'Sullivan et al. 2012a, 2012b; O'Keeffe et al. 2013; Curran et al. 2014).

The standard office chair (Figure 2) had a moveable backrest, was height adjustable and had wheels. The office chair was adjusted to allow an angle of 90° for both hips and knees with feet placed on the floor (Gregory, Dunk, and Callaghan 2006).

The instructions used were 'sit as you normally would' on the standard office chair and 'try to balance yourself' on the dynamic, forward-inclined saddle chair. An adjustment time (two min) was provided to allow participants to become familiarised with the chairs (Kingma and van Dieën 2009).

2.4. Procedure

2.4.1. Viewing station set-up

A viewing station was created for the standardised DVD viewing (see Figure 3). As self-selection of viewing station set-ups can be linked to the adoption of less than optimal sitting postures (Gadge and Innes 2007), participants' hands were placed on their thighs while viewing. The distance of participants from the viewing station was standardised to two metres. Participants chose from a finalised list of 15 movies which all were approx. two hours in duration and fulfilled the drama genre when crosschecked with the IMDb website (<http://www.imdb.com/>) in order to reduce boredom and any potential accompanying stress (Miles-Chan et al. 2014). All participants watched one hour of the selected DVD on each chair.

2.4.2. Testing protocol

All testing took place in the Health Sciences Building at the University of Limerick, Ireland. The set-up and testing protocol were piloted prior to the study to enhance consistency and accuracy. All participants were required to fast for four hours prior to testing. In addition, all participants were required to refrain from vigorous physical activity, caffeine and/or alcohol prior to presenting to the laboratory for testing, due to the impact of these variables on resting metabolic rate (Compher et al. 2006). The purpose of this was to control for the metabolic cost of digestion, and the four-hour fasting period is similar to that used in other similar studies (John et al. 2011; Swartz, Squires, and Strath 2011). On arrival at the laboratory, participants' weight was measured in kilograms using a digital weighting scale (shoes removed) and height was measured in centimetres with shoes removed. Participants were required to wear light and comfortable clothing for the duration of testing. The Oxycon Mobile® was initialised by inputting participants' data (weight, height, gender, date



Figure 3. Viewing Station set-up.

of birth) and current ambient conditions. Menstrual cycle phase was not accounted for in this current study.

For the initial 30 min of the testing protocol, participants were required to lie supine on a physiotherapy plinth and were instructed to remain as still as possible. Subsequently, each participant underwent the first hour of DVD viewing on one type of chair as dictated by randomisation. At the conclusion of the first hour of DVD viewing, the participants were provided with the opportunity to take a five minute break during which the oxycon mask could be removed but no food could be consumed. Participants were allowed to stand/move during this five-minute period. Each participant then underwent a 20-minute washout period, during which they returned to the plinth to lie supine and still, so that the effect of the previous data collection condition would be eliminated, prior to undertaking the second hour of DVD viewing on the alternative chair.

2.5. Questionnaires

As prolonged sitting is often associated with increased discomfort, discomfort levels were monitored as part of the testing period on both chairs to examine how discomfort might potentially affect compliance with the ergonomic chair. This is particularly relevant as changes to seating design are often associated with increased discomfort in the lower back, or other regions of the body (Curran et al. 2015).

At baseline, every 15 min and on completion of each sitting exposure, participants rated their perceived discomfort on the body part discomfort scale (BPDS). The BPDS (Corlett and Bishop 1976) uses a chart with 12 body parts. In this study, a version using a six-point scale was used (Vergara and Page 2002), where 0 represents 'no discomfort', 1 represents 'light discomfort' and 5 represents 'pain/extreme discomfort'.

2.6. Data processing

2.6.1. Energy expenditure

At the end of the testing protocol, the measurement was saved and an Excel file was created using the proprietary software program (JLAB, CareFusion, San Diego, CA, USA). EE (kJ/min) was recorded and presented in 30 s intervals. To calculate an individual's resting (baseline) metabolic rate (BMR), the final 10 min of the 30 min rest period that preceded testing was used to determine the average EE in that time period. The mean unit of outcome of the Oxycon Mobile® was kcal/day, however this was converted to kilojoule/min (kJ/min) (1 kilojoule/minute = 14.33075379765 kilocalorie (IT)/hour) (Desai 2000) to reflect how EE had been reported in previous similar studies (Levine and Miller 2007; Miles-Chan et al. 2013; Speck and Schmitz 2011). For each of the sitting tasks on alternate chairs (office chair vs. 'Back App'), the metabolic equivalent (MET) value for that activity was calculated by averaging the EE (kJ/min) over the 60-minute period and dividing this value by the resting metabolic rate (kJ/min).

2.7. Data analysis

Summary statistics are presented as mean (SD), median (IQR) or percentage, as appropriate. Numeric data was examined for skewness using the Shapiro-Wilks test and through the visual inspection the histograms. Data were examined for trend using time series plots. To compare steady-state EE between the three conditions (Baseline, Office chair and Back App) 10 min of data (21 data values) were recorded after the participant had been sitting for 25mins in the condition, giving 945 data values nested within participants. This period of 10 min was selected so as to hopefully remove from the data any variance or effects due to settling into the new chair. A random coefficients' linear mixed model (LMM) with a variance components covariance structure was used to analyse the EE and MET steady-state data. A random intercept was used to account for within subject correlation and random coefficients were used to model the effect of condition varying between subjects. Estimated marginal means from the LMM model are presented for EE and MET data for each of the conditions, where *post hoc* pairwise Bonferroni

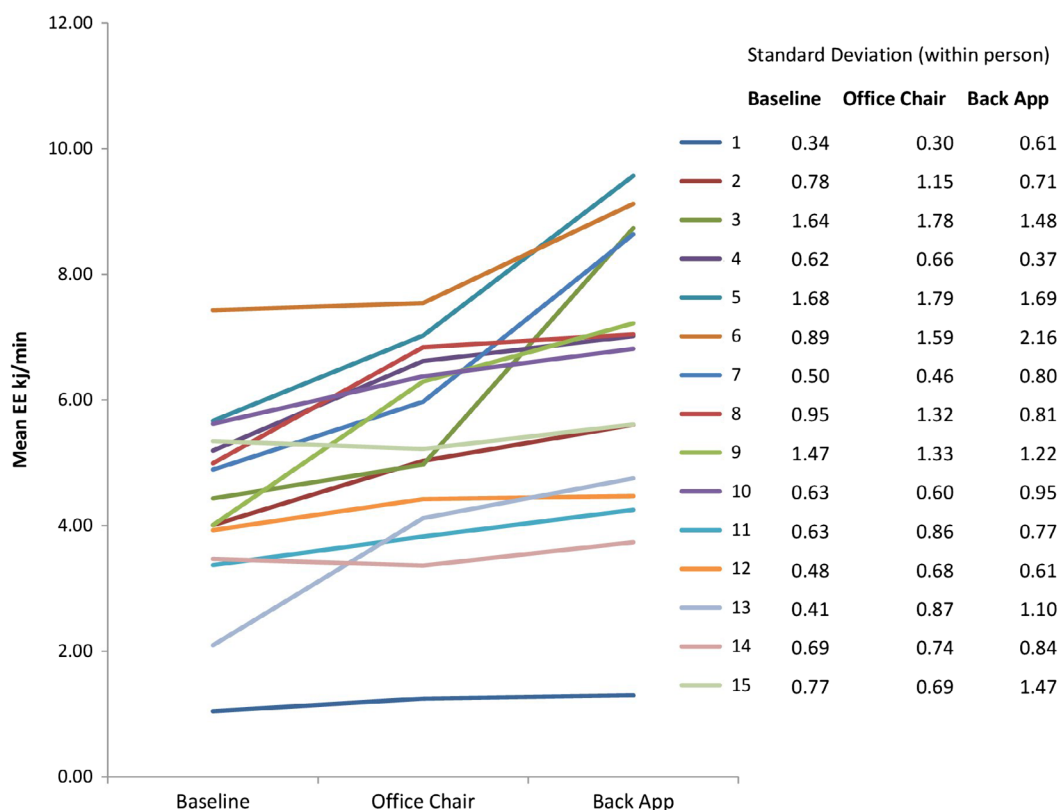


Figure 4. Mean EE per participant presented across three conditions.

adjusted comparisons report the significance of the mean difference (MD) between conditions.

Maximum discomfort scores recorded by participants were compared between the Office Chair and the Back App using a Wilcoxon Signed-ranks test. Data were analysed using IBM SPSS Statistics 22. Statistical significance was set at $p < 0.05$.

3. Results

A power calculation using nQuery AdvSior® software found that a sample size of 15 in a single-group repeated measures analysis of variance with a 0.05 significance level had 80% power to detect a difference in means across the 3 levels of the repeated measures factor characterised by a large effect size ($\eta^2 = 0.25$).

3.1. Energy Expenditure (EE) and MET

Demographic data is summarised in Table 1. Profile plots illustrating changes in participants' mean EE and mean MET across the three conditions are presented in Figures 4 and 5, respectively, with associated within-person standard deviations. Estimated marginal means and associated 95% confidence intervals from the LMM analysis of steady-state EE and MET for each of the conditions are given in Table 2. The analysis found that EE differed

significantly between the three conditions ($F(2, 28.01) = 21.27, p < 0.001$). The *post hoc* pairwise results from the LMM model found EE to be significantly higher for the Back App compared to the Office Chair (MD = 1.00, SE = 0.29, Bonferroni adjusted $p = 0.014$), and compared to Baseline (MD = 1.89, SE = 0.29, Bonferroni adjusted $p < 0.001$). MET differed significantly between the three conditions ($F(2, 28.01) = 25.11, p < 0.001$). The *post hoc* pairwise results from the LMM model found MET to be significantly higher for the Back App compared to the Office Chair (MD = 0.180, SE = 0.052, Bonferroni adjusted $p = 0.005$), and compared to Baseline (MD = 0.366, SE = 0.052, Bonferroni adjusted $p < 0.001$).

3.2. Overall body discomfort (OBD)

Over the hour of sitting, the maximum discomfort on the 'Back App' chair (median [IQR] = 1 [0,2]) was significantly greater than on the standard office chair (median [IQR] = 0 [0,0]), $p = 0.004$. When rating overall body discomfort, participants were given the option to denote where on body the discomfort was originating from. Within the BPDS, 12 different body parts are identified. For participants that reported discomfort (11 of the 15 participants), the discomfort was localised to region six (mid back: $n = 2$) and seven (lower back $n = 9$) as per the BPDS.

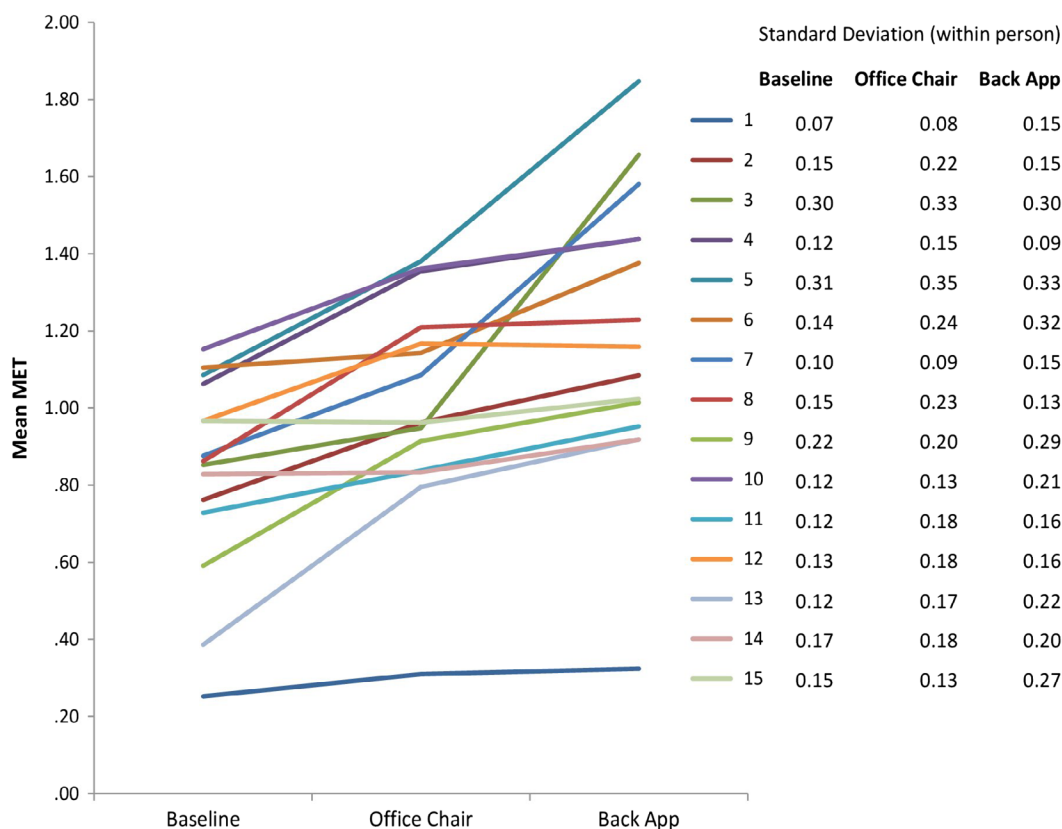


Figure 5. Mean MET per participant presented across three conditions.

Table 2. Estimated marginal means with associated 95% confidence interval levels from linear mixed model analysis.

Measure	Condition	Mean	95% CI
EE	Baseline	4.37	(3.35, 5.38)
	Office Chair	5.26	(4.24, 6.27)
	Back App	6.26	(5.24, 7.27)
MET	Baseline	0.83	(0.67, 1.00)
	Office Chair	1.02	(0.85, 1.19)
	Back App	1.2	(1.03, 1.37)

4. Discussion

The results indicate that over the course of an hour-long DVD viewing task, pain-free participants exhibited greater EE when sitting on a novel dynamic ergonomic chair compared to a standard office chair.

The current results on EE values achieved while seated on the 'BackApp' seat are comparable to EE values reported previously in studies evaluating standing and sit-to-stand desk interventions (Levine and Miller 2007; Miles-Chan et al. 2013; Speck and Schmitz 2011). However, it is important to highlight that while EE was seen to be higher on the dynamic chair, the MET values achieved were still below the 1.5 MET threshold (cf. definition sedentary behaviour). While the 'Back App' dynamic chair may pose the potential to rebalance the EE equation that has been considerably distorted by repeated modern advancement in the workplace, the MET values achieved when compared to the

Compendium of Physical Activities still remain rather low (Ainsworth et al. 1993) and walking EE values remain considerably higher than those reported here. In addition, MET values attained when technical advances were introduced to the workplace (e.g. recumbent elliptical machine stations) attained on average 3.1 METS in recently published research. (Botter et al. 2016).

Participants in this study were restricted to watching a DVD while seated on both chairs. However, even in this condition there was significantly more energy expended while seated on the BackApp. If the 'BackApp' was introduced in the workplace, EE may be further increased while employees carry out their daily work activities while seated on the dynamic chair, similar to the increased EE in sitting observed by Levine, Schleusner, and Jensen (2000) when participants were allowed to select their activity. Yet, in saying this, it remains unknown whether the difference in EE between the two experimental conditions would remain significant if an office activity was added as a task within both conditions.

Previous workplace strategies to promote PA have had limited success because either the activity component is too short in duration or the interventions require high levels of workforce commitment (Levine and Miller 2007). Since the 'Back App' dynamic chair allows the employee to remain seated, it may be less likely to affect productivity, though this requires further study.

There is ongoing debate as to whether interventions to promote PA and/or interventions to reduce sedentary behaviour should be employed. However, in a recent review, Gardner et al. (2016) highlighted that in targeting PA and sedentary behaviour, the greatest effectiveness is observed for those interventions that primarily aimed to change sedentary behaviour, rather than increased PA. This current study is in line with that directed within the review, with the introduction of the 'Backapp' chair in a typically sedentary activity and task. Nevertheless, the use of a dynamic chair should be seen as just one part of the management of sedentary behaviour, along with a healthy diet and greater PA outside of the workplace and other typically sedentary settings.

Over the course of the hour, the discomfort experienced was mild on both chairs, yet was significantly greater ($p < 0.05$) on the dynamic chair. It is not clear from the results of this study what lead to greater discomfort on the dynamic chair. Previous studies have reported reduced activation levels of some trunk muscles while seated on the same dynamic chair (O'Sullivan et al. 2012b). However, several large muscle groups were not examined in this study. It is very likely that other muscle groups, including major lower limb muscles, are more active on the Back App. While this may potentially cause discomfort initially for some, the concept of greater muscle activation while seated may appeal to others for its associated health benefits (Cuesta-Vargas and González-Sánchez 2013). Significant discomfort levels whilst sitting on the 'Back App' chair may influence compliance. However, due to the short duration of this study, it is not clear if this is necessarily a concern in the long-term or merely reflects the effort associated with unaccustomed activity. The fact that discomfort did not continue to increase after the first 15 min suggests that there is a possibility that people may just be adapting to the chair. The introduction of the 'BackApp' may pose its own difficulties in terms of expense and equitable distribution of such seating in the case of large scale industry (Tudor-Locke et al. 2014).

4.1. Limitations and recommendations

The primary limitation of this study may be that all measurements were not taken at the same time of day, i.e. some subjects were tested in the morning and effectively were fasting overnight, while some subjects were tested four hours after consuming lunch and this may have invariably influenced EE.

Although participants were randomly allocated, the novel appearance of the dynamic chair used makes participant blinding difficult, and could enhance a placebo effect. The assessor of seated discomfort was not blinded to the order of allocation. A randomised controlled trial

design would reduce the risk of participant bias further, but crossover design studies are commonly used in the initial evaluation of novel chair designs (Gregory, Dunk, and Callaghan 2006). However, measuring EE using the reliable method of indirect calorimetry (Blond et al. 2011) via the Oxycon Mobile®, as performed in this study, would make it difficult for participants to alter their exhibited EE based on chair appearance.

It is important to consider that the difference in EE observed between the dynamic chair and normal chair may simply be due to a stress response related to an unfamiliar chair, and this difference may potentially become less significant as habituation with the chair increases. Breathing rate or heart rate data were not collected as part of this study to decipher if increases in EE were related to a physical stress response. Future studies may consider repeating the chair measures with subjects within the same day or between days to demonstrate repeatability and to refute the potential of a stress response.

The feasibility and practicality of using this chair design in 'real-world' occupational settings have not been investigated in this study and is required. Whilst office chairs were used, the task was not typical of office-based work. This may inform future research where EE is compared between two different chairs whilst undertaking typical office tasks such as typing or sorting paperwork. Longer sitting durations, as would be observed in normal workplace setting are worthy of investigation to clarify the effects on both EE and discomfort. Although in this study, we could demonstrate that one hour was sufficient to observe increases in both EE and discomfort between chairs.

Future studies may consider evaluating EE while participants are seated on the dynamic chair with a self-selected instability level based on individual preference. For the purpose of this study, the instability level of the dynamic chair was standardised. Evaluating whether the energy expended remains similar when individuals select the instability level may be more realistic. Such an individual modifications may enhance compliance with the dynamic chair and may also serve to alter individual discomfort levels.

Previous studies have shown that these chairs are more comfortable for certain types of people, depending on the type of low back pain reported, and this may also be worthy of further study (Curran et al. 2014; O'Keeffe et al. 2013)

Evaluating secondary outcome measures in particular the degree of lower limb, abdominal and trunk muscle activation, some of which have been carried out in previous studies (Curran et al. 2014), could shed further light on the mechanism of effect of increased EE and provide further insight into the associated health effects of the dynamic chair such as reducing muscle atrophy often associated with prolonged rest (Cuesta-Vargas and González-Sánchez 2013).

Qualitative studies to explore the acceptability and usability of dynamic seating in the workplace, similar to that which has been carried out with the implementation of sit-to-stand desks previously (Grunseit et al. 2013), may also provide insights into employee compliance with the novel ergonomic equipment.

5. Conclusion

The use of a novel dynamic chair facilitates increased EE in a seated posture, during a DVD viewing task. The degree of discomfort was low but significantly greater while sitting on the dynamic 'BackApp' chair. The mechanism through which the dynamic sitting increases EE was not examined, but is likely to relate to increased muscle activation required to maintain seated equilibrium. Avoiding low levels of EE for prolonged periods, as seen during prolonged sitting on a standard chair, is potentially advantageous during prolonged sitting to reduce overall sedentary time.

Ethics approval

Ethical approval was obtained from the local university Research Ethics Committee, and written informed consent was obtained from all participants.

Disclosure statement

No potential conflict of interest was reported by the authors.

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ORCID

Aoife Synnott  <http://orcid.org/0000-0002-4658-1926>

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