Published in final edited form as:

Appl Ergon. 2017 April ; 60: 128–135. doi:10.1016/j.apergo.2016.11.003.

Utilizing anthropometric data to improve the usability of desk bikes, and influence of desk bikes on reading and typing performance

Jay Cho^a, Andris Freivalds^a, and Liza S. Rovniak^b

^aDepartment of Industrial and Manufacturing Engineering, The Pennsylvania State University, University Park, PA 16802, USA

^bDepartments of Medicine and Public Health Sciences, The Pennsylvania State University College of Medicine, Hershey, PA 17033, USA

Abstract

This study investigated the feasibility of using a desk bike in an office setting. Workstation measurements were introduced to accommodate 95% of the general U.S. population in using desk bikes. Reading and typing performances were compared at three different cycling conditions (no cycling, 10 and 25 watts). Thirty healthy individuals (15 female and 15 male; Age mean: 23.1, σ : 4.19) were recruited based on 5/50/95th percentile stature. Participants were required to select preferred workstation settings and perform reading and typing tasks while pedaling. According to anthropometric measurements and variability from user preference, recommended adjustable ranges of workstation settings for the general U.S. population were derived. Repeated measures ANOVA showed that pedaling had no significant effect on reading comprehension ($p > .05$), but had significant effect on typing performance ($p < .001$). A preferred level of cycling intensity was determined (mean 17.3 watts, σ : 3.69).

Keywords

Desk bike; Active workstation; Sedentary behavior; Reading and typing performance; Engineering anthropometry

1. Introduction

Excess body weight is considered a risk factor for mortality and morbidity from diabetes, heart diseases and cancer (Flegal et al., 2013; Wang et al., 2011). Despite the substantial efforts from healthcare practitioners, the weight-gain epidemic continues to accelerate (Finkelstein et al., 2012; World Health Organization, 2000). Studies have shown that one of the largest contributors to the weight gain epidemic has been the trend for work environments to require less physical activity in industrialized populations (Hamilton, Hamilton & Zderic, 2007).

As most working environments in developed and developing countries now require prolonged seated postures, physical inactivity has become more common in adults (Ma, Xiao, & Stafford, 2009). Tudor-Locke et al. (2011) reported that workers employed in

sedentary occupations (1.5 metabolic equivalent) were sedentary for approximately 11 hours a day. In addition, more than one third of U.S. adults do not meet recommended physical activity guidelines (Hallal et al., 2012). Healthcare researchers have been emphasizing the importance of physical activity and suggest that even low intensity exercise may have beneficial health outcomes (Neuhaus et al., 2014; Tudor-Locke et al., 2014).

Despite the known health benefits of regular exercise, in terms of practicality, it is difficult for most adults to invest additional time in exercise. Researchers have also found that regardless of physical activity, prolonged sedentary behavior can be independently associated with poor health and mortality (Parry & Straker 2013; Biswas et al., 2015). Therefore, introducing health promotion interventions to the workplace can be ideal in reducing prolonged sitting time (Carnethon et al., 2009; Van Uffelen et al., 2010).

Recent experimental studies have found that replacing excessive sedentary behavior with light physical activity may be beneficial to one's health (Levine & Miller, 2007; Dunstan et al., 2012). Carr et al. (2013) tested the practicality and feasibility of a portable pedaling exercise on middle-aged female participants working in sedentary environments. Results indicated that approximately an hour of daily sedentary time was replaced with pedaling at a moderate speed. Similarly, Rovniak et al. (2014) found that compact pedaling devices could help expend approximately 90 extra kilocalories per hour above sedentary sitting.

Although studies have been conducted to investigate the effects of simultaneous pedaling on work productivity (Elmer & Martin, 2014; Torbeyns et al., 2015), research on the ergonomic factors that may impede or facilitate use of these pedaling devices is limited. In the design of artifacts interacting with human users, the understanding of body dimensions and capabilities of the target population is critical in terms of maximizing fit, safety, and performance (HFES 300 Committee, 2004). Body measures have been used in various product design processes such as workstation designs, bicycle seat designs, and aircraft designs (Das & Sengupta, 1996; Garneau & Parkinson, 2011; Joslin, 2014). The concept of incorporating anthropometric measures should not be an exception for using exercise equipment in the office workplace.

The primary purpose of this study was to evaluate ergonomic factors associated with of using a desk bike in the office workplace by investigating the preferred office workstation settings (e.g., desk height and depth) with respect to anthropometric measurements and user preferences. In the authors' earlier research, the preferred workstation settings were established based on twelve undergraduate students (Cho et al., 2014). The current study is an outgrowth to that by broadening the sample to include the general U.S. adult population and increasing the sample size. Additional goals included: (a) Extending the limited literature on measuring cognitive performance when using a desk bike in the office by testing reading comprehension and typing tasks and (b) Finding the preferred exercise intensity on a desk bike while working on these tasks. The results from this study can be used to help understand the implications for and improve the usability of compact under-the-desk bikes at workstations and eventually improve health, safety and well-being.

2. Methods

2.1 Participants

Thirty participants (15 female) were recruited from The Pennsylvania State University and Centre County of Pennsylvania, U.S. All participants were healthy with an average age of 23.1 ($\sigma = 4.19$). Participants were recruited based on 5th, 50th and 95th percentile stature according to NHANES 2007–2010 (each with 5 participants for each gender; Fryar et al., 2012). All participants reported some experience in using a computer mouse and keyboard. The study was approved by the Human Subject Research Institutional Review Board at The Pennsylvania State University. All participants read and signed the informed consent prior to participation in the study and received compensation (\$14 for 2 hours).

2.2 Anthropometric Measurements

The nine anthropometric measurements in this study adopted the standards from the Anthropometric Survey of U.S. Army Personnel (Gordon et al., 1989; Figure 1).

The measurements were collected using an anthropometer (Model 101, GPM, Switzerland) on the right side of participants (with the exception of *ST* and *WT*). For *ST* and *TH*, participants were standing erect looking straight ahead without shoes. Other measures were taken with participants seated on a horizontal surface, elbows and knees flexed 90 degrees (verified with a goniometer), and feet set parallel to thighs on a height adjustable flat horizontal surface (footrest) in a relaxed and upright posture. The weight factor was evaluated by calculating the Body Mass Index (*BMI*) based on *ST* and *WT*.

2.3 Experimental Setup

An office workstation with a standard computer (Windows 7) and a 24 inch monitor (16:9 ratio and resolution of 1920×1080 at 60Hz) was set up in a controlled lab (54.1 m³; 3.6 × 4.7 × 3.2 m) with the temperature set to 23.3°C (Figure 2). The simulated workstation consisted of an office chair (Aeron Chair, Herman Miller, Zeeland, MI, USA) and a customized workstation desk (two adjustable industrial workstations connected with a flat plywood table top; 2.2 × 125 × 70 cm).

The desk bike DeskCycle (3D Innovations LLC., Greeley, CO, USA; Figure 3) was used in this study and was set to the intensity level of 2. Participants were required to pedal at 10 and 25 watts, which is approximately 45 and 90 RPM, respectively.

Participants were able to adjust the seat height pneumatically, while the desk height and depth were adjusted by the facilitators according to participants' request. Figure 4 shows the dimensions of the workstation that were measured.

2.4 Reading Comprehension and Typing Task Outcomes

Reading accuracy and times were measured through reading comprehension problems. Participants were required to read a passage (approximately 280 words) and answer five multiple-choice questions (each with four choices) on the computer. Eight passages were prepared with all written at the average U.S. adult reading level (Kirsch, 1993).

Typing speed (adjusted words-per-minute; AWPM) was measured using TypingMaster Pro Lite (TypingMaster Inc., Helsinki, Finland). Participants were required to copy a passage presented on the screen for two minutes as quickly and as accurately as possible. To ensure that the difficulty is consistent across the typing passages, eight passages with a syllabic intensity of approximately 1.3 was prepared (Straker et al., 2009).

2.5 Subjective Ratings

The intensity of cycling condition was evaluated subjectively with the Borg Rating of Perceived Exertion (Borg RPE; Borg 1982). Two additional questions were asked at the end of the study to assess the desk bike:

1. Do you think the DeskCycle would be possible to use at your desk?
2. How did you feel about completing the office tasks while pedaling the DeskCycle?

2.6 Procedure

An overview of the study was provided and all participants provided written informed consent. The nine anthropometric measures were obtained three times and the median score was computed. An introduction to the simulated office workstation and DeskCycle was provided. Participants were requested to adjust the desk and seat to their preference until they felt comfortable and were instructed on how to properly use the DeskCycle. The participants were guided through the procedure of completing the reading comprehension and typing tasks to eliminate any learning effects. The reading comprehension task was practiced for one passage and the typing task was practiced for one minute. After the practice session, the participants stepped aside and the workstation was set to a random setting. Last, the participants were guided through the experimental procedure that consisted of four cycling levels: no cycling (seated), low level cycling (10 watts), high level cycling (25 watts), and preferred level cycling. Each condition had two replicates with a total of eight sessions. The two preferred level conditions were assigned to the first and last sessions and the six remaining sessions were in between (Figure 5). To randomize the six sessions, random 6×6 Latin Squares were generated and each subject was assigned to each row. An example of one trial could be, preferred level cycling (practice) – no cycling – low level cycling – no cycling – high level cycling – high level cycling – low level cycling – preferred level cycling. The study took approximately two hours for each participant.

Each session (red block) in Figure 5 took approximately 10 minutes. First, the participants adjusted the workstation to their preferred settings. Next, they started pedaling and steadily increased to the assigned intensity and reached steady state within 2 minutes (excluded for seated condition). Then they completed the reading and typing task while pedaling. When participants started to lose pace an auditory signal (a small beep) was presented to bring the pace back to the designated level by briefly checking the monitoring device. For the preferred level intensity, the average wattage was recorded at every minute. After each session, participants rated perceived exertion (Borg RPE) followed by a two-minute rest to reduce the possibility of any fatigue effect. The settings on the workstation (e.g., desk height

and depth) were set back to random settings and participants were prompted to readjust each component before the next 10-minute session.

2.7 Data Analysis

Statistical analysis of the data was performed with SPSS software version 22 (SPSS Inc., Chicago, IL, USA) and Minitab 17 (Minitab Inc., State College, PA, USA). In all analyses, p -values less than 0.05 were considered statistically significant.

3. Results

3.1 Anthropometry and Preference for Workstation Settings

Baseline sample characteristics are shown in Tables 1 and 2.

Regression models of preferred workstation settings (1) – (4) were determined by best-subset regression analyses and the addition of stochastic variables (normal distribution with a mean of zero and a standard deviation equal to the root mean squared error of each regression model). The stochastic variables were added to ensure that the variability for each workstation setting can be explained by both anthropometric measurements and user preferences. For further details, refer to Garneau & Parkinson (2011). The four regression models (1) – (4) have an R^2 value of 0.47, 0.8, 0.44, and 0.66, respectively (all $p < .001$). ANCOVA showed no significant difference between males and females.

$$sh = 0.413 \times PH + 257.8 + N(0, 15.79) \quad (1)$$

$$dc = 1.009 \times PH + 340 + N(0, 18.32) \quad (2)$$

$$dd = 0.386 \times TH + 378.3 + N(0, 36.31) \quad (3)$$

$$td = 0.432 \times ST + 614.3 + N(0, 36.35) \quad (4)$$

PH , TH , and ST measures of the general U.S. adult population were required to calculate the preferred office workstation settings. ST was obtained from the NHANES 2007–2010 anthropometric database (Centers for Disease Control and Prevention, 2014). However, NHANES 2007–2010 did not record PH and TH values for their sample. Therefore, PH and TH were obtained by first finding the relations between (i) PH and ST and (ii) TH and ST for both genders from the U.S. Army data (Gordon et al., 1989). The regression models (5) – (8) have an R^2 value of 0.74, 0.78, 0.69, and 0.77, respectively (all $p < .001$). The regression models include residual variance since people with the same stature may contain varying

length in popliteal height (and trochanterion height). The subjects in the U.S. Army database were weighted to match 2010 U.S. Census distributions.

$$PH_{male} = 0.314 \times ST_{male} - 118.93 + N(0, 12.54) \quad (5)$$

$$TH_{male} = 0.623 \times ST_{male} - 169.7 + N(0, 22.23) \quad (6)$$

$$PH_{female} = 0.295 \times ST_{female} - 95.27 + N(0, 13.16) \quad (7)$$

$$TH_{female} = 0.583 \times ST_{female} - 96.9 + N(0, 21.61) \quad (8)$$

Then, a virtual population of PH and TH were estimated by using the ST of males and females (5647 and 5971, respectively) from the NHANES 2007–2010 data (weights carried out appropriately) into the above proportionality equations (Garneau & Parkinson, 2011).

Finally, preferred workstation settings were estimated by using equations (1) – (4) with the ST data from NHANES 2007–2010 and the PH and TH from the virtual population. Figure 6 shows an example of estimating seat height (sh) using PH , resulting in seat height ranges from 396.23 mm (15.6 inches) to 465.99 mm (18.3 inches) for 2.5th to 97.5th percentile popliteal heights, respectively. Table 3 shows the final results of the recommended adjustable ranges of the workstation settings that would accommodate 95% of the general U.S. population when using the DeskCycle.

3.2 Effects of Cycling on Reading Comprehension and Typing

Repeated measures ANOVAs showed that cycling condition had no significant effect on reading comprehension time ($F(1.59, 44.43) = 1.45, p = .246$; Figure 7 and 8) and accuracy ($F(1.6, 44.82) = .469, p = .586$; Figure 9 and 10). Because the sphericity assumption was violated for reading time and accuracy, the Greenhouse-Geiser adjustment was used. Data from one participant was discarded for failure to follow task instructions on the reading task.

Repeated measures ANOVA showed that cycling condition had significant effect on adjusted words-per-minute (AWPM) values ($F(2, 58) = 16.17, p < .05$; Figure 11). Post hoc analysis with Bonferroni correction showed that typing performances were significantly different across all three cycling conditions (all $p < .05$; Figure 12).

3.3 Borg Rating of Perceived Exertion (RPE)

Repeated measures ANOVA showed that cycling condition had significant effect on Borg RPE ($F(2, 58) = 131.76, p < .05$; Figure 13). Post hoc analysis with Bonferroni correction

showed that Borg RPE ratings were significantly different across all three cycling conditions (all $p < .05$; Figure 14).

3.4 Preferred level of Cycling

During the preferred level session, average speed was recorded every minute. The arithmetic mean, of these recorded times, was computed for each participant. The preferred level had an average of 17.3 watts (σ : 3.69), which is approximately 67 RPM.

4. Discussion

This study has investigated the ergonomic characteristics associated with using a desk bike (i.e., the DeskCycle for this study) in an office workstation. The results determined: (1) the recommended adjustable ranges of workstation settings when using the DeskCycle for the general U.S. population; (2) that cycling did not have significant effect on reading comprehension (time and accuracy); (3) that cycling had significant impact on typing performance; and (4) that the preferred cycling intensity was 17.3 watts (σ : 3.69), on average, when performing the reading comprehension and typing tasks. To our knowledge, this is the first study to investigate the ergonomic features of using a desk bike in a workstation setting, as well as determine preferred cycling speeds during office work tasks.

The required adjustable range of seat height (sh), for the general U.S. population to use the DeskCycle was in compliance with the ANSI/HFES 100-2007 (2007) office chair minimum height adjustable range (Table 4). However, the preferred desk clearance and depth determined in this study were much greater than the ANSI/HFES 100-2007 recommended guidelines. This was due to the increased range of motion from pedaling beneath the desk.

Based on these data, only a small portion of the general U.S. population will be able to use the DeskCycle with standard desks. Assuming we have a standard desk with a clearance of 718.8 mm (max value of ANSI/HFES 100-2007 recommended range), females up to the 25th percentile stature and males shorter than the 5th percentile stature (i.e. approximately 160 cm or 63 inches) will be able to use the DeskCycle with no interference based on the required desk clearance ranges from this study (Centers for Disease Control and Prevention, 2014). Therefore, an alternative to the traditional desk (e.g., height adjustable desk) will be required for the general U.S. population to use the DeskCycle and similar devices at the workplace.

Although this study established guidelines in using the DeskCycle at workstations by employing anthropometry and user preference, two limitations were identified. First, the sample did not entirely represent the general U.S. population due to the stratification considering only length (stature) and not weight. Evidently, the average BMI for the sample (23.92 kg/m^2) was different from that of the general U.S. population (27.5 kg/m^2 ; Centers for Disease Control and Prevention, 2014). Second, the popliteal height (PH) and trochanterion height (TH) of the U.S. population were synthesized by utilizing the U.S. army data due to the lack of civilian popliteal and trochanterion height data (Gordon et al., 1989). However, the U.S. army data was collected approximately 25 years ago from the military population, which brings two drawbacks: (1) it does not represent the civilian population and

(2) secular trends could have contributed to the change in proportionalities (Malina, Bouchard, & Bar-Or, 2004). Although, the Civilian American and European Surface Anthropometry Resource (CAESAR) does provide popliteal height and trochanterion height the research team did not have access to this database. Therefore, incorporating weight in the stratification and obtaining (or collecting) recent data on *PH* and *TH* could have the potential to improve the accuracy of study findings.

Reading comprehension performance (i.e., accuracy and efficiency) was not compromised by cycling condition. Similar to prior findings, four subjects commented that it was difficult to pedal on the DeskCycle while performing the reading comprehension tasks even though their performances were not significantly different compared to the seated condition (Commissaris et al., 2014). However, some have commented that it was difficult to select the correct answer (i.e., clicking the radio button) on the computer due to the simultaneous physical movement in the lower and upper limbs. This finding agrees with previous reports that pedaling could result in a decline in performance related to mouse tasks (Straker et al., 2009; Neuhaus et al., 2014; Tudor-Locke et al., 2014).

Typing performance was inversely proportional to cycling speed. This coincides with previous studies (Straker et al., 2009; Thompson & Levine, 2011), but contrasts with other studies which indicated that active workstations do not have significant effect on typing performance (Elmer & Martin, 2014). These opposing findings may be due to the availability of resources that an individual can allocate towards both the physical and cognitive task. Dynamic movements (e.g., walking and pedaling) would require more attention towards controlling/balancing the lower limbs and result in having more effect on typing performance compared to a static/secure movement (e.g. standing or secured seat pedaling; Winter, 1995).

In the authors' earlier research, a pilot study was conducted to test the desk bike with a standard office desk. However, most participants complained it was awkward to pedal in the current setup. Knees kept bumping against the desk as pedal strokes required more clearance than what standard desks provided. Unlike the responses from the pilot study, most of the participants in the current study have commented that they could see themselves using the desk bike setup for tasks that are not too mentally demanding, especially at the preferred intensity level (17.3 watts). This could indicate that this intervention has the potential to decrease diverse types of sedentary behavior.

Based on participant feedback, maintaining the pedaling speed at the lower level (10 watts) was difficult, which was mainly due to the pace being unnaturally slow. This led to the audio indicator (i.e., a small beep) signaling more often compared to the preferred and high level cycling and hence lose attention on the task due to checking the speed monitor more often. Future studies could employ the preferred level intensity (17.3 watts) as a 'moderate' level cycling, which could potentially allow the subjects to pedal at a more natural pace and minimize attention loss.

Currently, the speed monitor is an external device, which requires users to switch attention from the computer screen to the DeskCycle information display. If the speed were to be

displayed on the computer screen (e.g., as a small indicator) it could potentially minimize unnecessary movements, cause less mental stress and increase the attention span of the users to the task. That approach is similar to that of the benefits from using a head-up display compared to using a head-down display while driving (Liu & Wen, 2004). Future studies should examine ways to improve the notification system, which minimizes disruption effects.

Overall, this study has investigated the ergonomics features of using a desk bike, specifically the DeskCycle, in an office workstation. Recommended adjustable ranges of workstation settings for the general U.S. population were provided and a preferred cycling intensity was determined. This study also extends prior research by measuring reading and typing tasks when using a desk bike. These findings can help inform compact under-the-desk bike workstation design guidelines to improve health, safety, work performance, and user satisfaction.

Acknowledgments

This study was supported, in part, by the National Heart, Lung, and Blood Institute, National Institutes of Health, through NIH Grant R21 HL118453 (Principal Investigator: Dr. Rovniak). The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Heart, Lung, and Blood Institute or the National Institutes of Health.

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Figure 1.

Representation of the anthropometric measures

Stature (*ST*): The vertical distance between the floor and the top of the head.

Trochanterion height (*TH*): The vertical distance between the floor and the trochanterion (upper side of the thigh).

Sitting height (*SH*): The vertical distance between the sitting surface and the top of the head.

Elbow rest height (*ER*): The vertical distance from the sitting surface and the olecranon (bottom of the tip of the elbow).

Popliteal height (*PH*): The vertical distance from the footrest and the posterior surface of the knee.

Knee height (*KH*): The vertical distance from the footrest surface and the suprapatella (top of the knee).

Buttock-popliteal (*BP*): The horizontal distance from the posterior point of the buttock to the popliteal fossa (back of the knee).

Buttock-knee (*BK*): The horizontal distance from the posterior point of the buttock and the anterior point of the knee.

Weight (*WT*): Body mass measured to the nearest 0.1 kg on a digital scale.

Figure 2.
The simulated office workstation in the laboratory

Figure 3.
Participant pedaling the DeskCycle in the lab setup

Figure 4.

Representation of the workstation measures

Seat height (sh): The vertical distance between the floor and the lowest point of the buttock in contact with the seat.

Desk clearance (dc): The vertical distance between the floor and the lowest point of the table top.

Desk depth (dd): The horizontal distance between the back of the DeskCycle to the front edge of the table top.

Required minimum total distance (td): The horizontal distance between the back of the DeskCycle to the back of the chair.

Figure 5.
Flow diagram of the overall procedure

Figure 6.
Recommended seat height (*sh*) adjustable range to accommodate 95% of the general U.S. population

Figure 7.
Mean reading time (sec) of each cycling condition

Figure 8.
Bonferroni corrected 95% confidence intervals for the difference between mean reading times (sec)

Figure 9.
Mean reading accuracy (%) of each cycling condition

Figure 10.
Bonferroni corrected 95% confidence intervals for the difference between mean reading accuracies (sec)

Figure 11.
Mean typing performance (adjusted words-per-minute; AWPM) of each cycling condition

Figure 12.
Bonferroni corrected 95% confidence intervals for the difference between mean typing performance

Figure 13.
Mean Borg RPE of each cycling condition

Figure 14.
Bonferroni corrected 95% confidence intervals for the difference between mean Borg RPE

Table 1

Summary of Age and Anthropometric Measurements

	Age	ST (mm)	BMI (kg/m ²)	KH (mm)	PH (mm)
Mean	23.1	1688.23	23.92	513.83	417.07
σ	4.19	115.24	4.06	42.3	35.48

Table 2

Summary of Preferred Workstation Settings (mm)

	<i>sh</i>	<i>dc</i>	<i>dd</i>	<i>td</i>
Mean	429.91	760.84	719.25	1343.22
σ	21.33	40.07	47.46	61.25

Table 3

Recommended Adjustable Ranges of Workstation Settings when using the DeskCycle (mm)

	2.5th percentile	97.5th percentile
seat height	396.23 (15.6 inches)	465.99 (18.3 inches)
desk clearance	677.83 (26.7 inches)	813.71 (32 inches)
desk depth	668.75 (26.3 inches)	784.71 (30.9 inches)
required minimum total distance	1272.63 (50.1 inches)	1454.09 (57.2 inches)

Table 4

Comparison of Adjustable Ranges of Workstation Settings with respect to ANSI/HFES 100-2007 (mm)

	Study Results	ANSI/HFES 100-2007
seat height	396.23 – 465.99 (15.6 – 18.3 inches)	381 – 558.8 (15 – 22 inches)
desk clearance	677.83 – 813.71 (26.7 – 32 inches)	500.38 – 718.8 (19.7 – 28.3 inches)
desk depth	668.75 – 784.71 (26.3 – 30.9 inches)	At least 600 (At least 23.6 inches)