Driving Segway: A Musculoskeletal Investigation

Zavier Berti[1], Peter Rasche[2](✉), Robert Chauvet[1], Matthias Wille[2], Vera Rick[2], Laura Barton[2], Tobias Hellig[2], Katharina Schäfer[2], Christina Bröhl[2], Sabine Theis[2], Christopher Brandl[2], Verena Nitsch[2], and Alexander Mertens[2]

[1] University of Alberta, 116 St. and 85 Ave., Edmonton, AB T6G 2R3, Canada
{berti,rchauvet}@ualberta.ca
[2] Institute of Industrial Engineering and Ergonomics, RWTH Aachen University, Bergdriesch 27, 52056 Aachen, Germany
{p.rasche,m.wille,v.rick,l.barton,t.hellig,k.schaefer,c.broehl,s.theis,c.brandl,v.nitsch,a.mertens}@iaw.rwth-aachen.de

Abstract. Segways offer elderly users an opportunity to increase their mobility range and may also be useful as a training device. As of yet, very little is known about muscular activity during Segway use. Hence, the aim of this pilot study was to investigate the muscular strain during the use of Segways. For this purpose, 15 study participants were equipped with EMG measuring devices on rectus femoris, biceps femoris, tibialis anterior and biceps brachii of the right half of the body. Following maximum strength tests, the participants completed a defined course once on foot and three times on a Segway. The averaged EMG data during walking and Segway use were compared. The results show that the use of Segways leads to muscle activity. No statistically significant differences were found between the average muscular strain of the lower body muscles caused by walking and using a Segway. The systematic use of Segways may be an attractive option for the development of physical training programs to prevent falls.

Keywords: Segway · Musculoskeletal · EMG

1 Introduction

Transportation is a key factor enabling healthy aging [1]. The World Health Organization states that despite many efforts, public transport is not yet adequately equipped for the elderly. This is partly due to a too low density of stops or the design of public transport schedules [1]. Individual and self-determined transport options for older adults are therefore still a relevant issue.

A product addressing this issue is the Segway Personal Transporter [2, 3]. This is an electrically powered, two-wheeled, uniaxial and self-balancing vehicle which automatically moves in the direction in which the driver leans. It accelerates and brakes by leaning forwards or backwards. Tilting the handlebar to the right or to the left causes

N. Stanton (Ed.): AHFE 2019, AISC 964, pp. 585–595, 2020.
https://doi.org/10.1007/978-3-030-20503-4_53

the Segway to turn in the corresponding direction. Using a Segway is perceived as less stigmatizing than for example wheelchairs or scooters [4]. Thus, they are a promising solution to solve the last mile problem in terms of older adults' mobility [3, 5, 6].

Additionally, from a therapeutic and clinical standpoint, Segway use could also be beneficial to the physical fitness of older adults and have the potential to prevent falls. Using a Segway might have positive effects on the musculoskeletal system as it has been found that standing on a self-balancing, two-wheeled mobility device similar to the Segway (namely the "Hoverboard") for two minutes has comparable effects to standing the same amount of time on a traditional balance training device [7]. In a further study, Dias de Brito and colleagues have investigated simulated Segway driving in the context of exergames for fall prevention. The task of the older participants was to complete a Segway ride in-game, using a Nintendo Wii balance board to control an avatar driving a Segway within the exergame. This study showed that the Segway's intended control commands have the potential to strengthen muscles according to the Fitness and Mobility Exercise (FAME) programme and thus potentially prevent falls [8].

Based on these ideas and preliminary work, a study was conducted to determine whether real-life (as opposed to virtual) use of Segways in general has the potential to be used for fall prevention. Two fundamental research questions were formulated.

1. Does Segway use cause muscle activation in the selected muscles?
2. How does this muscle activation compare to that caused by walking?

The first research question is intended to clarify whether the muscles rectus femoris, biceps femoris, tibialis anterior and biceps brachii identified as important in the FAME program are actually activated when using a Segway [9]. The second research question was determined to reference and classify the potentially existing muscle activity when using Segways by comparing it to walking the same course.

2 Method

An experiment was conducted to answer the two defined research questions. For the experiment, healthy participants were first required to complete a short demographic questionnaire and, secondly, to complete a Segway course while data were recorded by electromyography (EMG). The course was completed once while walking and three times on the Segway. No older adults were included in this experiment due to the exploratory character of this study and the potential harm Segway use could cause with very limited training [10]. Young people were deemed to be more adaptable to unfamiliar technology and thus require less time to become comfortable and drive normally [2]. It is known that aging influences the neuromuscular function of older adults and associated EMG signals, however, the basic relationship between required force and muscle activation remains [11].

2.1 Participants

An opportunity sample of 15 participants was tested. The mean age of the sample was 24.6 (SD 1.06, 95%CI [22.3, 26.9]). The sample contained 33% (5/15) female and 67% (10/15) male participants. Only 2 participants reported having more than 1 h of Segway experience. Participant information is summarized in Table 1. All participants reported having no pain or soreness that limited their ability to move or exert themselves.

Table 1. Overview of participants

# of participants	15
Gender	5 female, 10 male
Mean age [years]	24.6 (SD = 1.06)
Age range [years]	20–32
Mean height [cm]	176 (SD = 2.90)
Mean weight [kg]	71.4 (SD = 3.29)
Segway experience [hours]	"Less than 1" (n = 13); "1 to 5" (n = 1); "5 to 10" (n = 1)

2.2 Applied Methods

Electromyography. Electromyography works by measuring the electrical potential created during muscle contraction. A high value for an EMG recording indicates higher muscle activity. In order to measure the potential, electrodes are placed on the skin over the muscle of interest and the signal is recorded by sensors. The software MyoResearch 3.8 (Noraxon, Scottsdale, AZ, USA) was used to recording and post processes all EMG data. The device used in measuring the data was the DTS Belt-Receiver (Noraxon, Scottsdale, AZ, USA).

In order to properly analyze the EMG data between participants, it is necessary to normalize the EMG signals. To this effect, Maximum Voluntary Contractions (MVC) were performed by each participant for each muscle. A MVC is a test during which an individual exerts maximum muscular effort against a particular static load while EMG data are recorded. This maximum value is used to normalize all other recordings so that the muscle activity is shown as a percentage of the maximum muscle activation (in %MVC) rather than a potential difference (in µV).

Muscle selection was done due ease of measurement with the EMG system. The selected muscles are therefore larger muscles in easily accessible locations on the body. The ease of producing a reliable MVC was also taken into account, as only certain equipment was available and the proper execution of the MVC is of high importance to data analysis. The "ABC of EMG" was used for guidance in the selection process [12]. In the end, four muscles were selected in accordance with these criteria. Due to the Segway's symmetrical design and the symmetry of the course requirements, data were recorded unilaterally on the right side of the body. The selected muscles are as follows:

- Rectus femoris: This muscle was selected as it is a major muscle in the knee extensor group. The FAME programme specifically cites this muscle group as a

target group for strengthening [9]. The muscle is also conveniently located and preforming a MVC for it is very feasible.
- Biceps femoris: This muscle was selected as it also targeted by the FAME programme. Further it is in an accessible location and has a feasible MVC test.
- Tibialis anterior: This muscle was selected as it is an important muscle for ankle dorsiflexion, a movement deemed important for balance. Also this muscle is targeted within the FAME program. The muscle also satisfies the accessibility and MVC conditions.
- Biceps brachii: This muscle was deemed relevant to explore the activity of the upper body during Segway use as the FAME program recommends also strengthening the upper body. This muscle also satisfied criteria as location and MVC conditions.

Questionnaire. A short questionnaire was given to each participant prior to completing the Segway Course. The questionnaire gathered the following basic demographic information: gender, year of birth, height and weight. Each participant was also asked if they were experiencing any pain, soreness or discomfort that could cause significant difficulty with movement or effort. They were asked to indicate the location of this affliction on a silhouette of a human body. This section was included to provide additional information in the event anomalies were present in the data for certain participants. Finally, the Segway experience of each participant was gauged by asking the number of hours for which they had used a Segway ("Less than 1", "1 to 5", "5 to 10" or "More than 10").

2.3 Experimental Procedure

Excluding the Segway introduction, the experiment took around 45 min to complete, with 25 min for preparation of the participant and 20 min for data collection.

Segway Introduction. All participants were given an introduction session with the Segway in the morning before the experiment later in the day. The orientation session lasted around 5 min and provided instructions on proper Segway use and a few minutes of driving to become more familiar with the device. Given the timing of the session, the time elapsed between the Segway introduction and the experiment varied from a few minutes to several hours.

EMG Electrode Preparation and Application. In accordance with the SENIAM guidelines, the skin was shaved and cleaned before the application of the electrodes [13]. Ag/AgCl self-adhesive 8-shaped dual electrodes (dimensions of adhesive: 4×2.2 cm; diameter of the two circular adhesives: 1 cm; inter-electrode distance: 1.75 cm) were then placed on the selected muscles.

MVC Data Collection. MVC tests were performed for each muscle and each participant. The tests were selected from the "ABC of EMG" and performed before completing the course [12].

Segway Course Data Collection. Each participant completed the course four times. EMG data were recorded during all runs. The first run was completed by walking through the course elements at a comfortable pace, ignoring the special instructions of the acceleration and braking sections. Markers were placed in the EMG data at the start and end of the entire course. Runs 2 through 4 were completed by driving the Segway successfully through the entire course from start to finish. Markers were placed in the data at the beginning and end of each section as well as at the start and finish of the course. A run was deemed inadmissible and redone if the participant failed to complete all course elements in accordance with instructions.

2.4 Experimental Apparatus

The Segway model used in this experiment was the "Segway I2 SE Transporter". The Segway course used in this experiment (Fig. 1) is designed to simulate tasks and obstacles that would be encountered in everyday operation and was adapted from a course previously used to study Segway proficiency in people requiring mobility aids [2]. It contains eight sections to simulate different situations encountered in community ambulation: Normal Driving, Left Turn, Slalom, Right Turn, Acceleration, Braking, Uphill and Downhill. The course was designed to take around 45 s to complete. Markers were placed in the EMG recording to indicate the location of the sections.

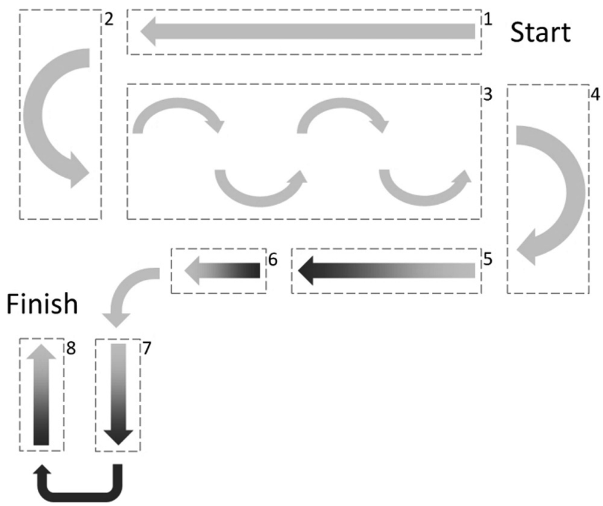

Fig. 1. Segway course with representative layout and elements numbered in order of completion; (1) Normal driving, (2) Left turn, (3) Slalom, (4) Right turn, (5) Acceleration, (6) Braking, (7) Uphill, (8) Downhill.

2.5 Statistical Analysis

Data processing was done using MyoResearch 3.8 (Noraxon, Scottsdale, AZ, USA). The data collected from the MVC tests was first filtered to remove signals recorded from electro cardiologic activity. Next, a curve smoothing algorithm using RMS and a 100 ms sliding window was used. Finally, the signal was normalized to its peak.

The data recorded from the four runs (walking and three Segway runs) were processed using the same ECG filter and curve smoothing algorithm. The processed MVC tests were used for the amplitude normalization of this data. Data were analyzed using Microsoft Excel 2010 (Microsoft, Redmond, WA, USA). Independent variables were not defined due to the explorative nature of this study. Dependent variables were measured 'muscle activity' during different tasks of Segway driving and 'time' measured for completing the three runs on the course. For the investigation of the second research question, a null hypothesis was formulated and examined by means of two-tailed t-tests. The hypothesis is that the mean muscular activity of the four examined muscles does not differ between the test condition "walking" and "Third Segway run". The third Segway run was chosen for this comparison as this was the run participants were most experienced in driving the Segway course.

3 Results

3.1 EMG Data

EMG data were analyzed for each muscle during both walking and Segway use. Results are presented separately for each muscle below. Figures 2 show the data for each muscle as a comparison between walking the Segway course and the mean activity measured during all three Segway runs.

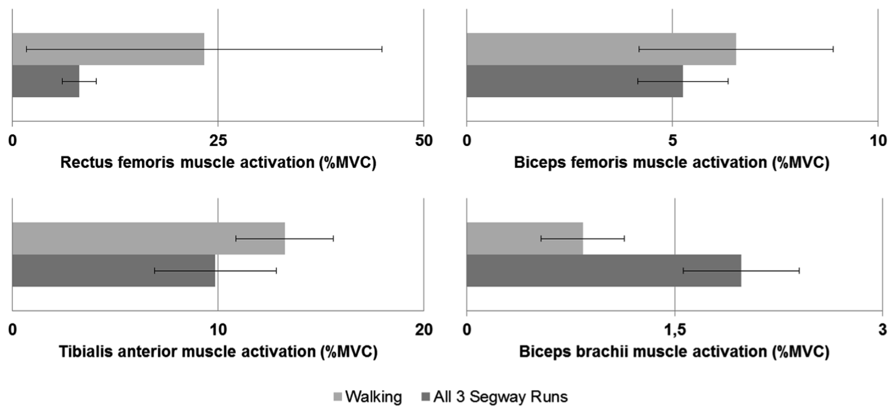

Fig. 2. Mean activation during walking (light) and all three Segway runs (dark) with 95%CI.

Rectus Femoris. For walking, the mean activation over the entire course was 23.3% MVC (SD 10.1, 95%CI [1.65, 44.9]). For Segway use, averaged over all 3 Segway runs, it was 8.13%MVC (SD 1.03, 95%CI [6.05, 10.2]). The section causing the greatest activation in the rectus femoris was Braking with a mean activation of 17.5% MVC (SD 2.83, 95%CI [11.7, 23.17]). The section causing the lowest activation was Normal Driving with 5.75%MVC (SD 0.962, 95%CI [3.81, 7.68]). The mean muscle activation of rectus femoris showed no difference between the third Segway run compared to walking, $t(14) = 2.1448$; $p = .1202$.

Biceps Femoris. For walking, the mean activation over the entire course was 6.54% MVC (SD 1.10, 95%CI [4.18, 8.90]). For Segway use, averaged over all 3 Segway runs, it was 5.25%MVC (SD 0.547, 95%CI [4.15, 6.36]). The section causing the greatest activation in the biceps femoris was the "Left Turn" with a mean activation of 9.15%MVC (SD 1.06, 95%CI [7.00, 11.3]). The sections causing the lowest activation was the "Right Turn" with 3.70%MVC (SD 0.480, 95%CI [2.73, 4.66]) and "Uphill" with 3.94%MVC (SD 0.436, 95%CI [3.06, 4.82]). The mean muscle activation of biceps femoris showed no difference between the third Segway run compared to walking, $t(14) = 2.1448$; $p = .2932$.

Tibialis Anterior. For walking, the mean activation over the entire course was 13.2% MVC (SD 1.38, 95%CI [10.3, 16.2]). For Segway use, averaged over all 3 Segway runs, it was 9.86%MVC (SD 1.17, 95%CI [7.50, 12.2]). The sections causing the greatest activation in the tibialis anterior were "Braking" with a mean activation of 16.7%MVC (SD 1.68, 95%CI [13.4, 20.1]) and "Acceleration" with a mean activation of 16.3%MVC (SD 1.74, 95%CI [12.8, 19.8]). The section causing the lowest activation was "Normal Driving" with 6.30%MVC (SD 1.34, 95%CI [4.36, 8.24]). The mean muscle activation of tibialis anterior showed no difference between the third Segway run compared to walking, $t(14) = 2.1448$; $p = .2430$.

Biceps Brachii. For walking, the mean activation over the entire course was 0.836% MVC (SD 0.141, 95%CI [0.534, 1.14]). For Segway use, averaged over all three Segway runs, it was 1.98%MVC (SD 0.208, 95%CI [1.56, 2.40]). The section causing the greatest activation in the biceps brachii was "Braking" with a mean activation of 5.02%MVC (SD 0.670, 95%CI [3.67, 6.37]). The section causing the lowest activation was "Normal Driving" with 1.16%MVC (SD 0.158, 95%CI [−0.777, 3.10]). The mean muscle activation of biceps brachii showed difference between the third Segway run compared to walking, $t(14) = 2.1448$; $p = .0036$; $|d| = 1.08$. During Segway driving biceps brachii is much more active than during walking maybe due to the control concept of Segways.

3.2 Course Completion Times

Times for course completion were measured for all three Segway runs as well as for walking. When compared to walking, times for all three Segway runs were significantly lower, as expected. Also, each subsequent Segway run yielded faster times than the previous one. The mean time for walking was 62.2 s (SD 1.86, 95%CI [58.2, 66.1]), the mean times for the first, second and third Segway runs were, respectively: 46.5 s (SD 2.38, 95%CI [41.4, 51.6]), 41.6 s (SD 2.04, 95%CI [37.2, 45.9]) and 40.0 s (SD 1.61, 95%CI [36.5, 43.4]). Data are represented in Fig. 3 below.

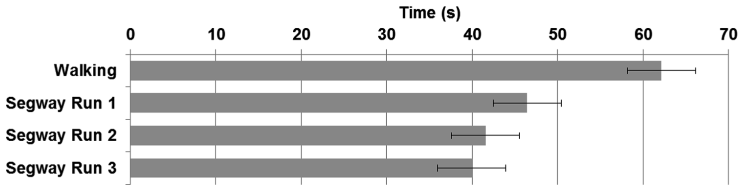

Fig. 3. Mean course completion times for the Segway course on each run

4 Discussion

Based on the results, it is possible to make determinations regarding the outlined research questions. The EMG data for rectus femoris, biceps femoris, biceps brachii and tibialis anterior during Segway use and walking offer relevant insights. Notably, the selected muscles showed activation over the course of Segway use. When compared to walking, there was a statistically significant difference in activity only in biceps brachii, where Segway use caused higher activation.

4.1 Muscle Activity and Comparison to Walking

Detailed review of data suggests that the selected muscles are active during Segway use. By descriptive analysis, tibialis anterior is most active and biceps brachii is least active. It is worth noting that the mean value for all muscle activity across the complete course does not exceed the 15%MVC fatigue limit for long term static contractions proposed by Rohmert [14]. Static contractions are referenced in this context as drivers of a Segway need to perform static posturers (for example leaning forward) to control the Segway.

When compared descriptively to walking, the mean values for the Segway use activation of rectus femoris, biceps femoris and tibialis anterior were lower. Despite this, no statistically significant difference between walking and Segway use was found for these muscles. For biceps brachii, however, the activation is significantly higher during Segway use ($p < 0.05$). Note that for this paired analysis, only the third Segway run was used as it was the run in which the participants were the most familiar with the Segway as completion time for the course was the shortest during this run.

These results, the high practicality and independence Segways offer it seems promising that older adults might choose this sort of transportation over less active modes of transportation, such as public transportation, when performing everyday activities.

4.2 Potential for Fall Prevention

The idea behind this study was to provide further insights on the idea of Segway use with regard to fall prevention. Results indicate that Segway use causes muscle activation in muscles relevant for fall prevention according the FAME program. Thus, this study extends the results of Dias de Brito and colleagues who found positive effects of virtual Segway use in terms of strengthening the muscles addressed for fall prevention.

From a strengthening and training standpoint, it cannot be conclusively determined from the data whether Segway use adequately trains muscles and strengthens them in a targeted way. However, the data suggest that this is a possibility as the applied course included sections with high muscle activity (rectus femoris during braking (17.5% MVC, SD 2.83, 95%CI [11.7, 23.17]), tibialis anterior during braking (16.7%MVC, SD 1.68, 95%CI [13.4, 20.1]) and tibialis anterior during acceleration (16.3%MVC, SD 1.74, 95%CI [12.8, 19.8])). Based on these results, future research should investigate whether a specially designed course including just sections causing higher muscle activity could cause training effects as targeted by the FAME program or whether general Segway use might cause training effects depending on the duration of the Segway ride.

4.3 Limitations

This study has several limitations which need to be taken into consideration for the interpretation of the results. For one, it was designed to assess general muscle activity and not specifically to examine training effects; therefore, conclusions cannot be drawn with regard to the effect of long-term Segway use on muscle strength. Further potential benefits of Segway use in terms of increasing drivers' balance, were also not addressed by this study. In this regard, further studies might consider analyzing effects of Segway use in the balance and muscle strength of users, as these are important aspect of fall prevention.

Another important aspect to consider in the interpretation of the results is the limited sample size, with which only very large effects can be detected using the applied inferential statistical methods. Nevertheless, in applied research, large effect sizes are typically of most interest as they are most likely to be of consequence in real-life settings.

The use of healthy young people instead of older adults is another limitation in this study. Uncertainty regarding the interpretation of %MVC measurements for a given task in a younger sample for an older population remains, as very limited research and literature was found on this topic. However, under the assumption that older adults do not operate Segways in vastly different ways from younger people, which is supported by the Segway's fairly restrictive driving controls, the results are still informative. Further research on this would nevertheless be required to draw valid conclusions regarding the effects of Segway use on elderly users.

Furthermore, it is worth noting that measurements were unilateral on participants' right side. Similar activation in the left leg is expected. This hypothesis should, however, be substantiated by further studies.

Future research into Segway use should also investigate how to achieve higher muscle activation levels. Based on this study, it can be inferred that a course which includes acceleration and braking would cause high activation in rectus femoris, biceps brachii and tibialis anterior. Furthermore, inclusion of several turns in both directions (left and right) would cause high activation in biceps femoris.

5 Conclusion

Personal mobility devices, such as a Segway, offer older adults the opportunity to increase their mobility radius independently from local public transport [2, 15]. Thus they might increase their quality of life [1]. On the other hand, the effects of the use of these devices on the physical fitness of users are still largely unknown. Preliminary work by Dias de Brito and colleagues showed that the virtual use of a Segway as part of an exergame motivates older adults to engage in physical activity and to perform exercises in support of fall prevention according to the FAME programme [8]. An initial study on the effects of static balancing on a Segway like personal mobility device (so called “Hoverboards”) was conducted by Rahman and colleges [7]. Results indicate a positive effect on muscle parties targeted by fall prevention exercise programs like FAME. Thus, real-life Segway use might also have positive effects as older adults might be more active due to the independence from public transport and additionally might achieve physical training effects by using a Segway.

The aim of this pilot study was to investigate fundamentally whether the use of a Segway activates muscles targeted by fall prevention programs like FAME. A second research question in this context was how the muscle activity induced by Segway use is compared to that of walking.

Results indicate that investigated muscles Rectus femoris, Biceps femoris, Biceps Brachii and Tibialis anterior are activated during Segway use. Comparison between walking and Segway driving revealed no statistically significant difference between the mean muscle activities of the lower body. Regarding the idea to incorporate Segway use as a way to perform fall prevention, these results are promising. Future research needs to expand on these results by investigating whether muscle activity present during Segway use causes trainings effects of corresponding muscles if the Segway is used for longer periods of time or during specially designed fall prevention courses.

Overall, Segway driving might be a suitable and efficient way to integrate aspects of fall prevention training into older adults’ everyday lives, while the use of a Segway increases users mobility radius and therefore might enrich their quality of life.

Acknowledgements. This study was conducted as part of the Undergraduate Research-Opportunity Program at RWTH Aachen University, Germany, in collaboration with the University of Alberta, Canada. This publication is part of the research project ‘TECH4AGE’, financed by the Federal Ministry of Education and Research (BMBF, under Grant No. 16SV7111) and promoted by VDI/VDE Innovation + Technik GmbH. For more details and information, please see www.tech4age.de.

References

1. World Health Organization. Global age-friendly cities: a guide, Geneva, Switzerland (2007)
2. Sawatzky, B., Denison, I., Tawashy, A.: The Segway for people with disabilities: meeting clients’ mobility goals. Am. J. Phys. Med. Rehabil. **88**(6), 484–490 (2009). https://doi.org/10.1097/PHM.0b013e3181909ef9

3. Jiménez, D., de La Fuente, Y., Hernández-Galán, J.: Diversity of "pedestrians on wheels", new challenges for cities in 21st century. Stud. Health Technol. Inform. **256**, 357–366 (2018)
4. Boutilier, G., Sawatzky, B.J.: The Segway personal transport as an alternative mobility device for people with disabilities: physiologic benefits? In: Rehabilitation: Mobility, Exercise, and Sports: 4th International State-of-Art Congress. IOS Press (2010)
5. Shaheen, S.A., Finson, R.: Bridging the last mile: a study of the behavioral, institutional, and economic potential of the Segway human transporter. Transportation Research Board, 03–4470 (2003)
6. Oxley, J., Whelan, M.: It cannot be all about safety: the benefits of prolonged mobility. Traffic Inj. Prev. **9**(4), 367–378 (2008). https://doi.org/10.1080/15389580801895285
7. Rahman, K.A., Azaman, A., Mohd Latip, H.F., Mat Dzahir, M.A., Balakrishnan, M.: Comparison of tibialis anterior and gastrocnemius muscles activation on balance training devices and hoverboard. Malays. J. Fundam. Appl. Sci. **13**(4–2), 495–500 (2017). https://doi.org/10.11113/mjfas.v13n4-2.820
8. Dias de Brito, C.M., Pinheiro Neto Jacob, J.T., Nóbrega, R., Nogueira Santos, A.M.: Balance assessment in fall-prevention exergames. In: Yesilada, Y., Bigham, J.P. (eds.) Proceedings of the 17th International ACM SIGACCESS Conference on Computers & Accessibility - ASSETS 2015, pp. 439–440. ACM Press, New York (2015)
9. Marigold, D.S., Eng, J.J., Dawson, A.S., Inglis, J.T., Harris, J.E., Gylfadóttir, S.: Exercise leads to faster postural reflexes, improved balance and mobility, and fewer falls in older persons with chronic stroke. J. Am. Geriatr. Soc. **53**(3), 416–423 (2005). https://doi.org/10.1111/j.1532-5415.2005.53158.x
10. Pourmand, A., Liao, J., Pines, J.M., Mazer-Amirshahi, M.: Segway® personal transporter-related injuries: a systematic literature review and implications for acute and emergency care. J. Emerg. Med. **54**(5), 630–635 (2018). https://doi.org/10.1016/j.jemermed.2017.12.019
11. Boccia, G., Dardanello, D., Rosso, V., Pizzigalli, L., Rainoldi, A.: The application of sEMG in aging: a mini review. Gerontology **61**(5), 477–484 (2015). https://doi.org/10.1159/000368655
12. Konrad, P. (ed.): The ABC of EMG. A Practical Introduction to Kinesiological Electromyography, version 1.4 (2006)
13. Hermens, H.J.: SENIAM. In: European Recommendations for Surface Electromyography: Results of the SENIAM Project, 2nd edn. Roessingh Research and Development, Pays-Bas (1999)
14. Rohmert, W.: Untersuchungen über Muskelermüdung und Arbeitsgestaltung; Schriftenreihe Arbeitswissenschaft und Praxis, Beuth-Vertrieb (1967)
15. Böcker, L., van Amen, P., Helbich, M.: Elderly travel frequencies and transport mode choices in Greater Rotterdam, the Netherlands. Transportation **44**(4), 831–852 (2017). https://doi.org/10.1007/s11116-016-9680-z