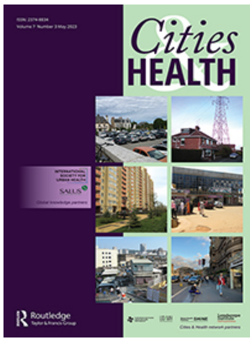

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Active urbanism: heart rate and oxygen consumption comparison when walking on imitation steppingstones versus a plain surface

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ABSTRACT

The aim of the study is to measure the effectiveness of steppingstones as an element of landscape design, to make walking a more effective exercise. Increased oxygen consumption and heart rate are important markers to estimate intensity of physical activity. To bridge the gap between physiological theory and the application in urban design, a combined experiment including 26 participants walked on a plain treadmill and then steppingstone imitations at the same speed. Physiological data were collected and compared using a heart rate monitor and a breath-by-breath metabolic system and supplemented with a questionnaire about body reactions and likelihood to perform a similar exercise in a life situation. The average increase in heart rate due to steppingstones was 17.22%. Results further showed that the exercise was more effective for the 30–60-year-old age group. Questionnaire data found that 69% of participants picked 'maybe' or 'definitely' for using similar steppingstones on their way to work and 100% walking in a park. In conclusion, we estimate that steppingstones can significantly increase people's metabolic and physiological parameters, and can help the wider population to achieve the recommended government and health guidelines of 'moderate exercise' of 150 min/week, improving population health. This new evidence can help designers to implement Active Urbanism strategies.

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Active urbanism; playful environment; metabolic rate; steppingstones

Introduction

A healthy body and better fitness broadens an individual's opportunities in life and makes everyday tasks easier, more achievable, and more enjoyable (Bouchard and Shephard 1994). Although, to some extent, health and fitness are determined by genetic factors, it should be noted that lifestyle, environment, and an individual's choices play a much larger importance (Bouchard and Shephard 1994, Foster and PJ 1995, Guthold *et al.* 2018).

While traditional health risks (such as undernutrition, polluted water, poor sanitation and hygiene, violence, old pandemics and indoor smoke from solid fuels) have been declining in more economically developed countries for decades, other modern health risks (such as new world pandemics, becoming overweight, physical inactivity, traffic mortality, external air pollution) have emerged. Most of these reached the level where action was taken, including policies, design interventions, and campaigns for lifestyle amendments. Some of the improvements were achieved using the built environment modifications (such as separation of smoking and non-smoking areas, increased access to natural light, ventilation, construction of sewer systems, and city zoning) (Richardson 1919, Huss *et al.* 2010, Lilley 2015). The results of these changing trends are shown in Figure 1. However, risks associated with physical inactivity (such as obesity, heart diseases, diabetes and others), are still increasing (WHO 2009).

Physical inactivity has been a major concern for decades and was reported in 2019 that the UK population was 20% less active than in 1960's (Public Heath England 2019). Despite promising positive trends in discretionary (leisure-time) physical activity in some countries and socio-economic groups; incidental, transportation-related, and occupational physical activity are decreasing, which can be linked to development of electronic entertainment, industrial machinery and private transport ownership (Kohl *et al.* 2012, Farrell 2014, Lieberman 2020). The situation is often described as 'The pandemic of physical inactivity' (Kohl *et al.* 2012), and this puts increasing strain on the UK NHS (National Health Service) (Burton *et al.* 2004). In relation to this, the estimated total annual cost of inactivity-related diseases to the UK economy is £7.4 bn (Public Heath England 2019). If physical inactivity continues to increase at this rate, the figure is likely to also increase (Kohl *et al.* 2012). Increase of working from home, electronic entertainment, and home delivery during 2020–2021 lockdowns has pushed the inactivity status even further (Jorstad and Piek 2021, Dao *et al.* 2021).

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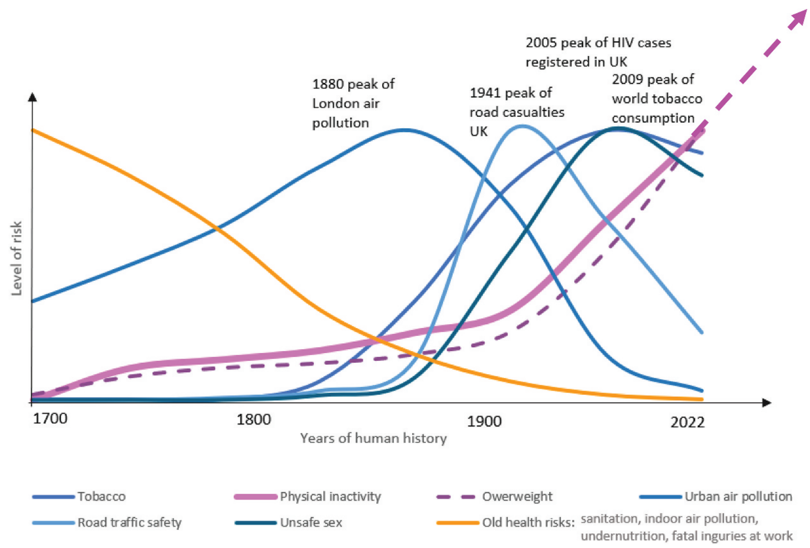

Figure 1. Health risks reduced in the UK population by the interventions to environment and lifestyle (WHO 2009, WBG 2014, Jackson and Cracknell 2018, Elflein 2019).

Physical activity interventions have proven to be effective to combat these associated risks and have a significant effect on health, fitness, and well being. They help to prevent and treat a host of health concerns such as coronary heart disease, stroke, hypertension, renal disease, type II diabetes, osteoporosis, certain forms of cancer, unhealthy weight gain, depression, and anxiety. It also enhances insulin sensitivity and cognitive function (Shinkai *et al.* 1995, Garber *et al.* 2011, Sofi *et al.* 2011, Kohl *et al.* 2012) and causes increase in serum immunoglobulins which benefits the immune system (Nehlsen-Cannarella *et al.* 1991).

In terms of the physical activity guidelines, the NHS and WHO (World Health Organisation) recommend a minimum of 150 minutes of moderate or 75 minutes of vigorous activity and strength training spread over a week for all adults to maintain fitness (NHS 2018, WHO 2018), plus stretching, and balancing exercises for people over 65 years old. Studies show a positive dose-response relation between increased physical activity and increase in health, fitness, and wellbeing, therefore, it is recommended to exceed the minimum amount (Haskell *et al.* 2007, Chang and Etnier 2009, Smith *et al.* 2022). Research has shown that even a small increase in physical activity that cause physical activity energy expenditure to increase over the period of 1 year are associated with a reduction in clustered metabolic risk (Simmons *et al.* 2008).

Nevertheless although physical activity and its benefits are well established, and multiple initiatives have been implemented to promote exercise and inform the population, there is still a dangerous level of inactivity present (Farrell 2014). In relation to this, the top two mortality causes, even when including COVID-19, in the UK for the 2021 statistics, were Alzheimer's and ischemic heart diseases, which are both affected by a person's level of exercise (NISPA 2021, Office for National Statistics 2021). This suggests that inactivity is one of the largest modern health risks to be actively targeted by research, interventions, and policies, with the aim of changing the trend as it was done earlier (at least in some countries) with air pollution, smoking, road mortality, and HIV. Studies show that the majority of sedentary people in Western countries are aware that they would benefit from being more active, and explain their lack of physical activity in terms of a shortage of time, motivation, and opportunities, as well as negative previous experiences (Ekkekakis 2003, Netz *et al.* 2008). According to statistics, individuals with a lower socioeconomic status and education are less likely to be engaged in fitness activities (Demarest et al. 2014; WHO 2018). Another social group often maintaining a sedentary lifestyle is office workers who stay at their desks for long and sometimes unpredictable hours (Sang *et al.* 2009), making it difficult to plan for exercise (Rassia *et al.* 2010, Clemes *et al.* 2014).

While spreading the information has proven to be only partially effective, widely known studies show that the environment strongly affects human behaviour and can be used to 'make good choices easier and bad choices harder' (Thaler and Sunstein 2009, Kahneman 2013). The connections between the built environment and health and well-being have also been receiving increased scientific attention in the last decades. Various aspects of the built environment have proven to have significant effects on the health and fitness of users (Boarnet and Takahashi 2005). Rather than only reducing harm, now the emphasis is shifting to also increasing positive effects, such as encouraging exercise (Panter *et al.* 2019), for example by moving up and down stairs (McGann *et al.* 2013, Peeters *et al.* 2013, Steemers 2015). Further to this, it is now suggested that a conceptual framework for integrating health into spatial planning decisions should be made (Barton and Tsourou 2000). The principles of healthy urban design are starting to be incorporated into official guidelines, such as the Major of London adopting an 'evidence-based approach to creating fairer, sustainable and attractive urban spaces' to make the capital's population healthier (Healthy Streets for London 2017).

Many researchers agree that biology of exercise should be explored in light of evolution, and exercise as a behaviour should be seen in light of anthropology (Grunspan *et al.* 2018, Lieberman 2020). This is closely linked to the concept of mismatch diseases that result from this frictionless urban environment. They were rare in previous generations, and are more likely to occur when bodies that have evolved under challenging conditions of stone-age are placed into an environment no longer offering the same physical challenges – the modern city (Lieberman 2013). Even few decades ago the European streets required the walker to watch where they were stepping and be prepared to react on changes in the terrain: crossing a flooded or muddy street on steppingstones, walking on streets covered with ice and piles of snow, stepping up and down retaining walls, over broken parts of pavement and walls, and walking on cobblestones and narrow bridges is part (Figure 2). Similar conditions still exist in many parts of the world. Such an environment required some attention, reaction, balancing and coactivation of a wider range of muscles and energy consumption (Voloshina *et al.* 2013, Chiovetto *et al.* 2015). Over time, greater comfort, safety and accessibility have created an environment which is smooth and step free, predictability of collision of a foot with the surface changes the gait, concentration, and the way the whole body moves (Kuo 2002, Eiken *et al.* 2022). Additionally, less active control of lateral balance is needed (Bauby and Kuo 2000). Urban environment became even further from what was natural for human bodies.

To combat this mismatch special landscape design features are already being employed in various settings. 'Senior Playgrounds' in parks and retirement homes are aimed to slow the ageing process, avoid risk of falling and reward participants with experiences of accomplishment, physical activity and enjoyment (Figure 2) (Lappset 2007, Lewis 2021). Similar principle is used in hospitals for postoperative rehabilitation (Illonga 2020). 'Reflexology passageways' with cobbled or steppingstones are popular in Asia and studies show they can be effective in lowering high blood pressure (Li et al. 2003), increase metabolic rate and muscle coactivation (Voloshina *et al.* 2013) and are used in sensory gardens to improve interaction of people with learning difficulties (Hussein 2010). Additionally, stepping or jumping down 380 cm on a hard surface, similar to tarmac, has proven to create an appropriate level of impact on bones to maintain healthier bone density (Anliker *et al.* 2012, Boldina *et al.* 2021).

The benefits of the above landscapes can be achieved with more consideration of aesthetical properties. In this respect, steppingstones or more specifically, objects with hard surfaces, distributed on a step-size distance from each other surrounded by grass, water or gravel could present one of the possible ways to provide alternative pedestrian experiences that make walking more interesting and challenging (examples are shown in Figure 2). By themselves they are not accessible for people with mobility constraints and need to be complemented with conventional routes. Such alternatives can be incorporated as sections of public passes on the sides of street, within campuses, parks, or residential developments. People

Figure 2. Examples of steppingstones in grass, water, and sand.

without mobility constraints can be encouraged to choose the steppingstones route over conventional by a variety of measures (Boldina *et al.* 2022). The benefits of steppingstones include visual variety, haptic pleasure of ground feel (Brown 2017), increased rainwater permeability, decreasing storm-water run-off, land drying and overheating (Zhou *et al.* 2018), and support of biodiversity (Baum *et al.* 2004).

In this connection, previous studies have identified walking on uneven surfaces increased mean muscle activity in the lower leg and thigh and increase in metabolic rate (Voloshina *et al.* 2013). Walking on sand requires 1.6-2.5 times more mechanical work and 2.1-2.7 times more energy expenditure than walking on even surface (Lejeune *et al.* 1998). Further changes in muscle coactivation in various stages of gait and metabolic rates were discovered when walking on grass (Davies and Mackinnon 2006), ice (GAO *et al.* 2008), and changing slope (Prentice *et al.* 2004). More importantly, to our knowledge, there are currently no studies specifically on physiological and metabolic effects of walking on steppingstones.

The intensity of physical activity can be measured by the Metabolic Equivalent of Task (MET), the rate at which a person expends energy, while performing a physical activity compared to resting. While 'mild' physical activity presents some health benefits, 'moderate' physical activity is recommended to reduce metabolic risk and is commonly defined as requiring 3-6 METs (Gaskill *et al.* 2001, Morrow *et al.* 2004). Another common and well-established method to identify exercise intensity is measuring heart rate and oxygen uptake (VO_2) (Chen *et al.* 2002). On average moderate exercise intensity is reached at 50% of maximum oxygen uptake and 64% of the maximum heart rate (CDC 2020). Another well-established method commonly used to measure difficulty of an exercise task is the rating of perceived exertion (RPE) (Borg 1998, Chen *et al.* 2002).

Therefore, the aim of this study is to identify if there is an increase in exercise intensity and effort when walking on distributed imitated steppingstones compared to a conventional flat continuous surface similar to a sidewalk. Additionally, what the metabolic cost of walking on steppingstones imitation is in comparison to walking on a plain treadmill at the same speed. Walking was chosen because it is the most natural everyday exercise (Kang *et al.* 2002) and is widely popular : 69.9% of UK residents in 2018 walked over 30 min a day, and 86% walk over 10 min. 26% of trips in the UK were done by foot (Department for Transport 2018, 2020). Our overall aim is to pave a route to involve the whole population in a life-long exercise habit by city landscape design, combating the inactivity pandemic and improving population health. Our previous socio-psychological study showed that up to 63% of 200 participants would pick a steppingstone route if it was shorter than conventional pavement, and up to 78% for other challenging routes, such as log over a stream (Boldina *et al.* 2022). This area of research will allow an estimate of the potential effects of using steppingstones in city landscape design on population health.

Materials and methods

Study design

This study was approved by the University of Cambridge Faculty of Architecture and History of Art Ethics Committee. Two separate experiments were performed in this study. Experiment 1 was a pilot study using a university student cohort from the Faculty of Sport Science and Physical Education at the University of Coimbra. This experiment focused on 2 aspects of physiology: oxygen consumption and heart rate. Metabolic is directly linked and proportional to oxygen consumptions (4.8 calories for each l of oxygen consumed). For example, if oxygen consumption increases by 10% then metabolic rate would also increase by 10%.

Experiment 2 was a follow-up study tailored further towards the target group of the intended interventions (Figure 3): UK population, with participants of various ages from 23 to 70. UK was picked as it is a country with the pavements regulated more in recent years towards the even step-free pedestrian routes and hence is likely to need the interventions more (Part M 2010, Part K 2016). For Experiment 2 we targeted participants with sedentary jobs. The aim of 2 studies was not to directly compare the groups, but to see if both groups (varying age ranges) can independently benefit from the steppingstone exercise.

Participants were instructed to dress normally, as they would for a city walk. Upon participant arrival, basic anthropometrics such as their height and mass were recorded. The laboratory experiments were both performed on a treadmill, with and without imitation steppingstones marked by high-performance coloured tape. All the participants were briefed and debriefed accordingly. During this time respiratory and heart rate data were collected.

Participants

In experiment 1, ten participants 19-22 years old, with BMI between 20-35 kg/m^2 including six men, were recruited from the Faculty of Sport Sciences and Physical Education. We deliberately picked participants with a wide BMI range as the intervention is

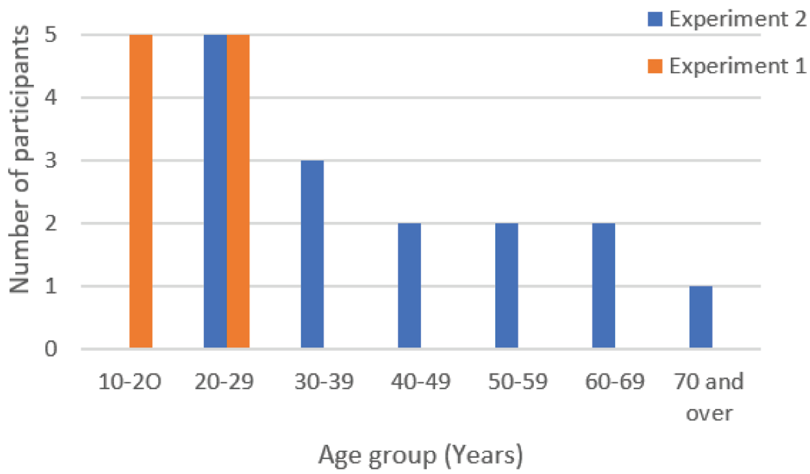

Figure 3. Participants age distribution.

intended for the entire population: seven participants with normal BMI 18.5-24.9 kg/m^2 two with BMI 25-30 kg/m^2 and one with BMI over 30 kg/m^2.

The participants for Experiment 2 were recruited in Cambridgeshire County, inclusion criteria were a job involving sitting over 4 hours a day, and not currently doing any sports professionally; anyone that was not meeting these criteria was excluded from the study. Participants were interviewed before being recruited into the study to determine their current level of exercise and physical activity habits. Sixteen participants 24-70 years old, (Figure 3) BMI 18-33 kg/m^2; including eleven men; nine participants with normal BMI (18.5-24.9 kg/m^2), three overweight (BMI 25-30 kg/m^2) and four obese with BMI over 30 kg/m^2. Six of them not reaching the 150 minutes exercises threshold.

One of the important aspects of Active Urbanism concept is inclusivity so for the questionnaire part of the experiment we included a participant with cerebral palsy. Studies show that physical activity improves cardiovascular health of participants with cerebral palsy (Physical Activity Guidelines Advisory Committee Report 2008) and scoliosis.

All participants received written and oral instructions for the study, and each gave their written informed consent prior to participation.

Experiment 1

Experiments took place in the Biokinetic Laboratory of the Faculty of Sport Sciences and Physical Education of Coimbra University. A treadmill for sports and medical research was used for all tests (h/p/Cosmos-pulsar mercury®, COS 10,198–01, 1.8 m long).

An imitation of steppingstones was created on the treadmill using high-performance coloured tape, stuck onto the treadmill belt surface. We recorded the steppingstones available on the UK market and in world landscapes, some of them were round, some square, some irregular varied shape (Figure 11). For this experiment we picked squares 200 × 200 mm each, replicating a large enough stone to position the participants' foot but requiring coordinated precision (Figure 4). The distance between the centres of the stones ranged from 350 to 750 mm and was picked at random to provide variety based on average step length of 725 mm (Murray 2022). There was 350 mm variability in left-right position of the steppingstones imitations.

At the start of the experiment, facepieces and a portable metabolic analysers (Cosmed K4b^2, Cosmed) were fixed on the participants' face and back for the collection of respiratory data. Additionally, a heart rate monitor was strapped to the participants' chest (Polar H10, Polar, Kemple) (Figure 5). After a 1 minute of warm-up at 4 km/h, usually required to reach the stable heart rate when switching from sedentary – participants were asked to walk on treadmill at 4 km/h for 4 minutes with their normal gait ignoring the tape, and then 4 minutes at the same speed but stepping only on the marked areas imitating the steppingstones.

Participants were shown the Borg Rating of Perceived Exertion (CR-10 RPE) scale before the experiment and familiarised themselves on how it worked. A detailed explanation was given to each participant on the differences between scores. After performing the tests, participants were asked to rate both parts of the exercise using Borg 1-10 perceived exertion scale.

Experiment 2

Experiments took place in the gym of a Cambridge College. For all trials a similar treadmill (Life Fitness 95Ti 1.8 m long), was used for all test trials (Figure 6).

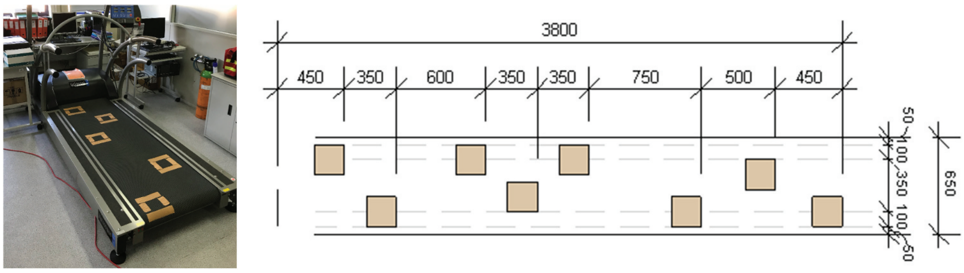

Figure 4. Treadmill with imitation of steppingstones.

Figure 5. Equipment: wearing polar cardio belts on participants, Cosmeg K4 metabolic facepiece and back device.

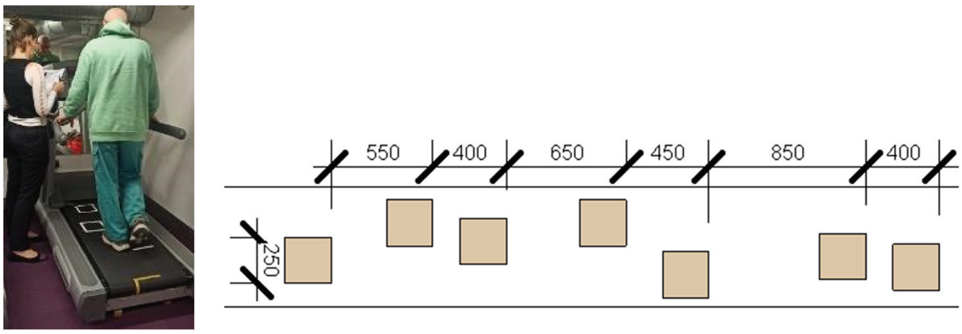

Figure 6. Treadmill life fitness 95Ti with imitation of steppingstones: photo and plan.

The data collected in Experiment 1 showed that participants responded consistently between heart rate and oxygen consumption and that both had a linear relationship with the exercise intervention. Therefore, in the Experiment 2 only the heart rate measurements were necessary to track the physiological and metabolic effects of walking (Polar H9 Heart Rate monitor, Malaysia). Another reason is that it allowed participants to feel more natural and did not disturb their walking gait replicating more real-life walking. Participants were asked to answer a short questionnaire in three stages: questions about their exercise habits, and physical parameters before the test, Borg CR-10 exertion rate during the experiment and after the experiment – muscles they felt were more involved while following the steppingstones. To increase the precision in defining muscles working the participants were given a scheme of the human body and asked to circle muscles they felt were working.

At the end of each session each participant was asked if they would use similar steppingstones in a city and park environment (Example questionnaire in Appendix A), based on their experience of performing similar exercise.

Due to a variety of physical abilities between participants the speed of the treadmill was adjusted during the warm-up to reach the speed comfortable for each participant, which was at a relative intensity at approximately 50% of maximum heart rate. Where the estimated maximum heart rate for each individual was calculated by the formula of 220 minus age in years (Grant *et al.* 1995).

The increase in participant's heart rate was recorded and marked if it reached the threshold for moderate intensity physical activity defined as 64% of the maximum heart rate, which is on average an equivalent of 50% of metabolic rate (Physical Activity Guidelines Advisory Committee Report 2008, CDC 2020). For example, for 40-years old participants the threshold heart rate for moderate physical activity would be (220-40) x 64% = 115.

Participants with disabilities were treated separately: one with cerebral palsy chose the speed of 0.8 km/h to match their physical ability. The participant was only included for the opinion study and excluded from heart rate comparisons and data analysis for the overall results.

Data and statistical analysis

The VO_2 data was collected using breath-by-breath sampling. The raw VO_2 data was exported into an Excel spreadsheet (Microsoft Corp, Washington, USA), where at 5 minutes to the end of the walking test (4 minutes) was averaged to determine overall exercise VO_2. The heart rate collection was synced to the metabolic cart with the same sample frequency. The exercise heart rate was determined similarly to the VO_2 (Figure 8). Metabolic rate increase would be proportionate to VO_2 intake increase.

The Statistical Package for Social Sciences (SPSS, Version 28, Chicago, IL) was used. All data was assessed for parametric assumptions using the Shapiro-Wilk test of normality and grouped assumed homogeneity of variance. The alpha statistical significance was set at $p \leq 0.05$. For parametric data, a paired samples t-test was used to compare the results of steppingstone and normal working on treadmill. For non-parametric data, the alternative Wilcoxon test was conducted. Post-hoc tests were conducted accordingly, such as Tukey test and mean ranks. Finally, Hedges' g effect size (ES) was also calculated and defined as: <0.19 = '*Trivial*', 0.20-0.49 '*Small*', 0.50-0.79 = '*Medium*' and ≥0.80 = '*Large*' (Lakens 2013).

Results

Descriptive results

Experiment 1

The group in experiment 1 on average when walking on a plain treadmill had relative VO_2 of 14.7 ml/m/Kg and heartrate of 115.4 b/min, respectively. When participants transitioned to walking on imitated steppingstones at the same speed the VO_2 increased on average by 3.41 ± 1.1 ml/kg/min, this is equal to 24% (range: 12-30%) as reflected in Table 1. The increase in Metabolic rate can be estimated to increase proportionally, by 16.4 cal/kg/min. Similarly, heart rate increased on average by 10.2 ± 7.6 b/min, this is equal to 10% (range:-6.6-19.4%). Figure 7 shows an example of the VO_2 consumption and heart rate increase as participants walk on steppingstones opposed to regular treadmill walking.

In terms of the Borg CR-10 exertion rating scores, these increased by 0.95 ± 0.76 (range: 0 to 2 points) showing that participants perceived walking on steppingstones slightly more difficult and had greater exertion.

When observing the participant's body position, we noticed that when following the steppingstones, the individuals' arms were spread further from the body comparing to the plain treadmill (Figure 8), and the neck was bend forward (Figure 9) adding variation to the muscles involved comparing to normal walking.

Table 1. Data collected during experiment 1.

Gender and age (years)	Height (m)	BMI (kg/m^2)	Oxygen consumption on plain treadmill (ml/m/Kg)	Oxygen consumption on treadmill With s.stone imitation (ml/m/Kg)	Increase in oxygen consumption (%)	Average heart rate on plain treadmill (beats/m)	Average heart rate on treadmill with steppingstones imitation (beats/m)	Increase in heart rate (%)	Borg perceived exertion rate increase.(-)
M 19	1.87	20	13	17	30	96	104	8	1.5
M 22	1.67	24	14	16	16	100	109	10	2
F 19	1.63	31	17	20	20	133	145	9	2
F 19	1.58	25	13	16	25	143	137	−5	0
M 21	1.88	25	14	19	30	111	122	10	0
M 19	1.74	30	15	21	37	85	105	23	0.5
M 23	1.72	33	14	16	13	disconnected			1
F 21	1.79	30	16	19	23	131	146	11	0.5
M 22	1.66	26	16	18	17	disconnected			1.5
F 19	1.85	24	15	18	26	124	138	11	0.5
Average			14.7	17.94	24±7	115.4	25.4	10±7	0.95

All participants perform over 150min of moderate activity/week, Speed of treadmill – 4 km/h.

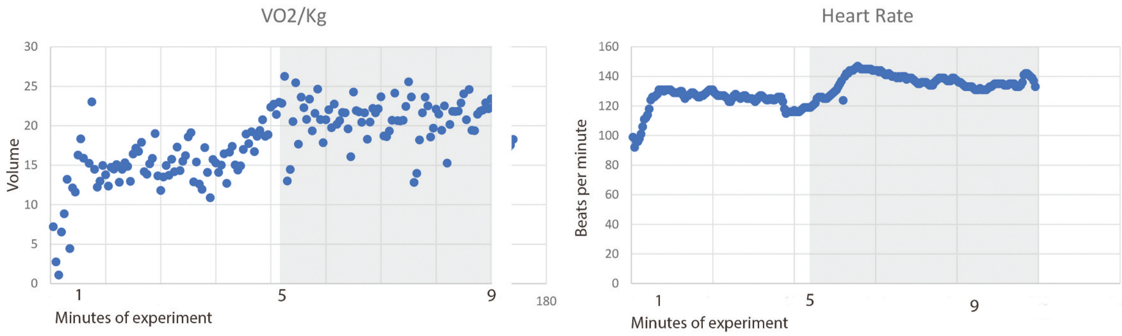

Figure 7. Example of participant's metabolic rate and heart rate recorded during the experiment 1.

Figure 8. Walking following and not following steppingstones: different position of arms.

Figure 9. Walking on steppingstones changes the body position.

Experiment 2

Similar to experiment 1, experiment 2 also found an average increase in heart rate by 15.9 ± 11.6 beats/min, equivalent to 11.25% (range: 3.7-37.6%), when walking on imitated steppingstones compared to a plain treadmill (Table 2). Based on the heart rate result the steppingstone intervention appeared most suitable for the 30-60 age group. Participants under 30 years old chose to walk at a higher speed (mean 4.26 km/h), which allowed them to reach the 'moderate exercise' threshold, but at the cost of feeling dizzy from watching patterns appearing on the treadmill. The effect might not occur on real-life steppingstones. Whereas participants over 30 years old managed to reach the

Table 2. Data collected during experiment 2.

Gender and age (years)	Height (m)	BMI (kg/m^2)	150 min of moderate activity/week	Speed of treadmill (km/h)	Average heart rate on plain treadmill (beats/m)	Average heart rate on treadmill with steppingstones imitation (beats/m)	Increase in heart rate (%)	Borg perceived exertion rate increase. (-)
M 23	1.75	18	no	4	72	115	60	3
F 24	1.73	20	yes	3.2	97	110	13	2
M 25	1.80	24	yes	4.5	94	120	28	4.5
M 26	1.93	24		4.8	91	125	37	2
M 27	1.87	27	no	4.8	115	140	22	4
Average under 30				4.26				
F 34	1.55	31	yes	2.2	108	113	2.7	2
M 36	1.75	25	no	3.2	89	91	1.8	0
F 39	1.86	25	yes	3.4	100	113	13	1
M 42	1.70	30	no	1.6	89	94	5.6	0
M 47	1.75	33	yes	3	100	106	6	1
M 51	1.88	22	no	3.7	89	103	16	2
F 59	1.61	25	no	3.2	98	109	7	1
F 64	1.82	30	yes	1.9	88	93	6	0
M 64	1.81	26	no	2.9	95	108	14	4
M 70	1.75	24	no	1.6	102	109	7	1
Average over 30				2.67				
Overall average							17.22	1.9

moderate exercise threshold at lower speeds (mean 2.67 km/h) and did not report dizziness.

Based on the follow-up questionnaire results, participants in all age groups reported wider variety of muscles involved while following steppingstones compared to plain treadmill, including calves, glutes, trapezius, infraspinatus, erector spinae, rectus abdominis, pectoralis major, and glutes (Appendix B). They also reported that they felt it was more difficult and this was reflected again in the RPE results: it increased by 1.9 ± 1.42 (range: 0 to 4.5 points).

From the questionnaire in the end of the experiment 9 out of 16 (56%) of participants would take the steppingstones route in a park, and the other 7(44%), including participant with cerebral palsy 'maybe' would. No participants said they would never take steppingstones route. 'On the way to work', the inclination to take challenging route was lower: 6(38%) 'Yes', 5 (31%) 'maybe' and 5(31%) - 'No', mostly not to lose the concentration on work matters.

Statistical results

The group in the experiment 1 was normally distributed for VO_2 scores, D (8), .971, $p = .906$ and heart rate D(8), .949, $p = .705$, but not for RPE, D(8), .774, $p = .015$. Paired samples t-test found that the VO_2 scores between regular plan treadmill walking and imitated steppingstone was significantly different, t (9) = −9.851, $p < .001$, ES = 2.84. Post hoc showed that those walking on imitated steppingstone had higher VO_2 scores. This was also similar with heart rate, t (7) = −3.790, $p = .007$, ES = 1.18. Again, Post hoc favoured those walking on imitated steppingstone had higher heart rate results compared to normal treadmill walking. For CR-10 RPE scores, Wilcoxon test found significant differences between regular plan treadmill walking and imitated steppingstone ($p = .011$, ES = 1.13), similarly post hoc results uncovered greater scores in imitated steppingstone.

The group in experiment 2, also was normally distributed for heart rate D (11), .937, $p = .481$, but not for RPE, D (11), .842, $p = .034$. Paired samples t-test found that the heart rate scores between regular plan treadmill walking, and imitated steppingstone was significantly different, t (10) = −4.629, $p < .001$, ES = 1.28. Post hoc showed that those walking on imitated steppingstone results in great heart rate. For CR-10 RPE scores, very similar to the first experiment, Wilcoxon test found significant differences ($p = .011$, ES = 1.13), uncovered greater efforts and exertions in imitated steppingstone.

Discussion

The aim of this active urbanism study was to identify if walking on distributed imitated steppingstones caused increases in physiological and biokinetic factors compared to a conventional flat surface similar to pavement. Additionally, we asked the participants who just experienced walking on steppingstones imitation – if they are likely to perform a similar exercise in real environments. The overall purpose of the study is aim to pave a route to involve the whole population in a life-long exercise habit by city landscape design, combating the inactivity pandemic and improving population health (Garber *et al.* 2011).

We hypothesis that imitated steppingstones would cause increases in physiological and metabolic variables and therefore, would be more advantageous on developing health, fitness, and active lifestyle when compared to conventional flat surface walking. This intervention may be useful for a wide range of age groups and populations, especially to those that spend most of the day in a sedentary state. The benefits of this study suggest having a wider implication for the health, exercise, policy, and city landscape design domains.

The results collected from this laboratory intervention study suggest that walking on the steppingstones significantly increases people's heart rate response as well as significantly increased breathing rate and the ability of the lungs' oxygenation process, when compared to walking at the same speed on conventional pavements. This study supports the notation that walking on steppingstones is a more physiologically effective exercise to challenge, maintain, and develop the cardiorespiratory system and can aid in preventing related diseases. In experiment 1, this included fit and healthy individuals, their oxygen consumption and metabolic rate increased by 24% and heart rate by 10%. In Experiment 2 the results were even more pronounced, less fit and older individuals with sedentary jobs had a 17% increase in heart rate, so there was a difference in reaction, but both groups were exercising more actively when following the steppingstones. Additionally, the Borg rating of perceived exertion (CR-10) collected over both experiments increased on average by 1.9 points, but for some participants at higher speeds it reached 4.5 points, agreeing that the participants found it more difficult regardless of grouping, age or fitness level. Steppingstones is a flexible exercise that can provide various levels of intensity depending on a pedestrian's preference, meaning that it has the potential to meet the physiological demands of a variety of groups, including fit and healthy individuals.

In agreement with the findings in this study, there have also been a number of studies demonstrating similar effects of the same intensities of exercise on the cardiovascular health and other aspects of health in participants of all ages (Takeshima *et al.* 2002, 2004, Vancampfort *et al.* 2015). Physical activity intervention (for 12-week, three 65 min sessions per week at 40-84% of the Heart Rate Reserve) increased the cognitive abilities of healthy adults of over 65 years of both sexes (Carta *et al.* 2021) and combined intervention of physical activity, aerobic exercise and cognitive exercise helped to slow down the cognitive decline in older adults with Mild Cognitive Impairment (Park *et al.* 2019). Another study found that daily moderate activity for 3 weeks improved sleep and psychological functioning in adolescents (Kalak *et al.* 2012). These findings might also be applicable and apply to the cohort of this study as we used a similar exercise intensity.

The level steppingstones appeared sufficient for the over 30 y.o. age groups, younger/fitter adults would benefit from an opportunity for a more challenging exercise, possibly steppingstones with changing levels (Yuvraj Singh 2013).

From the participant's responses to the questionnaire, steppingstone interventions could also add to the other parameters of health related fitness, such as strength, flexibility, proprioception and more. Studies have shown that variations in distances between the steppingstones could encourage stretching leg muscle, potentially leading to normalised spine curvature and reduced back pain (Stokes and Abery 1980). In line with the above two of the Experiment 2 participants mentioned stretching of hamstrings when following steppingstones. Provided as an option next to the conventional pavement (Figure 9), steppingstones can allow people walking together to perform different levels of exercise and opt in and out when they want While the increase in level and extent of activity level can be modest in some cases, when projected to the millions of people using cityscapes on a daily basis, it can have a significant and beneficial impact on population health. Previous examples of promoted travelling exercises, such as cycling and walking up the stairs have resulted in a stable increase of activity (McGann *et al.* 2013, Assunçao-Denis and Tomalty 2019). Repeated on a regular basis Active Urbanism could shift the calorie intake/expenditure balance (Hill James *et al.* 2003), and improve heart, bone, and mental health, especially when it results in the formation of new, healthier habits (Verplanken and Wood 2006)

Drop of intention to use steppingstones from 56% to 38% on routes to work compared to parks demonstrated in questionnaire suggests that places where people promenade might be suitable to start introducing steppingstones. From the other side – placing them where people walk every day makes it easier to get involved and repeat the exercise every day (Figure 12).

Previous studies showed that shortcuts are the most effective way to encourage people to take a challenging route, followed by health information posters and 'fun effect' – adding the intrinsic motivation to the exercise (Boldina *et al.* 2022). Making the exercise environment stimulating and exciting is a quickly developing way to encourage exercise (Peeters *et al.* 2013, Lima *et al.* 2022).

The findings from this study are not surprising, as walking on imitated steppingstone is more challenging than normal everyday walking, which the results have reflected. However, where this study contributes to the research areas is that, from our knowledge, there is currently no study that has used imitated steppingstone and compared it to normal flat surface walking.

Designing for pedestrian mobility specialists tend to focus on easy and energy efficient access, making

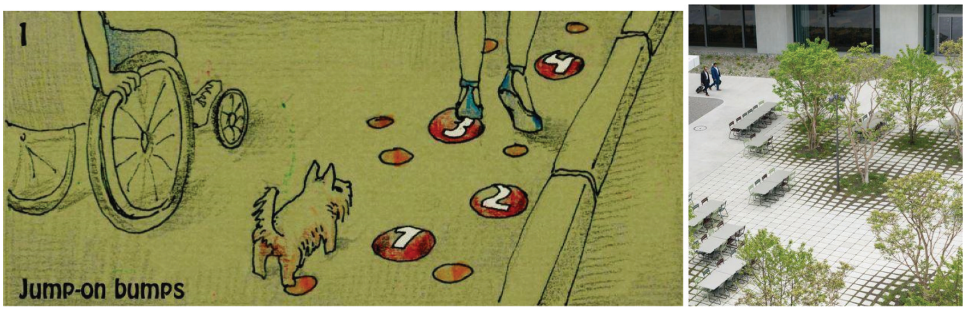

Figure 10. Steppingstones on the side of pavement.

Figure 11. Bodnant gardens. Wales and HyperLane development Chengdu, China by aspect studios.

Figure 12. Digitally modified images with steppingstones that show the steppingstones routes that were chosen by largest proportion of participants (Boldina *et al*. 2022).

mobility manageable for old and less able people and thus unifying the whole design to the least common minimum. However, exercising is one of key aspects of a healthy lifestyle and we should not forget that we should also offer routes to encourage increased variety of moves. For example, where there is enough space: one route can be easy but other options – more adventurous and energetic, so exercising can fit into the daily life without extra time spent on it. The methods and results uncovered can benefit multiple population groups and a wider age range.

Limitations

Although there were positive findings in this study and the main questions have been addressed, there are distinct limitations that should be noted. Firstly, although exercise treadmills are widely used in a laboratory environment to imitate walking through a city and on a regular hard ground surface, the effect of imitation steppingstones on a treadmill might not be a true reflection of walking on the actual outdoor steppingstones. However, a similar research approach using treadmills has been widely employed in research, for example of functional gait rehabilitation (van Ooijen *et al.* 2013). Steppingstones imitation on treadmill was used to research attention requirements during regularly and irregularly cued walking in younger and older adults (Mazaheri *et al.* 2014).

Secondly, it is important to note a number of factors could have contributed to the increase in heart rate when walking on the imitation of steppingstones, such as anxiety to fail a novelty task, and participating, heat, stress and more (Bassett and Howley 2000). Another noteworthy limitation was the use of the Cosmed K4b2 portable telemetric gas analysis system, used for Experiment 1. Due to participants having to wear the device this disturbed the natural gait of the walking test and was therefore excluded for the second phase. Additionally, the results consistently displayed higher O_2 and CO_2 measurements in comparison to a metabolic cart, but demonstrated satisfactory test-retest reliability and internal validity (Duffield *et al.* 2004). In this reflection and for future studies, we would suggest using a stationary breath-by-breath metabolic cart opposed to a portable one unless experiments are being conducted where portability is required.

Furthermore, the set of data collected, and the variables explored in this study should be increased in future experiments to include direct Metabolic Rate measurements, motion tracking, and electromyography (EMG) of muscle activation as direct measures of physiological effects. Finally, a main limitation to this study is the relatively small sample size recruited and representation of population. This means that any generalisations to the entire population should be treated with caution. Although statistical significance was computed, larger samples sizes may be required for concrete evidence in the result.

Future recommendations

The study forms a building block and foundation for future studies and could be developed further in a number of directions. The parameters of the built environment: steppingstone size and position could be manipulated to find an optimal proportion. The types of data collected could be expanded to include the biomechanical field, measuring muscle activation (EMG), balance using force plate activity, posture and coordination with camera motion and vision.

Some side data collected suggested the increased mindfulness and distraction from family and exams related problems when using steppingstones, compared to conventional walking. Further studies of stress levels when concentrating on steppingstones could potentially bring interesting results.

To identify the effect on health with confidence a long term intervention study in a real-world environment would be beneficial. It could be even more applicable to practice if it included the effect of the steppingstones with different parameters.

Study could be expanded to include specific population groups such as those with cerebral palsy, or diabetes as the literature review and pilot studies show that there may be additional effects.

Conclusion

Findings in conjunction with literature review showed that changes in the urban environment can have a significant positive effect on the population's metabolic health if opportunities for high impact exercise are provided and the layout nudges pedestrians into using them fluidly. The positive effect can be observed in increased heart rate and oxygen consumption as well as in co-activation of a larger group of muscles uncovered from this study. Additionally, the majority of participants in this study stated that they would take a steppingstone route to the one imitated on the treadmill if they saw it in a park. Therefore, these reported findings and results can be used in landscape design, such as in Figure 10 and 11 together with findings from the connected physiological and psychological studies (Boldina *et al.* 2021, 2022) to facilitate more various and effective physical activity in cities to prevent and treat diseases linked to inactivity.

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Appendix A

Experiment imitating waking on steppingstones.

Procedure (14 min in total at a comfortable speed close to 4 km/h based on your heart rate):

2 min warm-up walking, check if treadmill is not too fast
4 min walking at a normal speed ignoring steppingstones
4 min follow steppingstones
4 min normal walking

Questions to answer before the experiment:

Age in years	27
Height	187 cm
Weight	96 kg
Gender	M

A. Pease feel the table <
B. Do you have any health conditions?
No
C. How do you exercise/stay active?
No regular exercise

I agree to participate in the above experiment. Signature :

Questions to fill during the experiment: 3 m/h speed 3

0	None
0,5	Very, very light
1	Very light
2	Light
3	Moderate
4	A little intense
5	Intense
6	
7	Very intense
8	
9	Very, very intense
10	Maximum

Questions:

D. During each of 4 minutes sessions please think about your overall feelings of physical stress, effort, and fatigue. Circle the correct number on Borg Perceived Exertion Rate (left).

E. Is there any difference in your body sensations while walking on steppingstones comparing to normal walking?

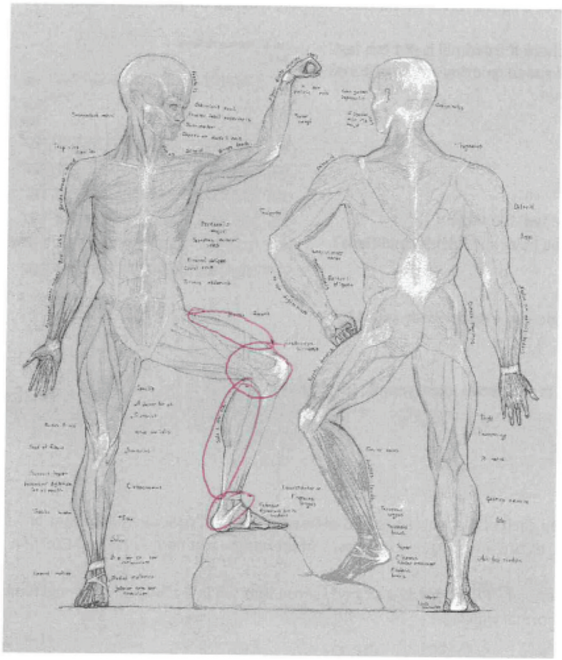
need to keep attention 21:26
smaller steps than usual

To be filled by researchers:

Stage	Heart rate	Notes
4 min plain treadmill	116,	
4 min steppingstones	90,	
4 min plain treadmill		

Figure A1. Questionnaires filled by the participants of the experiment 2.

Questions to answer after the experiment:



F. Please highlight on the scheme what muscles were co-activated while walking on steppingstones, that were not co-activated during normal walking (including arms for balancing, neck for looking down, etc)

calves

G. Would you take a steppingstones route like the one you just did on the way to work and why?

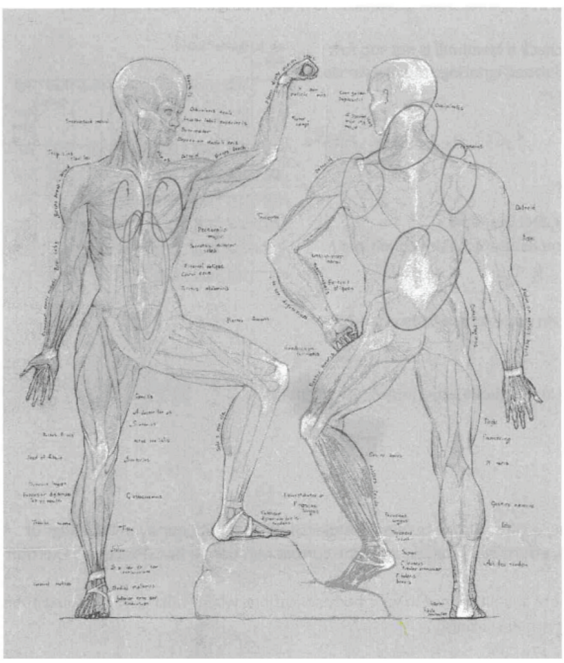
Probably as a short part of the route. It requires physical tension which will be hard to maintain.

H. Would you take it while visiting a park and why?

It can move away from thoughts which relaxes my mind. However, as for G, this will be hard to maintain on a long distance.

Other notes:

Questions to answer after the experiment:



F. Please highlight on the scheme what muscles were co-activated while walking on steppingstones, that were not co-activated during normal walking (including arms for balancing, neck for looking down, etc)

yes, alv

G. Would you take a steppingstones route like the one you just did on the way to work and why?

yes all ways do, love stepping stone

H. Would you take it while visiting a park and why?

yeah.

Figure A1. (Continued).

Subject N	Date and time	Age in years	Height in meters	Weight in kg	BMI	Gender	Heath conditions	Regular physical activity	Reach 150 min/ week?	Expected maximum heart rate (220- age in	Resting heart rate	64% of max heart rate - mode rate exerci	Speed of treadmil, km/h	Everage heart rate walking on plain treadmill 1	Everage heart rate walking on steppingstones 2	Increase	Borg exertion rate plain treadmill	Borg exertion rate steppingstones
1	8.10.2021 12.21	36	1.75	76	25	M	No	sporadically about once in 2 weeks, football,	no	184		137	3.2	106.8	124.8	16.85%	2	3
2	8.10.2021 12.22	37	1.68	62	22	M	Cerebral palsy	Dayly, lift weights, stretch, situps and pushups	no	183		117	0.8	89	90.6	1.80%	0	0
3	11.10.2021 12.31	42	1.7	86	30	M	No	Walk, most of days	no	178	78	114	1.6	88.8	93.8	5.63%	0	0
4	17.02.2022 13.48	47	1.75	##	33	M	No	Ex-military, gym 6 times/week	yes	173		111	3	100	106	6.00%	1	2
5	17.02.2022 13.25	39	1.85	86	25	F	No	Cycling, Aikido, playing with toddler	yes	181	70	116	3.38	100	113	13.00%	1	2
6	21.02.2022 11:42	64	1.81	85	26	M	No	Walking	no	156	82	99.8	2.9	95	108	13.68%	0	4
7	22.02.2022 16:13	25	1.83	79	24	M	No	Football, running	yes	195	60	125	4.5	94	120	27.66%	0.5	5
8	23.02.2022 15:18	34	1.55	74	31	F	Motion sickness	Cycling to work 40 min/day	yes	186		119	2.25	108	112	3.70%	1	3
9	18.03.2022 13.20	24	1.73	60	20	F	No	Rowing, squatts	yes	196	75	125	3.2	97	110	13.40%	1	3
10	19.03.2022 12.48	64	1.82	98	30	F	Artrosis	dancing, swimming, walking	yes	156	69	99.8	1.9	88	93	5.68%	0	0
11	19.03.2022 12:58	70	1.75	75	24	M	Recent covid	Squatting	no	150	98	96	1.6	102	109	6.86%	2	3
12	27.05.2022 14:48	59	1.61	64	25	F	Astma	Waking	no	161	72	103	3.2	98	109	11.22%	1	2
13	27.05.2022 17:30	23	1.73	53	18	M	No	Jogging 2/w	no	197	59	126	4	72	115	59.72%	2	5

Subject N	Was there any difference in your body sensations whie waking on steppingstones, comparing to normal walking.	Muscles marked by subject as more activated with steppingstones	Body position while following steppingstones+ notes	Would you take a steppingstones route like the one you just did on the way to work	Would you take it while visiting a park and why
1	Yes, it requires to focus first, it is slightly more difficult than normal walking	Calfs, brain	Arms bend and away from body, wrists moving, looking down, knees slightly bend all time	Yes, it is fun and probably healthy	Yes, if I have time and I am just passing by
2	Heping knees to loosen up. Walking pattern not like normal. Stretching hamstrings. More effort.	Legs	Moving much slower and less fidgety than normal, but achieving the same speed forwards. Holding on rail with one hand	The steppingstones route seems a bit irregular to my normal walking style	Sometimes, but I wouldn't make too much of an effect to meet the steppingstones
3	No	No	Same	No, not appropriate during thinking or processing info	Yes, just for fun
4	coordination, using different muscles. More on tips of feet.	Trapezius(neck),tibialis anterior, gastrocnemius, rectus femoris (leg)		Yes, I think it would help concentration	interesting and exercise could do it with the k..
5		Vastus lateralis, gracilis		Yes, to practice	Yes
6	Generaly tense, more concentrated on waking	Calves, quadriceps	Arms slightly elevated, looking down	found it required greater	For fun I would
7	Psychodelic tape, dizzy	Neck, upper body: rectus abdominus, legs	Had to hold on handles	No, too stressful, focusing on other stuff	Maybe for a change of scenary
8	more, looking at markers, more relaxed, different movement	Back of lower leg, left more than right	Same	a lot funner, did not clock in exercise. Became	Yeah, better way, doing something different
9	Like mario card			Yes, sounds fun	Yes, sounds fun
10	Brain efford rather than physical	Stetching leg, gluteus		No, why, they distruct me from thoughts	Maybe
11	Interesting, for some reason easier	Guteus maximum, vastus		Maybe	Maybe, it would be better if they were consistant distances for some time, then a different rythm
12	Changing pace needs concentration	Calves, vastus ateralis, gluteus		Depends on situation, if I am late, need to concentrate, didn't sleep	Same
13	Difficult to get al, got focused, switched mind from study-reated stress	Calves, quadriceps		Depends if anybody was around, if I was alone I would	Yes, park is different

Figure A2. Experiment 2 results.

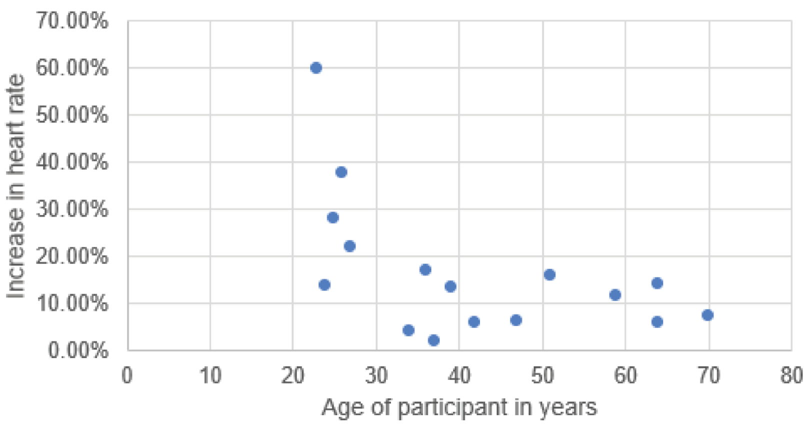


Figure A3. Experiment 2 participants heart rate increase.