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The Impact of Physical Activity on Attention Allocation in Normal and Narrow-Based Treadmill Walking

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ABSTRACT

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Regular physical activity is beneficial for cognitive function of people at different ages. As a critical component of cognitive function, how attention allocation could be affected by regular physical activity is not widely studied. It would be meaningful to start with investigating the effects of physical activity on attention allocation in young population, and further extend the research to other age populations, eg. middle aged and older adults. In this study, a validated and reliable short questionnaire was used to assess young, healthy subjects' physical activity level. Dual tasks including walking tasks on treadmill and secondary cognitive tasks were conducted to investigate subjects' performance. Different difficulty levels of walking tasks are normal-based and narrow-based walking. Gait parameters were computed and compared to assess gait performance. Modified attention allocation index (mAAI) was calculated for each gait parameter to assess attention allocation capacity. Results showed that subjects with regular physical activity had longer stride length, shorter stride time, longer step width and higher heel elevation. Furthermore, results showed higher correlation coefficient with mAAI of subjects who are more physically active in stride length and heel elevation compared with group who are less physically active. To summarize, regular physical activity improves gait performance and enhances capacity to allocate attention in young, healthy adults.

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LIST OF ABBREVIATIONS

mAAI	modified attention allocation index
TMS	transcranial magnetic stimulation
fMRI	functional magnetic resonance imaging
ERP	event related potentials
IPS	intraparietal sulcus
NPWT	narrow path walking test
DTE	dual-task effects
DTC	dual-task cost
WHO	World Health Organization
CDC	Centers for Disease Control and Prevention
ACSM	the American College of Sports Medicine
TUG	timed up and go
FITT	Frequency, Intensity, Time and Type
ASIS	anterior superior iliac spine
BPAQ	Baecke Physical Activity Questionnaire

CHAPTER 1: INTRODUCTION

Research shows that over ¼ of older adults have at least one fall each year (Bergen, Stevens, & Burns, 2016). Falls in older adults could lead to severe injury and even death with significant amount of both personal and public healthcare spending. Therefore, to investigate the risk factors becomes a critical topic. Besides commonly known risk factors like drug effects, vestibular dysfunction, muscle weakness, etc, deteriorated executive function in older adults has been discovered as one of the critical factors for potentially increasing the risk of falling (Mirelman et al., 2012).

Paying attention is a highly important aspect of executive function. It has been shown that to perform a successful gait requires a certain level of attention (Srygley, Mirelman, Herman, Giladi, & Hausdorff, 2009). When attention is divided, older adults are more likely to be affected in gait tasks like stepping over obstacles or dealing with perturbation (Chen et al., 1996; Mersmann, Bohm, Bierbaum, Dietrich, & Arampatzis, 2013). Thus, to understand the effects of deterioration of attention on daily life, such as gait in elderly population, dual task paradigms have been widely used to investigate those questions. While giving different cognitive instructions to the young and older population, the alteration of gait pattern, such as gait speed and spatial-temporal gait parameters reflects the levels of capability of attention allocation in gait.

Physical activity has been proven to have multiple benefits on people's health. Physical activity can help with both mental and physical health. Research also shows that regular physical activity reduces the deterioration of cognitive function (Physical Activity and Health 2015,).

This research is aimed to investigate the effects of regular physical activity on gait performance with normal and narrow-based walking under dual-task conditions. Further, the research is aimed to find out whether regular physical activity enhances ability to allocate attention between walking and cognitive tasks. In further studies, older subjects could be recruited to investigate the effects of regular physical activity on dual task performance of the older population. Potential meaningful results could also be found if a longitudinal study is conducted to track if regular physical activity prevents deterioration of attention allocation as people age, thus discovering a new method to see if regular physical activity would have a positive effect on preventing falls for middle age, older age population.

1 Cognition

Cognition is "the mental action or process of acquiring knowledge and understanding through thought, experience, and the senses" (Oxford Living Dictionaries.,). There are various levels of cognition function and processes. Basic levels of cognition function include attention, memory and orientation. Higher levels of cognitive function include initiation, insight, planning, organization, problem-solving, generalization, etc (O'Sullivan, Schmitz, & Fulk, 2014).

1.1 Effects of physical activity on cognition

Human observational studies have shown that people who have regular physical activity are less likely to be diagnosed with dementia (Larson et al., 2006). In addition, regular physical activity has been shown to slow the deterioration of cognitive function (Kramer & Erickson, 2007). It might be that cognitive function such as executive control, attention and verbal memory are highly associated with exercises. In a research study conducted by Pizzie et al (Pizzie et al., 2014), middle aged and older adults with higher physical activity levels have better performance in memory and visuospatial functioning, while the overtime benefits of physical activity on executive functioning and working memory tasks are more important for older adults who are at generic risk of Alzheimer's disease. Physical activity plays a positive role in treating cognition-related diseases. Physical exercise enhances neuroplasticity which augments cognitive remediation in schizophrenia by regulating central growth factor (Jahshan, Rassovsky, & Green, 2017).

Physical activity delayed motor skill degeneration and facilitates increasing the quality of life of patients with Parkinson's disease (Wu, Lee, & Huang, 2017). Among various forms of physical activity, aerobic training exercise showed significant benefits.

Being physically active at different points over the life course may have a different influence on cognition function in later life. Those who do regular physical activity early in life have a lower risk of cognitive impairment in late life (Middleton, Barnes, Lu, & Yaffe, 2010).

Physical exercises like running are proven to play a positive role on the neurotransmitter system of the adult brain through initial development of new neurons under the effects of glutamate and acetylcholine (Vivar & Van Praag, 2017). Research conducted by Gomes-Osman et al also indicated cognitive improvements resulting from exercise can be partly attributed to neuroplasticity changes in the nervous system. Transcranial magnetic stimulation (TMS) was used as a noninvasive tool to assess the neuroplasticity effect in the research and showed that short-term regular physical exercise has positive effect on brain plasticity of young adults (Gomes-Osman et al., 2017).

1.2 Cognitive function is associated with changes of gait parameters

Research on the aging population and various disease populations such as persons with multiple sclerosis and Parkinson's disease have shown that change in cognition status would affect gait parameters (Hsieh, Sun, & Sosnoff, 2017; Pal et al., 2016). Gait parameters like gait speed and gait variability are associated with fall risks in most of aging and pathological groups such as patients with Parkinson's disease and stroke (Pal et al., 2016). Research of Verghese et al (Verghese et al., 2008) indicated that people with mild cognitive impairment syndrome, which is a transition state from normal to dementia in older adults, have worse performance compared to healthy older adults as control group in domains of gait parameters like pace, rhythm and variability. Multiple sclerosis is a neurodegenerative disease and patients experience both motor and cognitive dysfunction. A recent study by Hsieh et al (Hsieh et al., 2017) found that worse cognitive processing speed was related to greater step length and step time variability in patients with multiple sclerosis. Research of Pal et al (Pal et al., 2016) found that level of global cognitive function is associated with stride velocity, turn duration, number of steps, and postural sway in a group of patients with Parkinson's disease.

2 Attention

Attention is a cognition process in which people concentrate on certain aspects of perceived information while ignoring other information (Anderson, 2004). Attentional allocation is defined as people's capacity to choose what they focus on and what they ignored. Attention deficits are associated with a variety of disorders of both adults and children, eg. neglect, schizophrenia, Attention-Deficit Hyperactivity Disorder, etc (Corbetta & Shulman, 2011; Han et al., 2013; Hodgkins et al., 2012). Attention allocation is also a very important aspect to include in the assessment of cognition in rehabilitation process of patients with disease such as stroke (van Ooijen et al., 2015).

2.1 Attentional control by brain structure

Functional Magnetic Resonance Imaging (fMRI) and Event Related Potentials (ERP) are used in research of attentional control (Astle & Scerif, 2009). fMRI detects blood flow and measures brain activation combined with anatomical structure imaging of the brain. ERP are the response of brain structures to certain stimuli. They are considered to reflect the activity of the brain while processing information. The process of attentional control is related to visual orientation in which a person pays attention to specific location. Increasing discharge rate of neurons in the posterior parietal lobe (Mountcastle, 1978), the lateral pulvinar nucleus of the postereolateral thalamus (Petersen, Robinson, & Morris, 1987), and the superior colliculus are seen when a monkey tries to attend to a certain location instead of others. People are also shown to have difficulty shifting spatial attention between locations with deficits of these three areas (Posner & Petersen, 1990). The two hemispheres are playing distinct roles in attentional control. The left intraparietal sulcus (IPS) and the left cerebellum are shown to be related to temporal orientation of attention. On the other side, activation of the right IPS was observed in spatial orientation (Coull & Nobre, 1998). In short, attentional control might involve the following: posterior parietal lobe, posterolateral thalamus, superior colliculus, and intraparietal sulcus.

2.2 Attention allocation on human movement

Attention allocation plays a significant role in motor learning, performance, and safety issues like driving, etc. Wulf et al (Wulf, Höß, & Prinz, 1998) investigated the process of learning complex skills with a series of different movements. External focus of attention refers to attention on the external environment (eg. apparatus or a target people used in the learning process) was shown to enhance improvements in motor learning compared to that of internal focus of attention, which means attention on people's body part movement itself. Further study results indicate that the farther the target away from the body attention is allocated on, the better the motor performance in the learning process (Bell & Hardy, 2009).

Training aimed to improve attentional control skills of novice drivers was shown to benefit the performance on a driving simulator (Regan, Deery, & Triggs, 1998). Varied mood states like anger affected attention allocation, which made drivers' minds wander. Degraded lateral control of vehicle which indicates higher lateral acceleration was observed in the condition (Techer et al., 2017).

2.3 Effects of physical activity on attention allocation control

Physical activity can affect cognitive function and some specific domains based on research discussed above. There is research showing that highly-fit subjects who do exercises (especially aerobic exercises) had greater activity in certain brain area that were responsible for attentional control, like prefrontal, parietal cortices and anterior cingulate cortex (Colcombe et al., 2004). However, research that investigates the direct effects of physical activity on attention allocation control is still limited.

Most research available on the association between physical activity and attention control is about the effects of physical activity on attention span. A research on elementary school students found that students who participate in school based physical activity have improved attention-to-task compared with a control group who do not participate in the physical activity (Mahar, 2011). Research of Silva et al showed that among subjects with ADHD the group who did physical exercise performed better in tasks that required attention (Silva, Prado, Scardovelli, Campos, & Frère, 2015).

3 Dual Task Paradigm

3.1 Application of Dual Task Paradigm

Dual task paradigms have become common tools to investigate the interactions between cognition and the control of posture and gait (Kelly, Janke, & Shumway-Cook, 2010). A dual task paradigm was carried out to compare attentional resources used for gait control in typically developing children of different ages (Boonyong, Siu, van Donkelaar, Chou, & Woollacott, 2012). Results showed that as children matured, they showed improved postural control during gait under dual-task conditions. Thus, the level of complexity of cognitive task in dual-task conditions could be used as an assessment for identifying the progress of cognition development of people in different age groups. Research showed performances in a dual task of texting while walking in the laboratory and in a real-world environment do not differ significantly (Plummer, Apple, Dowd, & Keith, 2015). In this research, healthy young adults were able to prioritize their attention based on the instructions between two tasks. This study indicated that results of research on dual tasks could be generalized to a real-world situation and further application. For patients after stroke, dual task experiments were able to assess the outcome of training program in rehabilitation post disease (van Ooijen et al., 2015).

Improved performance in cognitive tasks of the patients indicated less attentional demands required for motor tasks. The increased success rate of making gait adjustment prove the improvement in motor tasks.

Dual task paradigms could also be used for training a new motor task such as balance training including tandem standing and walking with reduced base of support (Silsupadol et al., 2009). In the study of Silsupadol et al, the training group that received instructions to focus on postural task performance in half of the training trials while focusing on cognitive tasks in the other half of the trials showed the best efficiency in training of both postural task and cognitive task. This training with variable-priority is more effective in improving balance and cognitive performance compared with the other two groups who did only single-task training or training with fixed-priority, in which subjects focused on cognitive tasks 100% of the time.

3.2 Walking tasks in Dual Task Paradigm

Various walking environments like stepping over obstacles, narrow-based walking and walking at a faster pace all could happen in daily life, which makes it clinically meaningful to include different walking tasks in dual task research. The complexity of walking tasks may have effects on attentional load of cognitive tasks as well as the gait control itself. Beurskens et al (Beurskens & Bock, 2013)studied the influence of different walking conditions on dual-task performances and the results showed both young and older subjects had reduced walking speed and increased temporal and spatial variability while walking on a narrow path or over obstacles. Moreover, older subjects were more affected compared to young subjects. “Stiffening strategy”, which refers to a reduced movement of the center of mass resulting in lower amplitude and higher frequency postural sway and is usually adopted by older adults to accommodate to potential unstable factors for postural control or walking (Young & Mark, 2015). “Stiffening strategy” was observed with increased cognition demands and would affect the capacity to complete other dynamic tasks (Gage, Sleik, Polych, McKenzie, & Brown, 2003). If the walking tasks gets more difficult, such as narrow-base walking, fear of falling or "stiffening strategy" could play a role in allocating attention. Research by Kelly et al (Kelly, Eusterbrock, & Shumway-Cook, 2013) indicated that prioritization in dual-task walking is dynamic and flexible based on the results that walking was prioritized during narrow-based walking while the cognitive task has the prioritization in normal-based walking. Due to the reason mentioned above, narrow path walking test (NPWT) has become a potential evaluation tool for walking instability. NPWT is used to assess one's balance when walking in a narrowed pathway. Based on the results of Gimmon et al (Gimmon, Jacob, Lenoble-Hoskovec, Bu¨ la, & Melzer, 2013), the NPWT is highly reliable, valid and reproducible for older subjects.

Gait speed may have interference with gait attentional load. Walking at a very slow or high spontaneous walking speed which was calculated from previous walking trials may take more attentional load than walking at a speed close to the middle of those two speeds (Nascimbeni, Minchillo, Salatino, Morabito, & Ricci, 2015). Thus, speed choice could affect the results of dual task research.

Moreover, both walking on level surface and on treadmill are widely studied in dual task research. Research by Riley et al (Riley, Paolini, Croce, Paylo, & Kerrigan, 2007) shows that treadmill gait is quite similar with over ground gait in terms of both kinematics and kinetics, which indicates treadmill-based gait analysis reliable in dual task research.

3.3 Assessment of Dual Task Paradigm

Parameters that are calculated in dual task research include relative dual-task effects (DTE), which refers to percent change in performance in the dual-task condition relative to the single-task condition (Plummer et al., 2015). DTE is a method to measure the change relatively. Dual-task cost (DTC) is another parameter commonly used in research of dual task conditions. It is computed as ([dual task-single task]/single task) ×100% and considered to measure the absolute change (Schwenk, Aieschang, Oster, &

Hauer, 2010). DTC of selected variables could be calculated to evaluate both motor and cognitive performance. Commonly selected variables include speed, stride length and other gait parameters, or secondary task errors. Generally, the lower the DTC is, the better the performance of dual-task condition. Combined DTC is sometimes computed to assess the dual-task performance from a combination of motor and cognitive perspective. The combined DTC was calculated as ([motor DTC+cognitive DTC]/2) (Schwenk et al., 2010).

For walking task, gait speed and stride time are usually measured. Step accuracy is needed for narrow-based walking (Kelly et al., 2010). For cognitive tasks, the most commonly used measurements are response latency and response accuracy.

4 Physical Activity

4.1 Physical Activity

According to the World Health Organization (WHO), the definition of physical activity is “bodily movement produced by skeletal muscles that requires energy expenditure” (World Health Organization, b). Physical activity includes various kinds of activities in working, playing, travelling and housework, etc. Based on the effort needed for an activity or exercise, physical activity could be classified as various levels of intensity. Moderate and vigorous intensity of physical activity are beneficial for people’s health.

The Centers for Disease Control and Prevention (CDC) and the American College of Sports Medicine (ACSM) published a recommendation in 1995 that adults engage in at least 30 minutes of moderate physical activity on most days and preferably on all days (Nelson, Rejeski, Blair, Duncan, & Judge, 2007). In 2007, recommendations for adults aged 65+ years, and adults aged 50-64 years with chronic conditions and certain functional limitations were made specifically focusing on aerobic activity and muscle-strengthening activity (Nelson et al., 2007). Moreover, aerobic and muscle strengthening activities over the minimum recommendation will be more beneficial.

Despite the benefits of physical activity, 1 out of 4 adults globally are not active enough and the number of whom are inactive is even higher for adolescents (World Health Organization, a). Several reasons underlie why people are not physically active enough.

The amount of physical activity varies among people with different ages, races and genders. A cohort study in the UK done by Metcalf et al found that there is a trend for decreasing amount of physical activity among adolescents (starting from 9 to 15 years) (Metcalf, Hosking, Jeffery, Henley, & Wilkin, 2015). The decreased of physical activity happens in both in-school and out-of-school settings and is related to the effects of puberty on different sexes and ages of participants.

Lack of accessibility to exercise equipment and facility, lack of opportunities for activity (Humpel, Owen, & Leslie, 2022), as well as the perception of being overweight or obese (Ball, Crawford, & Owen, 2000) contribute to environmental factors of barriers to physical activity.

4.1.1 Regular Physical Activity

Healthy People 2010 objective indicated that at least 30 minutes a day of moderate-intensity activity on 5 or more days a week, or at least 20 minutes a day of vigorous-intensity activity on 3 or more days a week, or both is regularly physically active (Healthy people 2010 operational definition.2010).

4.2 Effects of physical activity on health

According to CDC, regular physical activity has positive effects on multiple aspects of people's physical health. Regular physical activity reduces risk of cardiovascular disease, Type 2 diabetes and other metabolic syndrome, as well as some types of cancer (Physical Activity and Health 2015,).

In addition, physical activity would benefit people's mental health and mood. According to Wu PL et al (Wu et al., 2017), physical activity also improved scores of the Beck Depression Inventory among patients with Parkinson's disease. Supervised aerobic-based activity is shown to be effective for adolescents and young adults with depression (Bailey, Hetrick, & Rosenbaum, 2017). A cohort experiment conducted by Harvey et al (Havey et al., 2018) indicates regular exercises has protective effect from depression and even low intensity of physical activity provides certain protection.

4.3 Effects of physical activity on gait

Physical activity is known to be beneficial for muscle strengthening and slowing loss of bone density (Physical Activity and Health 2015,). It means physical activity makes people stronger in general and in turn gait and balance would also benefit from physical activity. In a cohort study among older participants (mean=82.1 years old) by Dawe et al (Dawe et al., 2017), total daily physical activity is related to certain tasks for walking, sit-to-stand transitions, and 180-degree turn. These tasks are important part of outcome measurement tools for assessing balance and gait for fall risk, such as 5 time sit-to-stand, the Timed Up and Go (the TUG), etc.

4.4 Physical Activity Assessment

Various assessment methods of physical activity are available and are adopted in different research. The FITT principle is commonly being used in prescription of physical activity by health providers such as physical therapists. There are four components to the FITT principle: Frequency, Intensity, Time and Type. Frequency is how often an individual is involved in physical activity. Intensity is the level of exertion that individual experiences in physical activity. Time is the length of time that an individual spends on the physical activity. And in the end, Type refers to several types of physical activity, such as aerobic exercise, strengthening exercise and more specific types of sports under those subtypes (Oberg, 2007).

Physical activity could be assessed using frequency, intensity, time and type of FITT principle. Most commonly used assessment methods fall into two categories: objective measures and subjective measures.

4.4.1 Objective measures

Objective techniques like pedometers, accelerometers and heart rate monitoring can be used to assess physical activity (Vanhees et al., 2005). Pedometers count and record steps in daily living (Ainsworth & Buchholz, 2017). They have gained in popularity in recent years as brands of pedometers appear on the market such as FitBit, Jawbone, etc. The technique becoming a function integrated in smartphones also makes this method very convenient to adopt. While pedometers are not accurate at measuring physical activity like swimming, cycling, accelerometers become very important since they monitor movement in different planes.

4.4.2 Subjective measures

Subjective methods like questionnaires or surveys are relatively easily conducted and inexpensive (Vanhees et al., 2005). Questionnaires and surveys of different lengths and including several types of items are being used based on the research content. Records and logs are sometimes encouraged so that answers to questionnaires and surveys are more reliable (Ainsworth & Buchholz, 2017).

Dyrstad et al (Dyrstad, Hansen, Holme, & Anderssen, 2014) showed that there is a difference when comparing results of physical activity assessment between self-report method and accelerometers. Participants tend to report more active time and less sedentary time using self-report. The difference is associated with sex, age and education.

4.4.3 Questionnaire of Baecke et al

Baecke et al developed a short-self-administered questionnaire to assess physical activity in daily life (Baecke, Burema, & Frijter, 1982). The questionnaire covers occupation, sport and leisure time activities excluding sport. Information such as level of education, subjective experience of workload and habitual physical activity is also collected to adjust the results. In this research, the short questionnaire is used to assess subjects' physical activity. In the questionnaire, questions cover the "frequency" component of FITT principle by asking how many hours the subject is spending on specific sport during a certain time such as a week or a year. There are specific questions on time and intensity of doing certain sports. Type of FITT principle is assessed by division of 3 levels of sports, which would be specified in Chapter 2.

5 Conclusion

Regular physical activity plays a positive role on improving people's health in many ways, including enhancing, maintaining and delaying deterioration of cognitive function. As a critical component of cognitive function, however, the effects of regular physical activity on attention allocation is not much studied yet. Dual task paradigms including walking tasks and cognitive tasks are common tools used to assess attention allocation. In the current study, effects of regular physical activity on ability to allocate attention of young healthy subjects is investigated using normal-based and narrow-based walking combined with secondary cognitive tasks. We hypothesized that regular physical activity would improve dual task performance in young healthy subjects (aim1). We also hypothesized that regular physical activity would enhance ability to allocate attention (aim2).

CHAPTER 2: METHODS

1 Participants

This study was carried out in accordance with relevant guidelines and regulations of the University of Nebraska Medical Center Institutional Review Board. In addition, all experimental protocols were approved by the University of Nebraska Medical Center Institutional Review Board (IRB Protocol # 304-14-EP). All subjects signed informed consent documents before experiments began.

Subjects were recruited by emails sent out to students at the University of Nebraska Medical Center or flyers posted in school library and university offices. Subjects who participated were between 19 to 35 years old, able to understand English and follow simple instructions. Subjects were excluded from the study if they had a history of visual or vestibular deficits or any neurological disorders that would debilitate their ability to complete a secondary task. Every subject participated in a one-time experiment which was 2-hours long in total. Prior to the experiment, subjects were asked to fill in information including their age, height and weight. Specific parameters were measured, including leg length (Anterior superior iliac spine ASIS-medial malleolus), width of knee, width of ankle, width of foot, etc.

Experimental materials: An infra-red eight-camera Qualisys motion capture system (Qualisys AB, Gothenburg, Sweden) was used to collect three-dimensional kinematic data, with Qualisys Tracker Manager software (Qualisys AB) at 100Hz. Spherical retro-reflective markers were placed on bony landmarks including sacrum, ASIS, greater trochanter of the femur, lateral side of thigh, lateral epicondyle of the femur, shin, lateral malleoli, second metatarsophalangeal joint, fifth tarsometatarsal joint, and heel of bilateral lower extremities, so that motions of subjects could be captured by cameras. The heel strike was defined at the same instant as the horizontal heel displacement in anteroposterior direction reaches a maximum. The stride length and stride time were determined by consecutive heel strikes. A stride time was defined as the time between two heel strikes of the same foot. In addition, a stride length was defined as the horizontal anteroposterior distance of heel marker traveling between two heel strikes of the same foot. Step width was defined as the mediolateral distance between heel markers at successive heel strikes of different feet. Heel elevation was defined as the maximum height of heel mark trajectory in each gait cycle. In addition, both stride length and heel elevation were normalized by the leg length. Also, step width was normalized by the distance between two lateral knee markers.

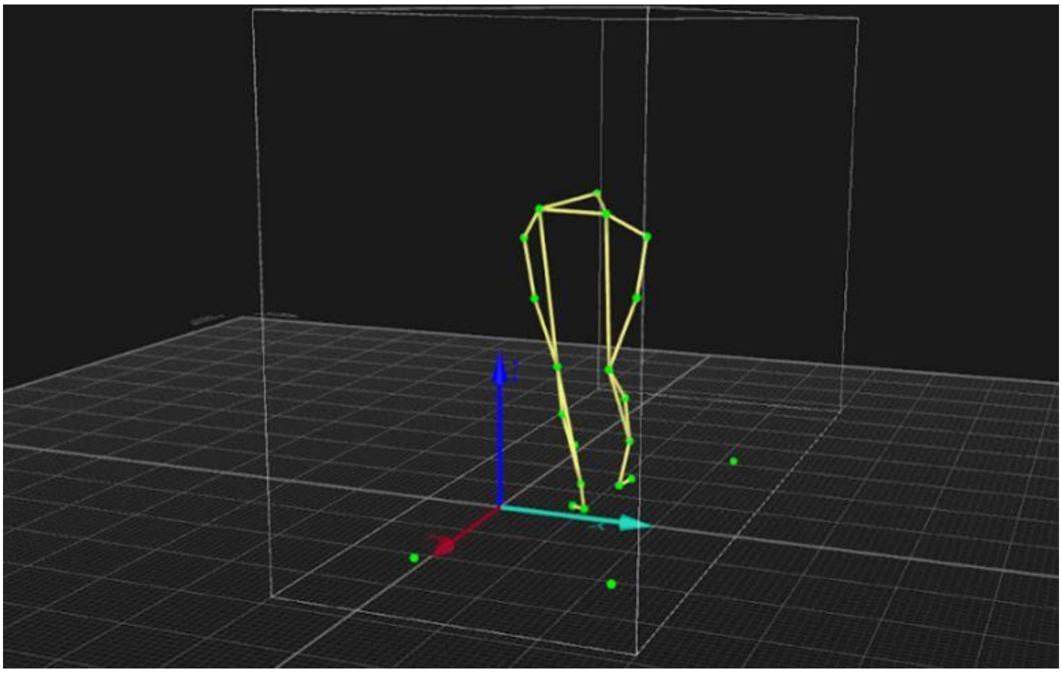


Figure 1. Model built in Qualisys Tracker Manager Software using information collected from the retro-reflective markers.

2 A physical activity questionnaire

All subjects completed a short questionnaire with questions about their daily physical activity level. The short questionnaire by Baecke et al (Baecke et al., 1982) was used in the research to assess the physical activity level of subjects (Baecke Physical Activity Questionnaire, BPAQ). The 16-item questionnaire includes 3 components: occupation, sport and leisure time activities excluding sports.

There are three levels of occupational physical activity according to Baecke et al (Baecke et al., 1982): low level for occupations such as clerical work, driving, shop keeping, teaching, studying, housework, medical practice and all other occupations with a university education; middle level such as factory work, plumbing, carpentry and farming; high level such as dock work, construction work and sport. Besides occupational physical activity, sports are also divided into 3 levels of physical activity based on average energy expenditure: low level for sports such as billiards, sailing, bowling, and golf; middle level such as badminton, cycling, dancing, swimming and tennis; high level such as boxing, basketball, football, rugby and rowing.

Except for types of occupation and sports, answers to all the other items were pre-coded on five-point scale. Other items include questions about intensity of physical activity during work, frequency and time spent on the sports, leisure time activity habit such as watching TV, walk and cycling, etc. Simple sport-score could be calculated based on the answer to Item 9 in the questionnaire. Moreover, indices of physical activity including work index, sport index and leisure-time index could also be calculated respectively using the equations provided with the questionnaire. A total index would be the sum of three indices.

Table 1 Summary of the contents of the Baecke Physical Activity Questionnaire

Occupation	Low: clerical work, driving, teaching, studying, etc Middle: factory work, plumbing, farming, etc High: dock work, construction, sport, etc
Sports	Low: billiards, sailing, bowling, golf, etc Middle: badminton, cycling, dancing, swimming, tennis, etc High: boxing, basketball, football, rugby, rowing, etc
Leisure time activities	Watching TV Cycling, walking

In this research, the total index of each subject was selected as the final score to divide the subjects into two groups: physically active and physically inactive (Florindo &

Latorre, 2003; Ono et al., 2007). After the first ten subjects were recruited in the research, the information gathered from the questionnaire was analyzed. The cut-off point between physically active group and inactive group was selected as total index of 8.3 based on the results from the first ten questionnaire filled. The following potential subjects completed the questionnaire first and subjects whose questionnaire index fell in either category was informed to complete the experiment. In this way, there were 10 subjects in each group by the end of the research.

3 Secondary tasks

The secondary task chosen in this experiment is called the three-letter back recognition test. A secondary task should be challenging enough for participants to complete in a dual task setting (Lajoie, Teasdale, Bard, & Fleury, 1993). The most commonly used secondary tasks include forward or backward calculation by specific numbers (Schwenk et al., 2010), Stroop task (Siu, Catena, Chou, van Donkelaar, & Woollacott, 2008), etc. For healthy and young subject, however, those secondary tasks could be easy and not challenging enough, thus we predicted they would not require enough attention from the subjects so that the results would possibly be biased. In the three-letter back recognition test, subjects hear 36 letters of random order in a 3-minute trial (1 letter every 5 seconds). Subject was asked to verbally respond “Yes” or “No” to every letter they heard, based on if the letter was the same as the letter 3 steps before or not. This test would require subjects to use short-term memory and pay much attention to what they hear as well as their interactions about the answers. The letters and audio recordings were arranged randomly to decrease bias. Subjects completed this task as two 3-minute audio trials while sitting in chair at the beginning of the data collection session to get familiar with the tasks and decrease the effect of a learning curve (Merriam-Webster Online,).

An example of the secondary task is shown in the table below. The first row with audio would be letters subjects hear and they should respond verbally by saying “Yes” or

“No” as Row Two shows. If the answer provided by a subject does not correspond with the answer predetermined, one error is indicated. The number of errors of each trial is counted and recorded for further data analysis. In this example, the 6th letter the subject hears would be C, and since it is the same letter as the third letter that they heard, 3 steps ahead of the 6th letter, it would be correct to respond with “Yes”.

Table 2. An example of secondary task: three-letter back recognition test.

Audio	A	F	C	M	H	C	L	S	D	L	M	…
Response by subject				No	No	Yes	No	No	No	Yes	No	…

4 Walking Task

Subjects completed two kinds of walking tasks on treadmill, normal-based walking and narrow-based walking. Prior to data collection each subject need to determine their preferred walking speed. Subjects stood on the side of the treadmill without touching the belts. Subsequently, treadmill belt velocity was incremented from 0 to 0.8 m/s. Then the subjects were asked to step onto the treadmill while holding onto the handrail. After the subjects started walking on the treadmill, experimenters asked the subject to evaluate the speed as follows: “Do you feel comfortable with this walking speed like you are walking around the grocery store?” The treadmill velocity was increased or decreased, with subject directions. Once a comfortable walking velocity was determined, the subject walked continuously for 3 minutes to become familiar with the treadmill walking. Normal-based walking referred to walking using subjects’ preferred walking speed and preferred step width. The width of the walking belt of the treadmill used in this research is 50 centimeters. For narrow-based walking, subjects are asked to walk while trying to place feet between two white lines drawn on the treadmill using the same speed. The width of the narrow-based walking is chosen as half of width of normal-based walking (the width of treadmill). Each condition lasted for 3 minutes. Four reflective markers were also placed on four corners of the treadmill to provide information of relative position of the treadmill in the experiment space under the camera system. Subjects completed 2 baseline walking tasks at the beginning for both normal-based and narrow-based walking to get adjusted to walking on the treadmill. In addition, they completed 2 baseline walking tasks in the end of the experiment to improve the validity and reliability of baseline walking trial results.

Figure 2. The experiment environment of narrow-based walking between two white lines on the treadmill.

5 Attention Allocation Condition

During the experiment, subjects were given different instructions for attention allocation condition. They were instructed to place attention allocation on walking and secondary tasks based on certain percentages, eg. W0A100, W50A50, W100A0, where letter “W” and letter “A” represents walking and auditory tasks respectively. Among the instructions, W0A100 means 0% of attention was paid on walking task and 100% of attention was placed on secondary task which indicates trying to complete the secondary task as accurate as possible. W100A0 means 100% of attention was paid on walking task to try to walk as stable and safe as possible, while 0% of attention was placed on secondary task. Here the number of 0 and 100% is a relative amount to each other, which does not necessarily mean no attention for walking or secondary task at all. Subjects still need to complete the respective task for which 0% of attention was given based on instruction, just less amount of attention will be used. Supplemental instructions included “In this trial, pay more attention on walking/secondary task”, or “In this trial, try to pay the same amount of attention on both walking and secondary task”. W50A50 indicates subjects are asked to pay the same amount of attention to both tasks. Subjects completed 2 trials for same condition to increase the reliability of results and single task trials both at the beginning and in the end of the experiment to provide the result of baseline performance.

Following is an example of the process of the experiment shown in the table below. In the experiment, order of dual task trials was designed to be varied between subjects to decrease the effect of a learning curve of both walking task and secondary task.

Table 3. Single task and dual task conditions conducted in the experiment. At Row 3, “Normal” and “Narrow” indicate the width of walking task. “W” and “A” represent walking and auditory task in the dual task condition respectively.

1	Baseline-secondary task	Seated Auditory Three-back Test (trial1,2)	
2	Baseline-walking	Normal-based Walking	Narrow-based Walking

3	Dual task trials (trial1,2)	Normal W0A100	Narrow W50A50	Normal W100A0	Narrow W0A100	Normal W50A50	Narrow W100A0
4	Baseline-walking	Normal-based walking			Narrow-based walking		
5	Baseline-secondary task	Seated Auditory Three-back Test					

6 Dual Task Effect

As it is stated in Chapter One, relative dual-task effects (DTE) and dual-task cost (DTC) both could be utilized to assess dual task performance and represent the ability to allocate attention during dual-task situations (Schwenk et al., 2010). Besides, both parameters above are meaningful to compare dual task and single task.

While in this research, there are three different conditions of dual tasks designed with different amount of attention allocation divided to motor and cognitive tasks, which indicates the use of modified attention allocation index (mAAI) to calculate the effects to combine all the conditions together and assess the performance comprehensively (Kelly et al., 2010). Values of mAAI would indicate shift of performance towards the instructed taskydg5fyg. We assumed that a higher correlation coefficient indicated higher capability to shift attention because of the correlations of less errors. The mAAI selected in this research for walking variables is computed as follows:

mAAI=[(P-G)-(S-G)]/(N-G)

Where P, S and N represent conditions with 100-0%, 0-100% and 50-50% attention on walking to secondary task respectively, G represents single walking task.

Table 4. Percentage of attention allocated on walking task and secondary task in different dual task conditions.

Attention Instructions (%)	P	N	S	G
Walking Task	100	50	0	-
Secondary Task	0	50	100	-

7 Statistical Analysis

We wanted to understand the effect of attention allocation, the effect of treadmill width of walking tasks, and the effect of regular physical activity. Therefore, a three-way repeated ANOVA measure was conducted for mean value of each dependent variable in the 3-minute trials: stride length, stride time, step width, and heel elevation. If there was a significant interaction, a Tukey post hoc test was used for pair-comparisons.

For the second part, for modified attention allocation index, a Pearson Correlation was used to measure the capability to follow instruction and allocate attention (the relationship between mAAI of each gait parameter and mAAI of errors made for each trial). The scatter plot and trendline was drawn using above mAAI of each subject. X-axis would be the mAAI of specific gait parameter and Y-axis would be mAAI of errors reported for the subject. The correlation coefficient was calculated. A higher correlation coefficient indicates better performance to shift attention and adapt the challenge environment. A positive correlation coefficient indicates the subjects can follow instructions to shift their attention between walking task and cognitive task and a negative correlation means the subjects are not following instructions in the specific condition.

CHAPTER 3: RESULTS

1 Patient characteristics

From July 2015 to Jan 2016, 21 young, healthy subjects (6 males and 15 females) in total were recruited in the research. All the subjects completed physical activity questionnaire and dual-task experiment. Data of 20 subjects were used for analysis based on the results of physical activity questionnaire. Subjects were divided into two groups by total score of the questionnaire. In the final data analysis, there are 10 subjects in physically active group and 10 in physically inactive group. No health problem or safety incident occurred during the study.

The subjects' average age was 25.5 ±3.7 years and there was no significant difference of age between two groups($p=0.64$). There are 7 females of ten subjects in each group. There are no significant differences of the stature data such as weight, height and leg length, etc between the two groups. Meanwhile, the preferred walking speed selected by subject between two groups are not significantly different from each other ($p=0.48$). The comparison of demographic data of both groups were listed in Table 4.

Both the experimenter and subjects were blinded and did not know which group the specific subject fell into during the experiment. The results of physical activity questionnaire were calculated and compared using independent samples t-test. Based on Table 4, the active group had a significant higher sport index score than the inactive group ($p<0.001$). There was a narrowly missed significance of occupation index between two groups (p=0.051), in which the active group showed a higher score. For leisure-time index however, there was no significant difference between two groups (p=0.31).

Table 5. Demographic data and clinical characteristics of participants

Characteristics	Active group (n=10)	Inactive group (n=10)	P value
Female, n (%)	7(70%)	7(70%)	1
Age, y, mean (SD)	25.1(2.6)	25.9 (4.7)	0.64
Height, cm (SD)	174.0 (12.8)	168.1 (6.4)	0.21
Weight, kg (SD)	72.2 (15.6)	64.1 (10.6)	0.19
True leg length, cm, mean (SD)	88.6 (8.7)	85.2 (3.2)	0.28
Width of knee, cm, mean (SD)	11.3(0.8)	10.5 (1.0)	0.051
Walking speed, mph,mean (SD)	1.74(0.46)	1.61 (0.33)	0.48
Occupation index, score, mean (SD)	2.24 (0.61)	1.78 (0.26)	0.051
Sport index, score, mean (SD)	4.16 (0.92)	2.42 (0.81)	0.000291
Leisure-time index, score, mean (SD)	3.03 (0.78)	2.73 (0.46)	0.31
Total score, score, mean (SD)	9.42 (0.83)	6.92 (0.93)	0.000184

2 Secondary task performances

Errors recorded in each trial in the experiment were analyzed as assessment of secondary/cognitive task performance. Three-way ANOVA was conducted to analyze the effects of physical activity level, dual-task conditions and different walking width on the errors from the three-letter back recognition tasks. However, there were no interactions found between the three parameters above, or either two of the parameters. Dual-task condition is shown to have significant effect on subjects' secondary task performance

(F=5.54, p=0.001). Among the three dual task conditions, including W0A100, W50A50 and W100A0, combined with the single task, errors recorded was most of all from the condition W100A0, where subjects were asked to place all of the attention on walking while still need to complete the secondary task. However, there was no significant effect on secondary task error numbers shown of physical activity level (p=0.815) or walking width on the treadmill (p=0.417).

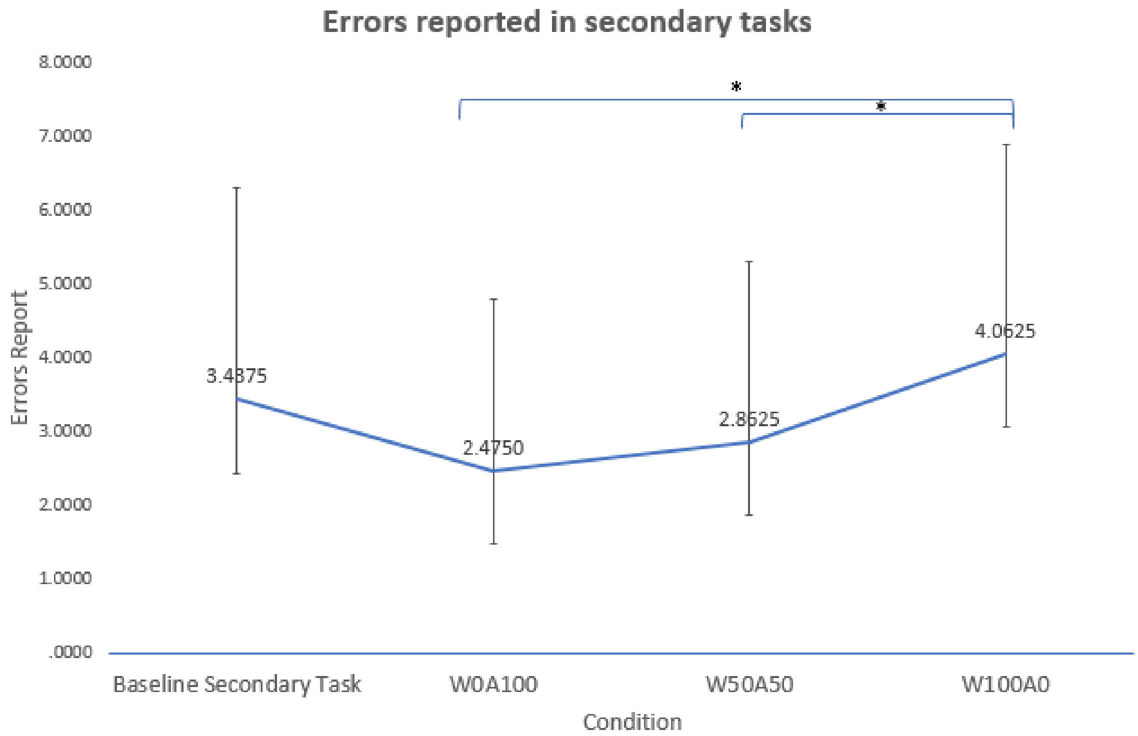


Figure 3. The post hoc indicates that in condition W100A0, subjects demonstrated the most errors compared with other conditions. The mean errors in condition W50A50 was in the middle of other two dual-task conditions. * represents p < 0.05.

Result 1 The effect of regular physical activity, treadmill width, and attention allocation

1. The effect of regular physical activity

A significant main effect of regular physical activity was found in stride length ($F_{1,18}$ = 4.40, *p* = 0.05), stride time ($F_{1,18}$ = 7.82, *p* = 0.012), step width ($F_{1,18}$ = 5.465, *p* =

0.03) and heel elevation ($F_{1,18}$ = 6.53, p = 0.02). The group in which subject did regular physical activities showed increased stride length, reduced stride time, increased step width, and increased heel elevation compared with the group of subjects who were relatively physically inactive.

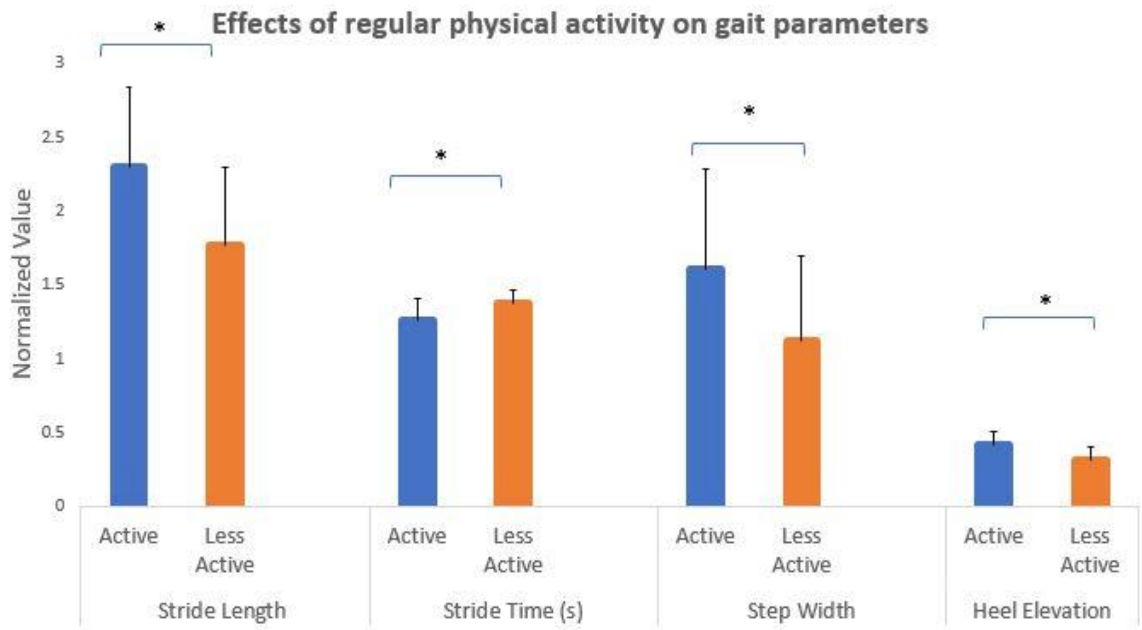


Figure 4. The marginal means of the effect of regular activity in stride length, stride time, step width, and heel elevation. The stride length and heel elevation were normalized by leg length. The step width was normalized by the length between two lateral knee markers. The error bars here represent standard deviation. * represents p < 0.05.

2. The effect of walking width on treadmill

A significant main effect of treadmill width was found in stride time ($F_{1,18}$ = 10.482, p = 0.005), in step width ($F_{1,18}$ = 69.49, p < 0.0001), and in heel elevation ($F_{1,18}$ = 6.51, p = 0.02). Forcing subjects to walk in narrow-based treadmill width increased the stride time, decreased the step width, and increased the heel elevation. In addition, a significant interaction between the effect of walking width on the treadmill and the effect of regular physical activity was found in step width ($F_{1,18}$ = 10.02, p = 0.005).

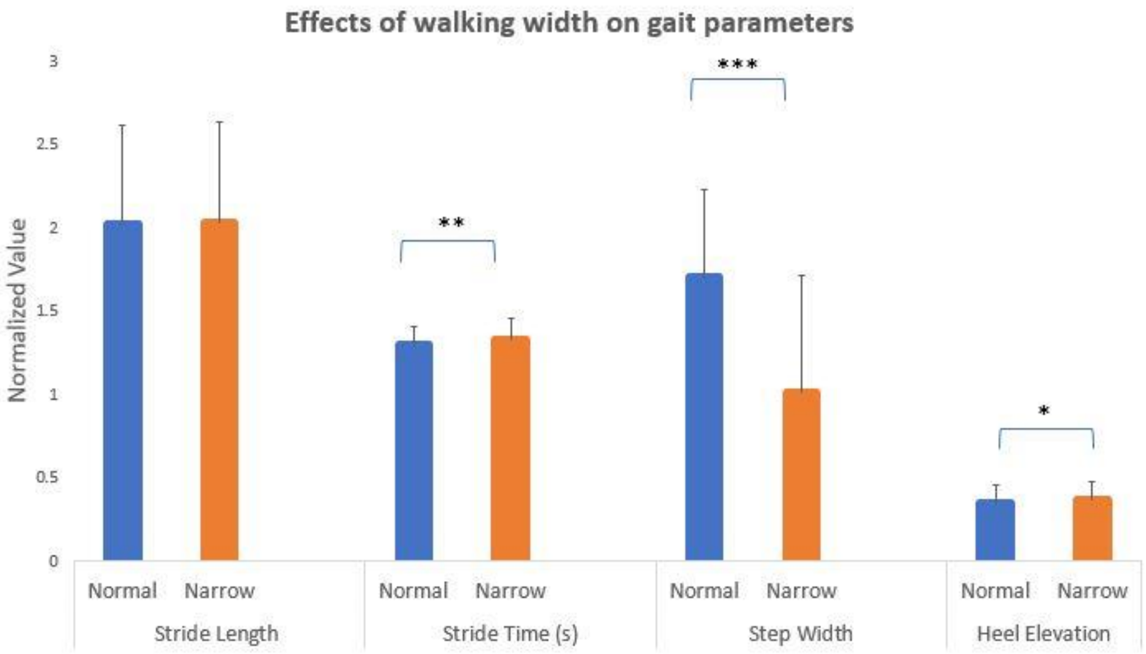


Figure 5. The marginal means of the effect of treadmill width in stride length, stride time, step width and heel elevation. * represents $p < 0.05$; ** represents $p < 0.001$, *** represents $p < 0.0001$.

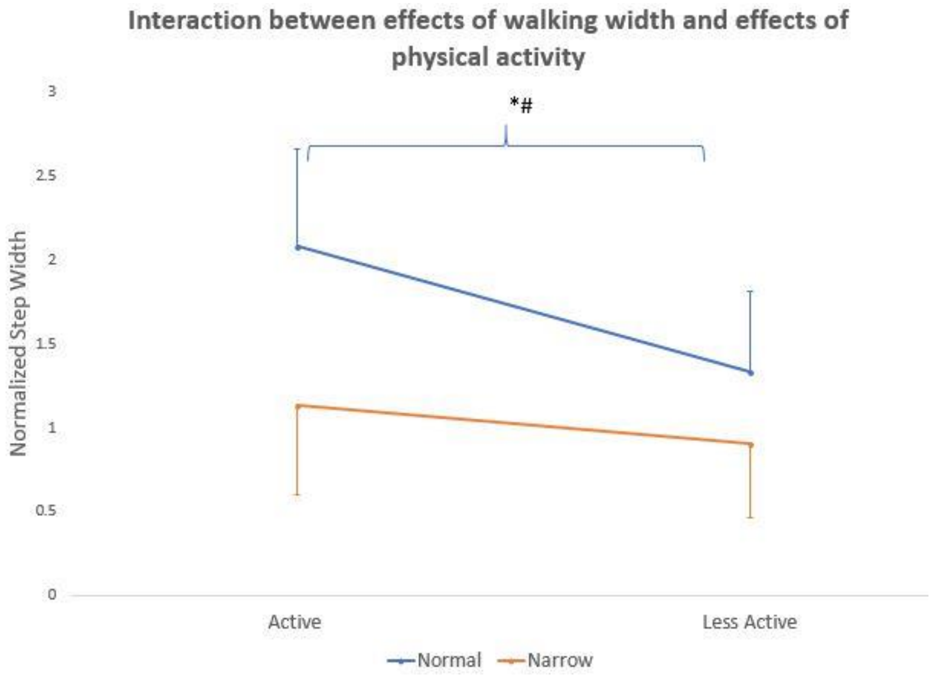


Figure 6. The interaction between the effect of regular activity and the effect of treadmill width. #: significant higher step width in active group than in less active group when walking in narrow-based treadmill. *: significant higher step width in active group than in less active group when walking in normal-based treadmill.

3. The effect of attention allocation condition

A significant main effect on attention allocation was found in heel elevation ($F_{3, 54} = 4.12$, $p = 0.011$). Post hoc indicates that giving any attention allocation task decreased the heel elevation in comparison with baseline walking task. As used in the name of condition, the letter W represents walking tasks and letter A represents secondary task. The number 0, 50 and 100 represent the percentages of attention.

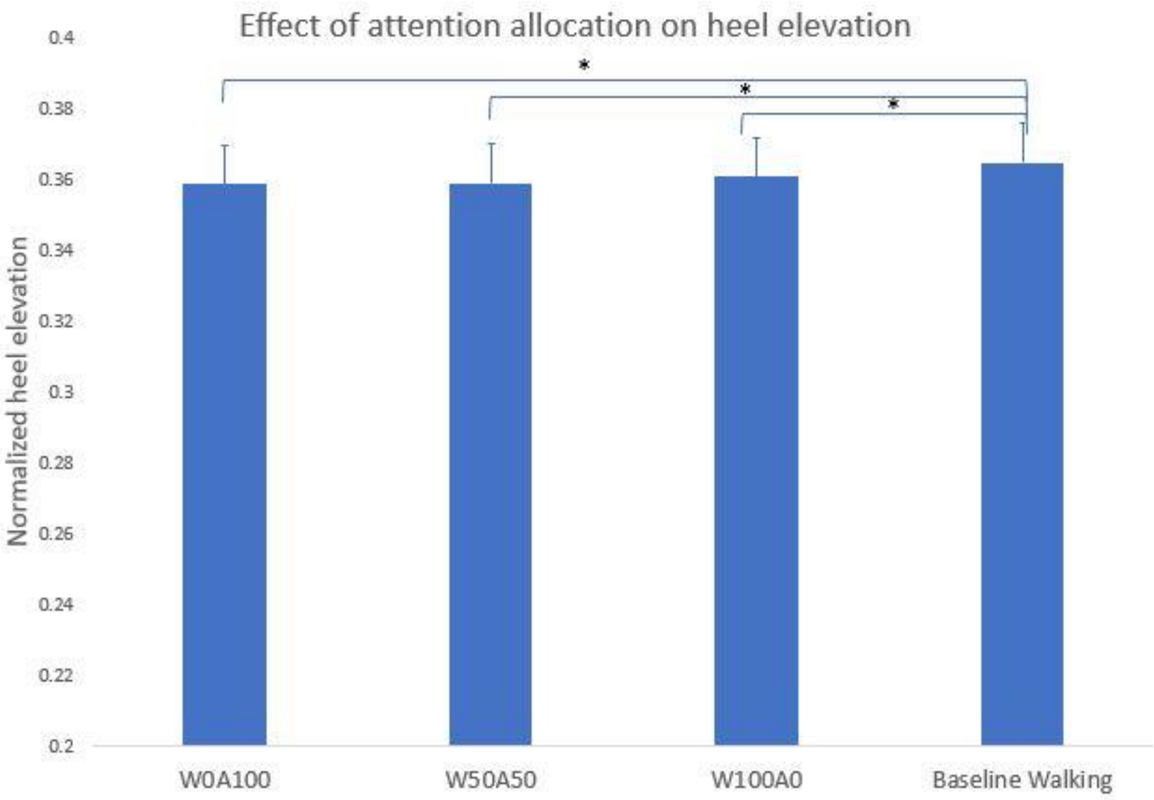


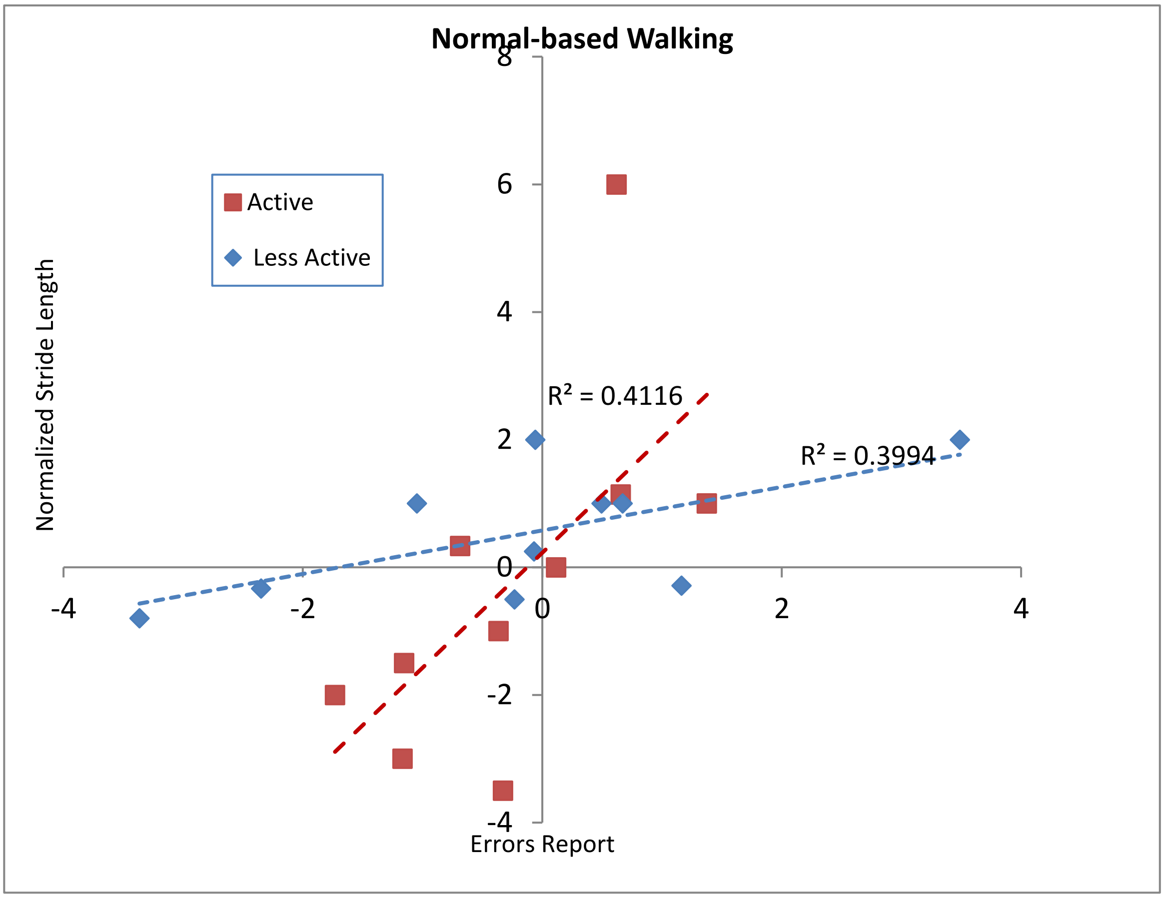
Figure 7. The post hoc indicates that giving any attention allocation task decreased the heel elevation in comparison with normal walking. W: focus on walking on treadmill, A: focus on the dual task. * represents $p < 0.05$.

Result 2 Understanding the attention allocation using modified attention allocation index (mAAI)

1. Stride length

The results indicated that a positive correlation between modified normalized stride length and errors reported in active (R=0.642, p=0.046) and less active groups

(R=0.632, p=0.049) in normal-based walking. However, the results showed that a negative correlation between modified stride length and errors reported in the less active group (R= - 0.479, p=0.162) but a positive correlation in the active group (R=0.756, p=0.011) in narrow-based walking.



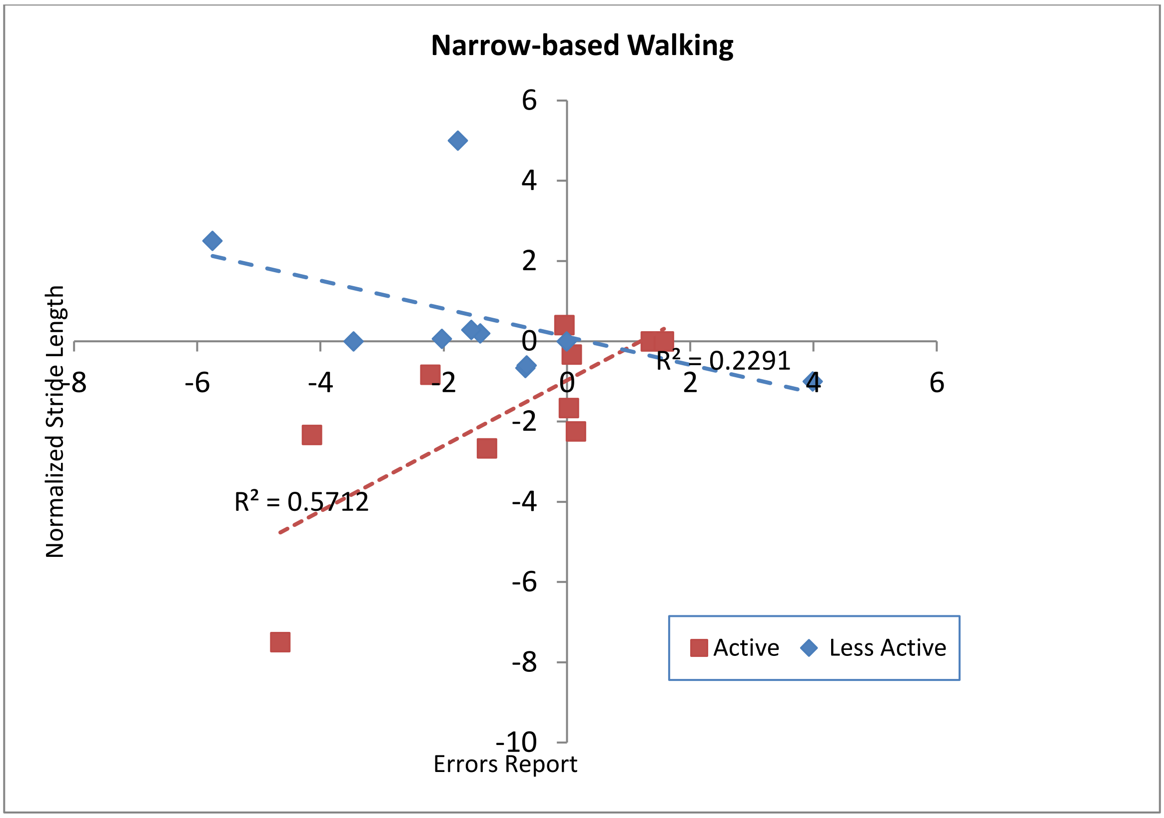
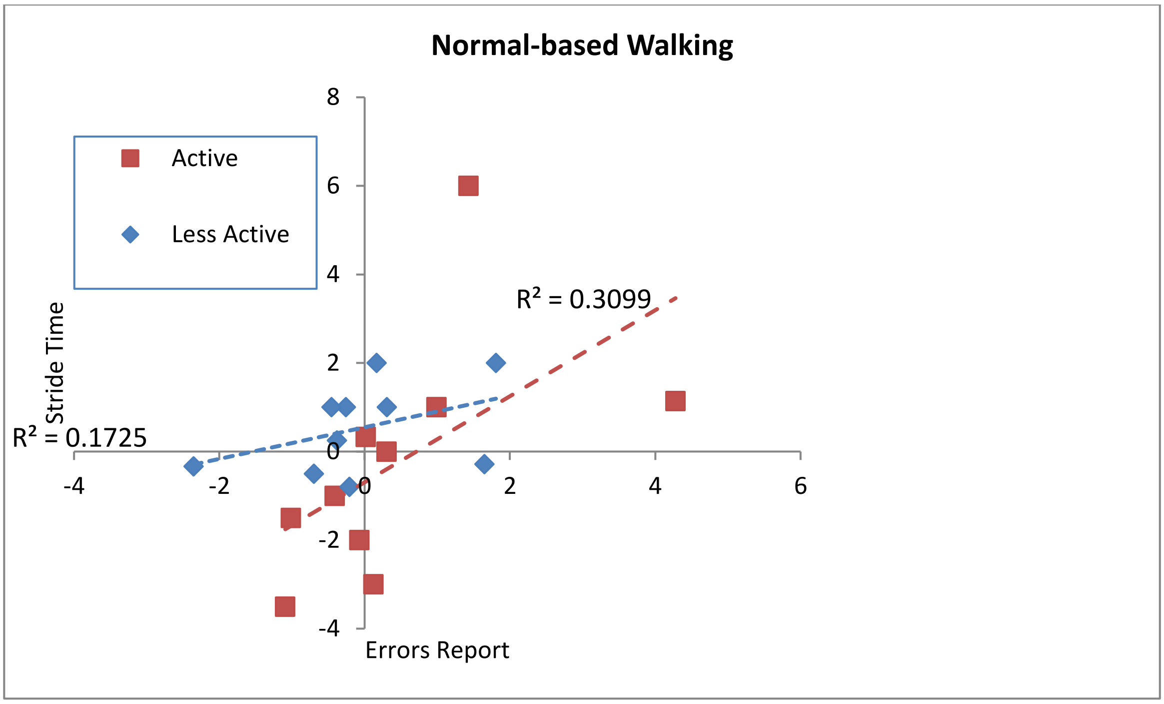


Figure 8. The mAAIs of stride length were shown in normal-based walking and in narrow-based walking.

2. Stride time

The results indicated that a positive correlation between modified stride time and errors reported in both active (R=0.557, p=0.095) and less active groups (R=0.415, p=0.233) when walking normal-based. However, the results showed a negative correlation between modified stride time and errors reported in the less active group (R= - 0.851, p=0.002) but a positive correlation in the active group (R=0.059, p=0.87) when walking narrow-based.



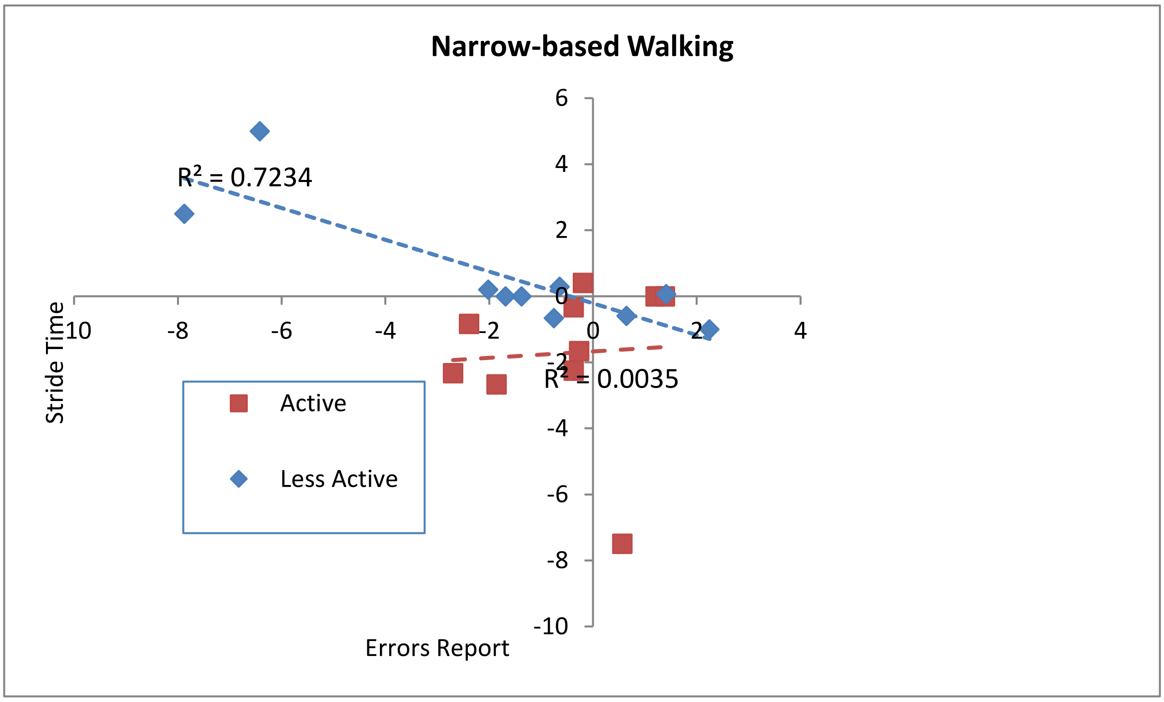
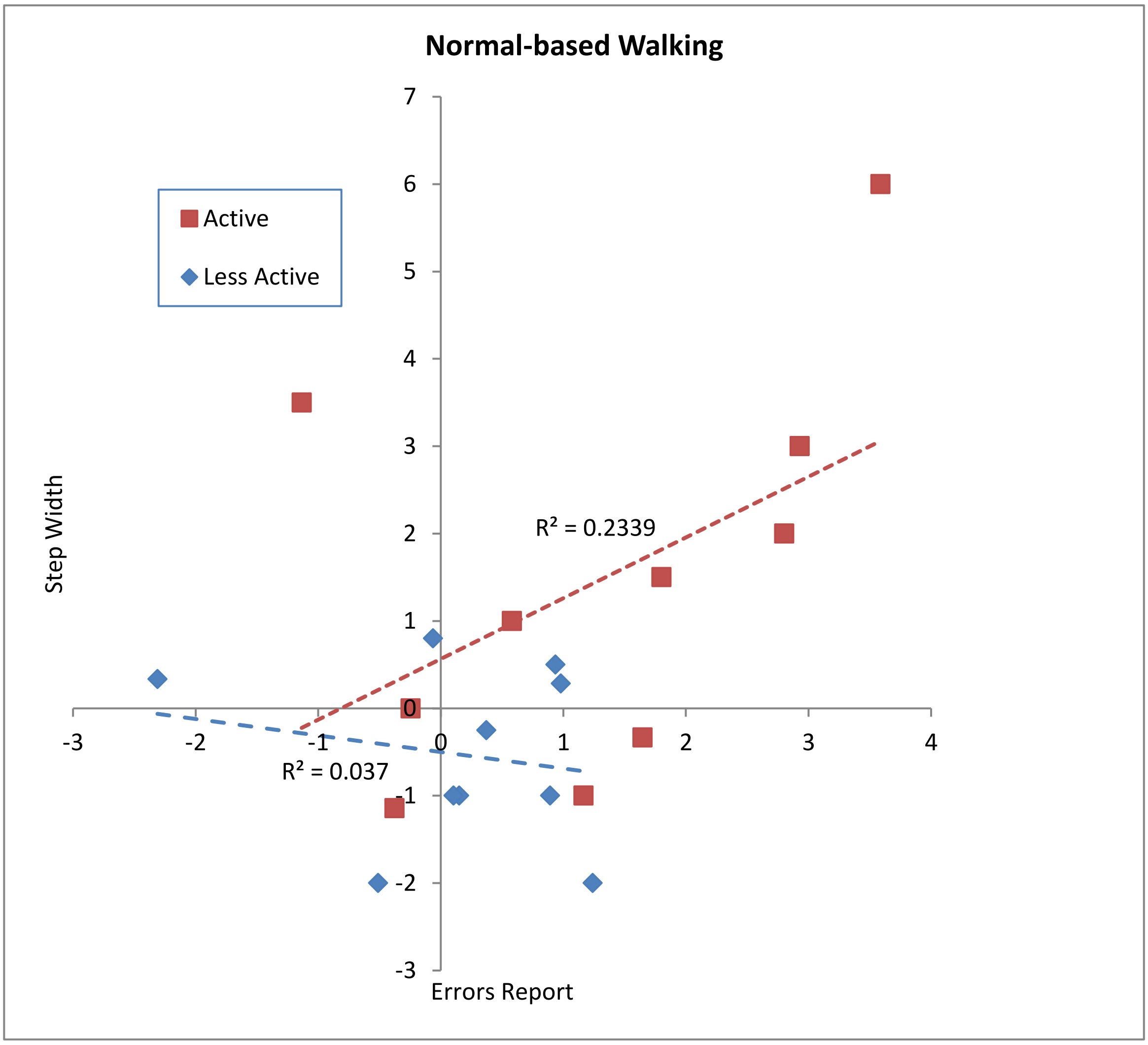


Figure 9. The mAAIs of stride time were shown in normal-based walking and in narrow-based walking.

3. Step Width

The results indicated a positive correlation between modified stride width and errors reported in the active group (R=0.484, p=0.157) but showed a negative correlation in the less active groups (R= - 0.192, p=0.595) when walking on the normal-based treadmill. However, the result indicated that a negative correlation between modified stride width and errors reported in the active group (R= - 0.362, p=0.304) but showed a positive correlation in the less active group (R=0.081, p=0.823) when walking on the narrow-based treadmill, which indicated opposite results for both groups in two walking conditions.



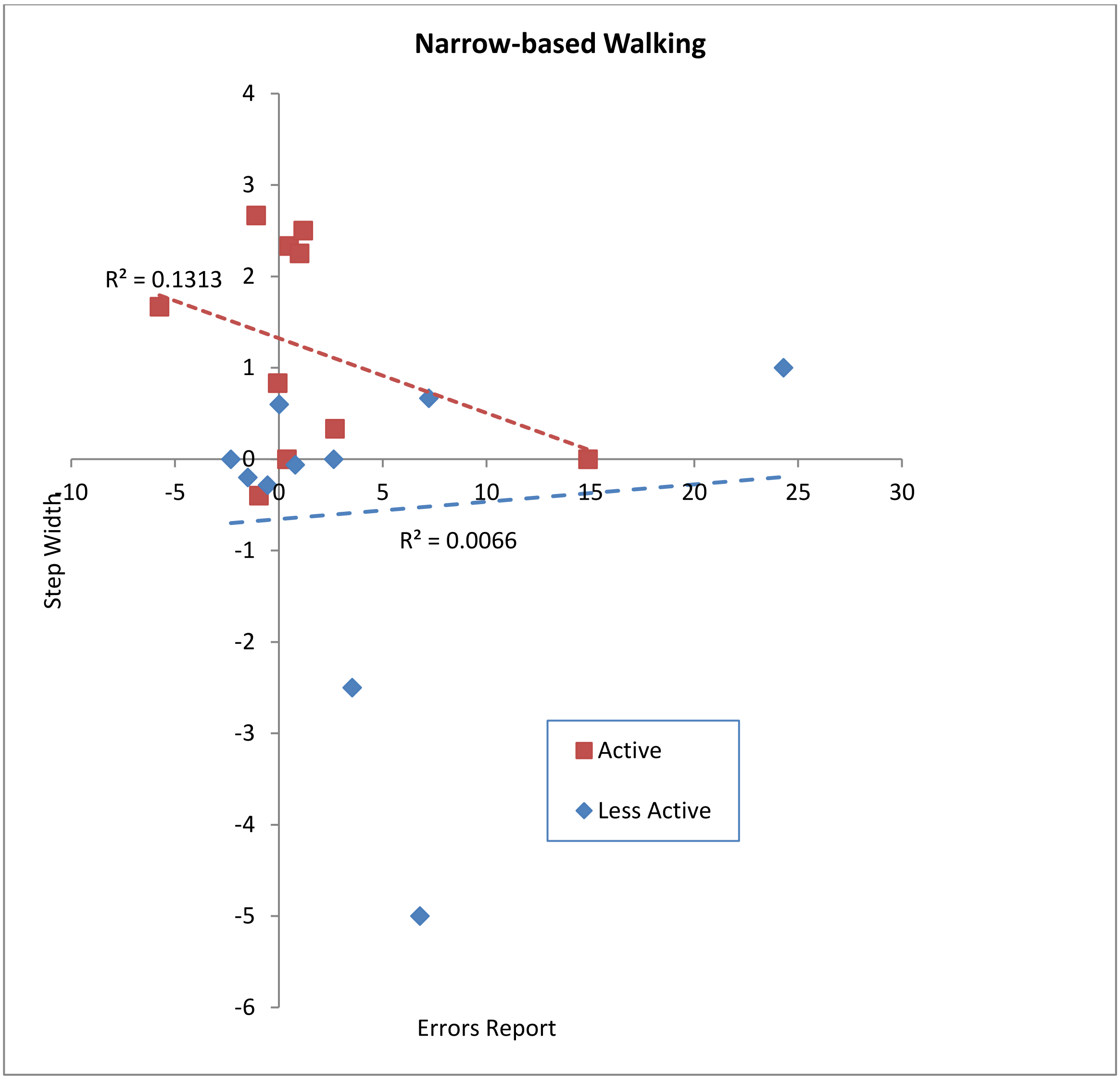
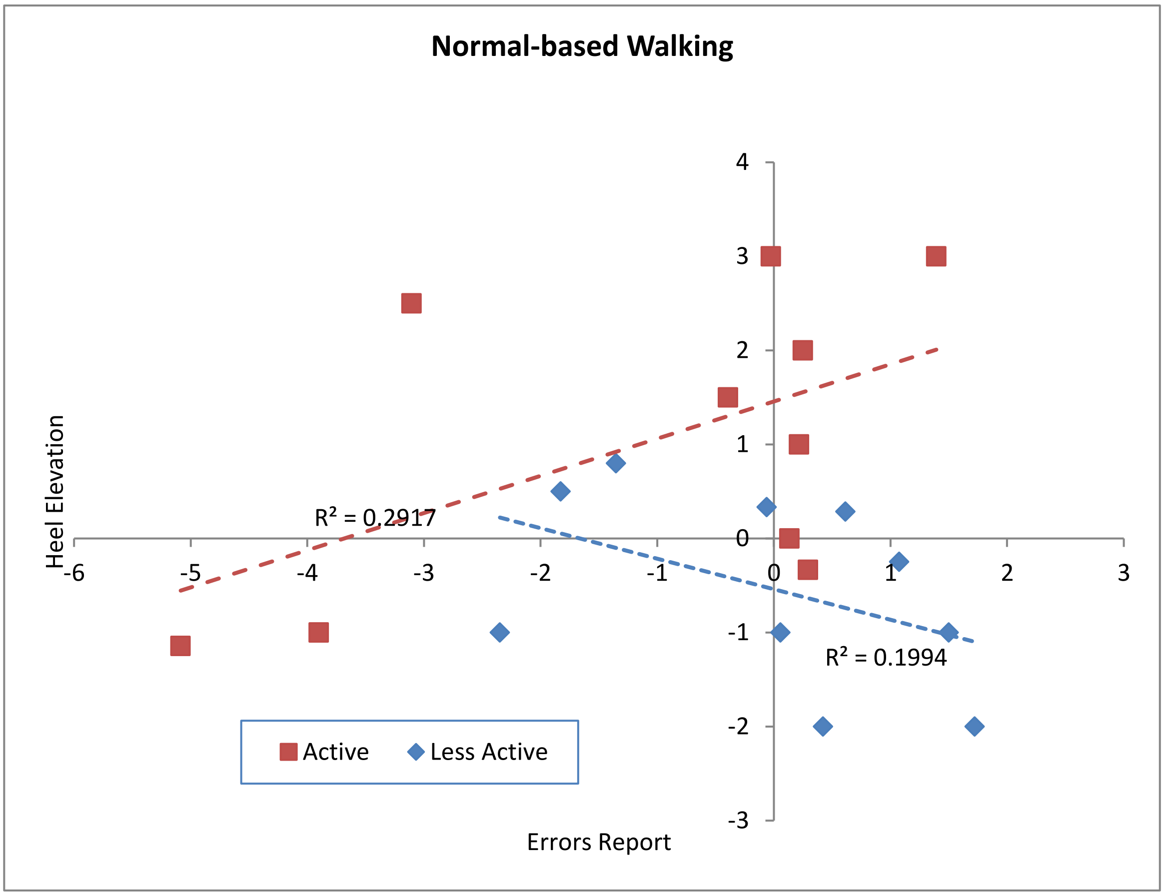


Figure 10. The mAAIs of step width were shown in normal-based walking and in narrow-based walking.

4. Heel elevation

The results indicated a positive correlation between modified heel elevation and errors reported in the active group (R=0.540, p=0.107) but showed a negative correlation in the less active group (R= - 0.447, p=0.195) when walking on the normal-based treadmill. Similarly, the result indicated a positive correlation between modified heel elevation and errors reported in the active group (R=0.320, p=0.367) and showed a positive correlation in less the active group (R=0.116, p=0.750) when walking on the narrow-based treadmill.



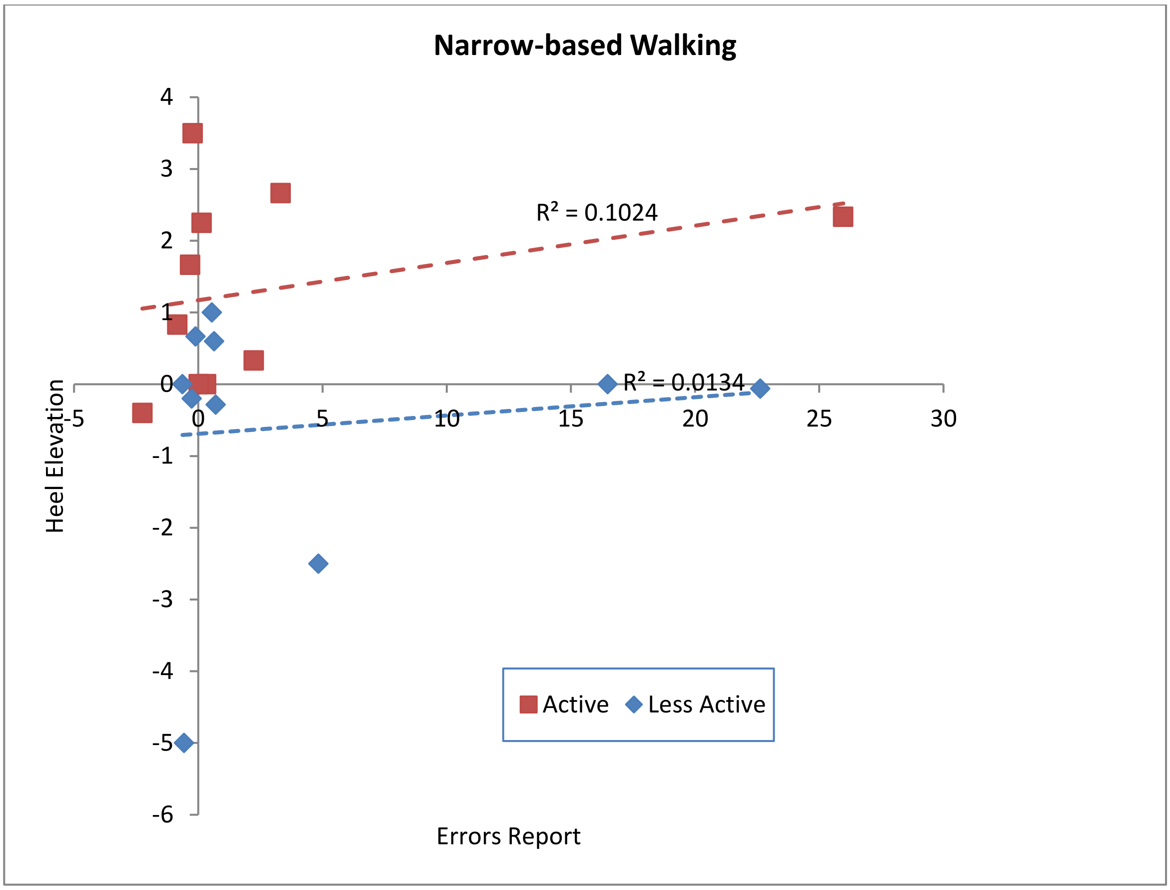


Figure 11. The mAAIs of heel elevation were shown in normal-based walking and in narrow-based walking.

CHAPTER 4: DISCUSSION

This study investigated the influence of daily physical activity on dual task performance in healthy young adults. Instructions to allocate attention to secondary task or walking task at a specific percentage of attention amount had effect on both secondary task and walking task, which indicated the instructions were able to serve to purpose to guide attention allocation on varied tasks. Walking tasks of different difficulty level including normal-based and narrow-based on a treadmill were conducted to examine the attention allocation performance in the experiment.

This study had two major aims. The first aim was to determine to positive effects of routine exercise or daily physical activity on dual task performance across walking trials on different width of the surface. The second aim was to understand whether regular physical activities would enhance the capability of attention allocation when walking on treadmill normal and narrow-based. The results agreed with our hypothesis that regular physical activities indeed improved the gait performance and enhanced the capabilities of attention allocation.

In the research, subjects responded well according to specific instructions of attention allocation amount, showing that less errors of auditory task existed while subjects are paying more attention to the auditory tasks and vice versa. While physical activity and walking width on treadmill is not proved to enhance the performance on auditory task across different attention allocation condition. This result could be attributed from several reasons. Firstly, subjects recruited in this study were all healthy, highly educated graduate students studying in University of Nebraska Medical Center, which potentially indicated most of them were very intelligent regardless of any other factors at baseline. In the experiment, subjects heard an English letter every 5 seconds, which means that they had around 5 seconds to think and respond. Because the response time was not selected as a parameter in this research, subjects were not under pressure to give their answer as soon as possible. In this way, different amount of daily physical activity might not affect their accuracy in cognitive tasks by itself. Secondly, individual differences made it less possible to find a perfect auditory task that were of appropriate level of challenge for everyone which might results in interactions within some subjects while no interactions within others.

Result 1 The effect of regular physical activity, width of walking, and attention allocation

Results showed that the group who is more physically active have increased stride length, decreased stride time, increased step width, and increased heel elevation.

Previous literatures have shown that typical gait characteristics in the older population include shorter stride length and longer stride time (Judge, Davis, & Ounpuu, 1996; C. McGibbon & Krebs, 1999; C. K. McGibbon DE. & Puniello, 2011; Skeleton, Greig, Davies, & Young, 1995). And these characteristics might be related to the conservative balance strategy adopted by the older population, to keep their center of mass within their base of support as much as possible (Judge et al., 1996; C. McGibbon & Krebs, 1999; C. K. McGibbon DE. & Puniello, 2011; Skeleton et al., 1995). The spatiotemporal adaptations shown by older adults could also be attributed to limitation of their ability to minimize the forces acting on their musculoskeletal system during the stance phase, which is deteriorated by aging. For instance, the gluteus medius muscle is crucial to generate large mediolateral momentum to maintain the center of mass within the base of support (Rogers & Pai, 1993). Weakness of gluteus medius muscle has been found in older adults. Weakness of gluteus medius muscle would force older adults to adopt a gait pattern that minimizes the mediolateral forces. A longer stride length during walking has been highly related to the greater propulsive forces from gluteus medius muscle; therefore, a shorter stride length would be associated with decrease of propulsive force from the muscle. In this study, our results showed that subjects with regular physical activity had increased their stride length and decreased their stride time.

Therefore, regular physical activity may have strengthened certain muscles and led to increased stride length in young adults from our observations. In addition, our observations are supported by statements of the American Heart Association that regular physical activities increase muscle strength and would further improves the quality of life (American Heart Association, 2015).

Step width has been widely accepted as an indicator of falls (Brach, Berlin, VanSwearingen, Newman, & Studenski, 2005; Callisaya et al., 2011; Guimaraes & Isaacs, 1980; Maki, 1997). However, the results of measuring the step width are mixed. A study indicated that older adults tend to walk with narrow step width in comparison with healthy young adults (Maki, 1997). This study indicates that narrow step width is highly correlated to slow walking speed, shorter stride length, and longer stride time. However, some studies observe wider step width in older adults (Callisaya et al., 2011; Guimaraes & Isaacs, 1980). Those studies believe that the purpose of adopting wider step width is to provide a wider base of support during double support phase. Moreover, a study summarizes that too much or too little step width variability is associated with a fall history in older adults (Brach et al., 2005). In the current study, we found that the step width was bigger in persons who do regular physical activities compared with persons who do less regular physical activities. For healthy young adults in the current study, to increase the step width in persons who do regular physical activities was not necessarily related to large base of support; instead, it might be associated with the long stride length and short stride time.

In abovementioned studies, most studies only focus on the gait characteristic in the anterior-posterior (e.g. stride length and stride time) and medial-lateral (step width) directions. What is known about how the gait characteristic changed in the vertical direction is limited. Research has shown that forty-seven percent of falling accidents are caused by tripping over obstacles due to misjudging heel or toe elevation while walking (Campbell et al., 1990). Thus, it is worth investigating the effects of regular physical activities on heel elevation in walking. Since there is limited information about heel elevation during walking, we could discuss the change of heel elevation from obstacle negotiation. The most consistent observation across studies is that there is significant increase in the elevation of the swing leg over an obstacle with healthy older adults compared with healthy young adults, in an effort to maintain a safe elevation distance between the swing foot and the obstacle (McFadyen & Prince, 2002; van Hedel, Biedermann, Erni, & Dietz, 2002; Weerdesteyn, Nienhuis, Hampsink, & Duysens, 2004; Yogev, Hausdorff, & Giladi, 2008). Therefore, a question is raised – do people who do regular physical activities increase the heel elevation to generate a safe distance to ensure that they do not trip by electronic propelling treadmill? In our opinion, we suspected that the increasing of heel elevation was related to the increasing stride length. Walking on treadmill was a continuous motion which was different from stepping over an obstacle in a discrete motion. For example, subjects, particularly for older adults, might stop in front of the obstacle for short moment, then try to achieve high heel elevation to ensure they do not trip over the obstacle. While presenting with the longer stride length, higher heel elevation seems to be an efficient way to walk. In summary, we speculated that increased stride length, decreased stride time, increased step width, and increased toe elevation might improve the efficiency of walking performance among young healthy people who do regular physical activities.

Results also showed that active group have increased the step width even while walking on the narrow-based treadmill. Walking in the real world requires the ability to modify the way one walks to negotiate with task and environment demands. This ability may be deteriorated by being less physically active. Assessment of gait under demanding functional conditions might allow for identification of factors contributing to deteriorated walking adaptability that are not detected under normal walking conditions among healthy young adults who are less physically active. For instance, measurement of gait under conditions of narrow-based walking could improve our understanding of effect of regular physical activity because of extra attentional demands. Previous study showed that attentional costs (over-ground walking on narrow-based trail, ½ of width of normal-based trail) didn't affect the step width in comparison with normal walking in healthy young and in healthy older adults (Mazaheri, Roerdink, Duysens, Beek, & Peper, 2016). They speculated that walking was an activity that highly relied on visuomotor processes rather than adjusting the gait parameters. Therefore, when visual information is sufficient or abundant, there should be no change in gait parameters (e.g. step width) while walking on narrow-based trail (Mazaheri et al., 2016). In this study, however, a decreased step width was found when walking on the narrow-based treadmill in healthy young adults. This result might be due to that walking on treadmill was quite different than walking on over-ground when requiring extra attentional cost. Based on abovementioned hypothesis, while walking on treadmill narrow-based, subjects need to continuously use their vision to track the width between the two lines drawn on treadmill. In this situation, the step width had to be adjusted to counterpart the insufficient visual information (Regnaux, Roberston, Smail, Daniel, & Bussel, 2006). Another interesting finding was that the step width was still wider in active group than in less active group even walking on the narrow-based treadmill. Again, we speculated that wider step width might be an efficient strategy for persons who did regular physical activities.

Moreover, results showed that attention allocation task affected the heel elevation. It is known that older adults are more likely to be affected in gait tasks than younger adults when their attention is divided. The most common observation is the decrease heel elevation when stepping over the obstacle or walking with perturbations (Chen et al., 1996; Mersmann et al., 2013). The purpose of lowering heel elevation might be related to attempt to increase the stride time, which increased the double support time to maintain balance when attention was divided. Moreover, in the current study, our results found that attentional re-allocation task affected the heel elevation when walking on the treadmill. There were three-folded meanings associated with that. Firstly, our results agreed with previous studies that even in healthy young adults, the heel elevation was reduced to increase the stride time to maintain balance when attention was divided. Secondly, there were no significant differences of heel elevation when subjects were instructed to shift their attention from walking to secondary task, or vice versa, or divided their attention half/half to both tasks. These results indicated that when subjects' attention was divided, they adjusted their heel elevation to maintain balance. Finally, to our best knowledge, our study was the first to discuss the heel elevation while performing dual tasks. Our results indicated that heel elevation was sensitive enough to detect the effect of dual tasks in young adults, particularly with treadmill walking.

Result 2 Understand the effect of regular physical activities on attention allocation cost using modified attention allocation index (mAAI)

We hoped to investigate the effect of regular physical activities on attention allocation in different gait parameters with normal-based and narrow-based walking. We used correlation coefficient between each gait parameter and reported errors of secondary tasks to identify the attention allocation cost. We assumed that a higher correlation coefficient indicated higher capability to shift attention.

Stride length: When walking on a normal-based treadmill, both groups of subjects demonstrated strong positive correlation between step length and error reports, which indicated that both groups followed the given instructions to shift their attention. In addition, active group had higher correlation coefficient than less active group. This result indicated the active group had a higher capability to shift attention to control stride length than the less active group. However, when walking on narrow-based treadmill, a moderate negative correlation was shown in the less active group, which indicated that subjects didn't follow the given instruction to shift their attention. In other words, while during narrow-based walking, the less active group had a difficult time to follow the instructions to shift attention. Comparing mAAI between normal-based and narrow-based walking, it is shown that there is more trade-off of stride length required by the physically inactive group to perform the dual task with more difficulty in the walking task. To complete the narrow-based walking task, the physically inactive group need to shift more attention to walking to maintain the walking speed and perform the task safely, while keep doing the auditory task at the same time. They tended to focus majorly on the width of walking base. In addition, the correlation coefficient was much higher in active group than in less active group.

This result indicated that regular physical activities enhanced the capability to shift attention even in narrow-based walking on treadmill.

Stride time: Like stride length with moderate positive correlation in both groups, we observed that the physically active group followed instructions tighter than the inactive group; moreover, the active group had better adaptive capability to shift their attention. However, this was not the same story in narrow-based walking. For the less active group, the correlation coefficient was at strong negative correlation, indicating that the less active group majorly controlled stride time to adapt to the narrow-based walking without following the given instruction. For the active group, to control stride time in narrow-based walking did not seem to be as crucial as it was in the less active group.

Step Width: For step width, the correlations were very weak for the inactive group whether in normal-based or in narrow-based walking. These results might infer that regardless of the width of walking base, the less active group always used a similar strategy to control step width. Or, it was also possible that step width was not the major gait parameter for controlling balance. Surprisingly, a weak correlation was found in the active group when walking on the narrow-based treadmill. Therefore, we speculated that both groups might use a similar conservative strategy (shorter step width) to walk no matter what attentional allocation conditions were.

Heel Elevation: Moderate positive correlations were found for the active group when walking on normal-based treadmill, indicating higher capacity to adapt to different attention allocation conditions and a stronger ability to follow the given instructions in comparison with the less active group. Importantly, this gait parameter could also be used to measure the attentional allocation.

Limitation and Future studies

There are some limitations of this study that could be discussed. One of the main limitations of this study is the sample size and that the subjects are all within a young age group. While this study could be regarded as a start for a specific method of research, the results are still limited by lack of variety in subjects who were recruited(Rankin, Woollacott, Shumway-Cook, & Brown, 2000). In the future, we intend to recruit more subjects to explore the interaction between dual-task condition and physical activity. Further study on subjects of different age groups are indicated to generalize the results to middle age, and elder age populations. Another limitation is that in this study we used the questionnaire to assess physical activity of subjects, which could create some bias for the results. As it is stated in Chapter 1, there are different methods to assess physical activity as the technology develops, and it will get more and more convenient to apply such technology in research. The short questionnaire of Baecke et al was selected as the method used to assess physical activity in this research because it has been proven to have relatively good validity and reliability (Pols MA et al., 1995) and it is convenient to conduct as well. There are only 16 items in the short questionnaire, thus serving the purpose to fit in the one-time experiment format of this study. The subject’s perception of the questions in the questionnaire or the sports the subjects do daily might vary individually which would limit the validity of the results of assessment at individual level (Vanhees et al., 2005). Objective methods such as portable pedometers or accelerometers could be conducted combined with the subjective questionnaire to improve the overall validity of the assessment. Another limitation is that the learning curve and improved familiarity with both walking tasks and secondary task throughout the experiment session might play a role to affect the results. As the tasks are getting more familiar to subjects after they have done several trials, decreased attention demand of the specific task might start to occur, which might affect the reliability in consequence (Harbluk, Noy, Trbovich, & Eizenman, 2007). In the study, two different sets of orders, by which the dual tasks trials were organized, were adopted randomly to subjects to decrease the bias along with the learning curve effect. However it is still impossible to eliminate the effect due to the natural existence of learning curve in these kinds of tasks in our study. The last limitation is that all the walking tasks including normal-based and narrow-based were completed on treadmill, which would possibly contribute to difference from over ground walking or even walking in a real-world environment. A question would be whether different muscle activation pattern, joint moments and joint powers when comparing treadmill vs. over-ground walking contribute to different attentional demand of the task (Lee & Hidler, 2008). Treadmill walking was used in this study because the high repetitions of gait cycles obtained while walking on treadmill for an extended period (3 minutes) would provide data sets which were more reliable to serve for analysis for gait, variability and dual task performance. Future study is indicated to perform the tasks and assess gait over ground in a real-world walking environment.

Conclusion

This study showed that regular physical activity was beneficial for controlling gait parameters in both normal and narrow-based walking on a treadmill. In addition, regular physical activity also helps young adults to allocate their attention, which shed a light to encourage older adults to do regular physical activity for this specific purpose.

To further analyze the effect of physical activity on dual task performance and attention allocation ability, the step errors in narrow-based could be calculated. Variability of gait parameters is also an important indicator of dual task performance as it is stated in previous session.

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APPENDICES

Appendix 1 Physical Activity Questionnaire

Subject #________ Gender________ Age________ Date________
Dominant Hand Right/Left

1) **What is your main occupation**
①. Clerical work, driving, shop keeping, teaching, studying, housework, medical practice; other occupations with a university education
②. Factory work, plumbing, carpentry, farming
③. Dock work, construction work, sport
2) **At work I sit**
Never/seldom/sometimes/often/always
3) **At work I stand**
Never/seldom/sometimes/often/always
4) **At work I walk**
Never/seldom/sometimes/often/always
5) **At work I lift heavy loads**
Never/seldom/sometimes/often/very often
6) **After working I am tired**
Very often/often/sometimes/seldom/never
7) **At work I sweat**
Very often/often/sometimes/seldom/never
8) **In comparison with others of my own age I think my work is physically**
Much heavier/heavier/as heavy/lighter/much lighter
9) **Do you play sport?**
Yes/no
If yes:
-which sport do you play most frequently?
①. Billiards, sailing, bowling, golf
②. Badminton, cycling, dancing, swimming, tennis
③. Boxing, basketball, football, rugby, rowing
-how many hours a week?
0.5——1.5——2.5——3.5——4.5h
-how many months a year? ___________
If you play a second sport:
-which sport is it?
①. ②. ③.
-how many hours a week?
0.5——1.5——2.5——3.5——4.5h
-how many months a year? ___________
10) **In comparison with others of my own age I think my physical activity during leisure time is**
Much more/more/the same/less/much less
11) **During leisure time I sweat**
Very often/often/sometimes/seldom/never
12) **During leisure time I play sport**
Never/seldom/sometimes/often/very often
13) **During leisure time I watch television**
Never/seldom/sometimes/often/very often
14) **During leisure time I walk**
Never/seldom/sometimes/often/very often

15) **During leisure time I cycle**
Never/seldom/sometimes/often/very often

16) **How many minutes do you walk and/or cycle [per day] to and from work, school and shopping?**
<5/5-15/15-30/30-45/>45

Appendix 2 Cognitive Allocation Data Collection Sheet 1

Subject #____________ Gender________ Age________ Date________

Anthropometric Information

Height_____ Weight_____ Inter ASIS distance_____ B ASIS to GT____ _____

True Leg Length (ASIS to M Mall)_____ _____ B Width of knee_____ _____

B Ankles_____ _____ Width of the Foot(1st to 5th Met head)_____ _____

Baseline	Auditory Three-Back Test	Error#	Remarks
1	Seated		
Baseline	Walk	Speed	Remarks
1	Normal-base Walk		
2	Narrow-base Walk		
Baseline	Auditory Three-Back Test	Error#	Remarks
2	Seated		

Trial#	Walking Base	Walk%	Three-Back%	Error#	Remarks
1	NORMAL	0	100		
2	NORMAL	0	100		
3	NARROW	50	50		
4	NARROW	50	50		
5	NORMAL	100	0		
6	NORMAL	100	0		
QUESTIONNAIRE					
7	NARROW	0	100		
8	NARROW	0	100		
9	NORMAL	50	50		
10	NORMAL	50	50		
11	NARROW	100	0		
12	NARROW	100	0		

Baseline	Auditory Three-Back Test	Error#	Remarks
1	Seated		

Baseline	Walk	Speed	Remarks
1	Normal-base Walk		
2	Narrow-base Walk		
Baseline	Auditory Three-Back Test	Error#	Remarks
1	Seated		

Cognitive Allocation Data Collection Sheet 2

Subject #____________ Gender_______ Age_______ Date_______

Anthropometric Information

Height_____ Weight_____ Inter ASIS distance_____ B ASIS to GT____ _____

True Leg Length (ASIS to M Mall)_____ _____ B Width of knee_____ _____

B Ankles_____ _____ Width of the Foot(1st to 5th Met head)_____ _____

Baseline	Auditory Three-Back Test	Error#	Remarks
1	Seated		
Baseline	Walk	Speed	Remarks
1	Normal-base Walk		
2	Narrow-base Walk		
Baseline	Auditory Three-Back Test	Error#	Remarks
1	Seated		

Trial#	Walking Base	Walk%	Three-Back%	Error#	Remarks
1	NARROW	100	0		
2	NARROW	100	0		
3	NORMAL	50	50		
4	NORMAL	50	50		
5	NARROW	0	100		
6	NARROW	0	100		
QUESTIONNAIRE					
7	NORMAL	100	0		
8	NORMAL	100	0		
9	NARROW	50	50		
10	NARROW	50	50		
11	NORMAL	0	100		
12	NORMAL	0	100		

Baseline	Walk	Speed	Remarks
1	Normal-base Walk		
2	Narrow-base Walk		
Baseline	Auditory Three-Back Test	Error#	Remarks
1	Seated		