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Original Article

Automated stride assistance device improved the gait parameters and energy cost during walking of healthy middle-aged females but not those of young controls

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Abstract. [Purpose] The aim of this study was to clarify the effects of an automated stride assistance device on gait parameters and energy cost during walking performed by healthy middle-aged and young females. [Subjects and Methods] Ten middle-aged females and 10 young females were recruited as case and control participants, respectively. The participants walked for 3 minutes continuously under two different experimental conditions: with the device and without the device. Walking distance, mean walking speed, mean step length, cadence, walk ratio and the physiological cost index during the 3-minutes walk were measured. [Results] When walking with the stride assistance device, the step length and walk ratio of the middle-aged group were significantly higher than without it. Also, during walking without assistance from the device, the physiological cost index of the middle-aged group significantly increased; whereas during walking with assistance, there was no change. The intergroup comparison in the middle-aged group showed the physiological cost index was lower under the experimental condition with assistance provided, as opposed to the condition without the provision of assistance. [Conclusion] The results of this study show that the stride assistance device improved the gait parameters of the middle-aged group but not those of young controls.

Key words: Gait exercise, Robotic device, Physiological cost index

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INTRODUCTION

Gait is one of the most important elements in maintaining quality of life (QOL). Gait functions (gait speed, step length, cadence, and walking energy cost) begin to gradually deteriorate from the age of 40 years, and a significant and rapid decline in function occurs over the age of 60 years[1–3)]. Gait speed is associated not only with lower physical function, but also with the risk of falling, future disability, and death[4, 5)]. Thus, maintaining optimal gait function is important for reducing the risk of a decline in physical function and for improving mortality risk in middle age.

Walking is the most popular type of exercise performed by the middle-aged population and confers the potential benefit of reduced morbidity[6)]. A meta-analysis showed walking for exercise improved the gait speed and balance of older adults[7)]. Another study provided evidence that brisk walking is beneficial for cardiovascular health[8)]. Recently, robotic devices have been shown to be useful methods for increasing the gait function of individuals with disability in the elderly population. The

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positive effect on gait function and speed provided by these machines has been well documented, especially for patients with stroke or Parkinson's disease[9–11]. However, disadvantages have been noted, such as the large size of the equipment and the need for trainers to assist the patients[11, 12]. The automated Stride Management Assist (SMA) device is a simple robotic device that provides gait assistance to adults by mechanically altering individuals' walking actions by increasing their walk ratio via mechanical torque generated to assist hip joint flexion and extension while walking. The SMA device improves gait speed and walking parameters without increasing the energy cost in the lower-extremity muscles of healthy older adults[13, 14]. However, it is unclear whether the SMA device has an effect on gait parameters and energy cost during walking performed by middle-aged or young adults.

The aim of this study was to clarify whether this robotic device can change the walking parameters and energy cost of healthy middle-aged and healthy young females.

SUBJECTS AND METHODS

The recruited participants were 10 middle-aged females aged between 51 and 64 years old (the MID group) and 10 healthy young females aged between 21 and 34 years old (the YNG group). Inclusion criteria were as follows: no history of disease(s) that might have affected the ability to walk for 3 min, such as orthopaedic diseases of the lower limbs, neurological disorders, cardiovascular disease, or pulmonary disease, and the ability to walk independently without the use of an assistive-device. In this study, middle-aged females who were capable of independent daily living and performed a job and/or housework were selected. All participants provided their informed consent before any study procedures were initiated. This study was approved by the local ethics committee of the Faculty of Medicine, Tottori University (No. 2371). Muscle strength during knee extension, and one leg standing times were evaluated for both groups. Bilateral muscle strength during knee extension was recorded using a hand-held dynamometer (μTas F-1, Anima Co., Tokyo, Japan). Each participant sat in a chair with their hips flexed at 90°, and the knee being tested flexed at 90°. The hand-held dynamometer was placed in front of the facies anterior cruris, or the anterior region of both legs, and the examiner measured the resistance of a 5-s maximal isometric knee extension twice. The measured values were divided by the subject's body weight (Nm/kg), and the highest value was used as the representative value. One leg standing times were measured using a stopwatch. Participants were asked to stand on one leg as long as possible with their arms resting by their sides; the maximum possible time was 30 s. Standing times were measured twice, bilaterally, and the longest time was used. A SMA walking assistance device (Honda Co., Tokyo, Japan) was used in this study. The SMA has an internal electrical actuator and is equipped with angular and current sensors which monitor the range of motion (degrees) of the hip joints and the torque (Nm) generated by the SMA device. Stride assistance is generated by electrical actuators which are located in close proximity to the hip joints and torque is transmitted to the thighs through thigh frames. The SMA device is attached to the pelvis and thighs with belts that do not restrict movement in a standing position (Fig. 1). A 3-min walking test was performed for gait assessment of both groups whilst the participants used the SMA device. The walking was conducted indoors, in a hallway with a level surface. A 30-meter-long quadratic-shaped track with gently rounded bends was used. In addition to the SMA device, the participants also wore a heart rate (HR) monitor (BMS-7200, Nihon-Koden, Co., Tokyo, Japan) around the chest. They were asked to sit for approximately 5 min so that resting HR could be recorded. Participants were then requested to walk for 3 min under two experimental conditions: with and without the torque assistance provided by the SMA device. The order in which the two experiments were performed was determined by the random selection envelope method. Torque generation was set at a moderate degree, a setting determined for each participant using the specific software on the tablet personal computer (PC) of the SMA device. Participants were blinded to the presence or absence of SMA device activity. Walking parameters during the 3-min walk were assessed and the mean values were calculated. The physiological cost index (PCI) was assessed every 30 s during the 3-min continuous walk. The PCI was proposed by MacGregor, and is based on the linear relationship between VO2 and HR[5]. It represents the energy cost during walking and requires a simple recording of the HR at rest and while walking, and it can be measured with inexpensive equipment[15]. The participants were asked to walk at a self-selected comfortable speed, and the gait parameters during 3 min of continuous walking were evaluated. Walking distance, mean walking speed, mean step length, cadence, and walk ratio were computed using the custom software installed on the tablet PC of the SMA device. The PCI was calculated as the quotient of the difference between working and resting HR[15]. HR during the 3 min of continuous walking was recorded every 30 s. Participants rested for approximately 5 min between the trials to ensure their HR returned to its resting rate. The PCI value reflects the increase in HR as a result of performing the walking required in each trial and it is expressed as heartbeats per meter by the formula: *PCI = [Mean HR at work − Mean HR at rest]/ Walking speed (m/min).* The unpaired t-test was used to compare the characteristics and physical performance data of the MID and YNG groups, and to compare the gait parameters of both experimental conditions between the groups. The paired t-test was used to perform intragroup comparisons of the walking parameters between the two experimental conditions. Using repeated-measures ANOVA, each 30-s change in the PCI under each experimental condition was compared. Post hoc analysis was performed using the Bonferroni correction. All data were analyzed using software for statistical analysis (SPSS for Windows Version 22; IBM Co., Ltd., Tokyo, Japan). A p-value<0.05 was considered statistically significant.

Fig. 1. Stride management assist device

Table 1. Comparison of the characteristics of the middle-aged and young adult female groups

	Middle-aged (n=10)	Young (n=10)
Age (yrs)	55.2 ± 3.2	25.8 ± 2.7 *
Body height (cm)	155.6 ± 6.4	157.9 ± 5.3
Body weight (kg)	52.6 ± 6.0	51.8 ± 5.3
BMI (kg/m^2)	21.8 ± 3.1	20.8 ± 2.2
Muscle strength during knee extension (Nm/kg)	0.61 ± 0.14	0.62 ± 0.15
One-leg standing times (s)	27.6 ± 7.6	28.5 ± 4.7

The data are mean ± SD.
*Significant difference between middle-aged and young
BMI: body mass index

Table 2. Comparison of the walking parameters with and without SMA assistance of the middle-aged and young adult female groups

Parameter	Group	Without assistance	With assistance
Walking distance (m)	MID	231.8 ± 23.2	236.7 ± 25.8
	YNG	221.8 ± 24.4	221.6 ± 22.4
Walking speed (m/min)	MID	77.3 ± 7.7	78.9 ± 8.6
	YNG	73.9 ± 8.1	73.9 ± 7.5
Step length (m)	MID	0.62 ± 0.05	0.67 ± 0.09**
	YNG	0.63 ± 0.06	0.63 ± 0.06
Cadence (steps/min)	MID	123.7 ± 5.6*	117.8 ± 9.6
	YNG	117.0 ± 7.2	116.6 ± 6.6
Walk ratio ($^{-5}$min/m)	MID	505 ± 44	579 ± 12**
	YNG	543 ± 66	546 ± 69

The data are mean ± SD.
*Intergroup difference between the middle-aged and young adult female groups.
**Intragroup difference between without and with SMA device assistance.
MID: middle-aged female; SMA: stride management assist; YNG: young healthy adult female

RESULTS

There were no significant differences in characteristics between the MID and YNG groups of participants, except for mean age (Table 1). Table 2 shows the comparison of gait parameters during the 3-min walks performed by both groups. Without assistance being provided by the SMA device, cadence was significantly higher in the MID group than in the YNG group; however, this difference was not observed when assistance was provided by the SMA device. The step length and walk ratio were significantly higher, but only within the MID group with assistance being provided compared with no provision of assistance. The comparative changes in the PCI of the two groups between the two experimental conditions are shown in Tables 3 and 4. In the YNG group, without assistance from the SMA device during the 3-min walk, the PCI was significantly higher at the end of the 3-min walk compared with the 1-min time point after starting the test, but there was no change when SMA-assistance was provided. No significant differences in the PCI of the YNG group were observed between the two experimental conditions. In the MID group, without assistance from the SMA device during the 3-min walk, the PCI was significantly increased 2 min after starting the trial, compared with 1 min after the start of the trial; however, when SMA-assistance was provided, no change was observed. The intergroup comparison in the MID group showed the PCI was lower under the experimental condition with assistance provided, as opposed to the condition without the provision of assistance at the 2- and 3-min test times.

DISCUSSION

The results of this study suggest that the SMA device temporarily improved the gait parameters and walking cost of the MID subjects. The SMA device is very useful clinically. Older adults can put it on by themselves and walk smoothly and

Table 3. Changes in the PCI of young adult females without and with assistance from an SMA device

	T1	T2	T3	T4	T5
Without assistance	0.31 ± 0.12	0.34 ± 0.11	0.32 ± 0.12	0.34 ± 0.11	0.36 ± 0.11*
With assistance	0.22 ± 0.40	0.37 ± 0.09	0.35 ± 0.14	0.32 ± 0.17	0.33 ± 0.16

The data are mean ± SD.
*Significant difference from T1, $p<0.05$
PCI: physiological cost index; SMA: stride management assist
T1: 1 min after start, T2: 1 min and 30 sec after start, T3: 2 min after start, T4: 2 min and 30 sec after start, T5: 3 min after start

Table 4. Changes in the PCI of middle-aged females without and with assistance from an SMA device

	T1	T2	T3	T4	T5
Without assistance	0.30 ± 0.08	0.34 ± 0.10	0.36 ± 0.11*	0.36 ± 0.12	0.36 ± 0.13
With assistance	0.33 ± 0.08	0.34 ± 0.10	0.33 ± 0.11**	0.33 ± 0.12	0.32 ± 0.13**

The data are mean ± SD.
*Significant Difference from T1, $p<0.05$.
**Difference between the experimental conditions
PCI: physiological cost index; SMA: stride management assist
T1: 1 min after start, T2: 1 min and 30 sec after start, T3: 2 min after start, T4: 2 min and 30 sec after start, T5: 3 min after start

comfortably when wearing it. In the present study, walking with the assistance provided by the SMA device elongated the mean step length and improved the walking rate of the MID group to the value of 0.0063, which is an appropriate value for this age group[16]. However, these changes were not observed in the YNG group, regardless of the assistance provided by the SMA device. In another study, 15 females (72−85 years old) performed walking exercises twice weekly for 90 minutes per session using an SMA device, and their walking speed was improved by the intervention[14]. Using the SMA device, 25 patients with chronic stroke (mean age, 60 years) performed walking exercises for several months and significantly improved their gait speed, step length of the unaffected side, and cadence compared with a control group of 25 patients with stroke who performed functional task-specific training[17]. The subjects of that previous study were older and more disabled than the participants in our present study. Thus, the SMA device may be more beneficial for subjects with severe disabilities or for older adults than for healthy young adults, since improvements in gait function were only observed in the healthy middle-aged females in the present study. In general, the deterioration of gait function (gait speed, step length, and cadence) becomes more prominent in individuals aged 40 to 60 years old[1–3], the age range of the middle-aged participants in the present study. This is the first study to demonstrate the potential of the SMA device to improve the gait parameters of this age group. The results suggest that walking exercise, using an SMA device to maintain step length and walk ratio, would be beneficial for middle-aged females who are starting to experience deterioration in physical fitness, compared to young adult females, because the gait cadence of the MID group was not different from the YNG group when the SMA device provided assistance. We speculate that this is because the SMA device increased the step length of the MID group. The SMA device system mechanically alters participants' walking actions and increases the walk ratio by torque-assisted hip joint flexion and extension movements. This would have helped the MID group by forcing the cadence closer to the gait pattern of healthy young adults. This may lead to an appropriate walking rate for the MID group.

The PCI showed no changes during consecutive 3-min walking exercises when the SMA device provided assistance to both groups; however, it increased in the absence of assistance. The PCI is useful for assessing energy cost in clinical situations because of the significant relationship it has with maximum oxygen uptake[15, 18–20]. We speculate that the SMA device reduces the muscle activity of the lower extremities by mechanically altering an individual's walking action, increasing the walk ratio via mechanical torque generated to assist hip joint flexion and extension whilst walking. Therefore, if the muscle activity of the lower extremities were reduced by the use of this device, blood return to the heart would also reduce, reducing the heart rate and improving walking efficiency, directly affecting the PCI value. A previous study showed that the fluorodeoxyglucose uptake of the hip muscles was significantly decreased by an intervention in which an SMA device was used by 9 elderly subjects[14]. Another study of 10 young subjects also showed that an SMA device reduced oxygen consumption per unit time (VO2) and HR during walking[21]. These results indicate that the SMA device improves the efficiency of muscle activity during walking, even though it does not redistribute muscular effort, and could potentially performed by increase the walking endurance of the young and elderly. The results of the present study are in agreement with previous studies because the PCI theory is based on the premise that a correlation exists between HR and VO2 when submaximal efforts are involved. Thus, it is likely the reduction in the activity of the lower extremity muscles elicited by an SMA device reduces the load on the cardiovascular system improving walking energy cost. The SMA device may be suitable for middle-aged people considering the beneficial effect it has on the energy cost during walking.

The PCI tended to decrease 2 and 3 minutes after the start of walking, but only when the MID intergroup comparison was made. This shows the SMA device may affect HR following the start of walking. Generally, the increase in HR immediately after the start of exercise is faster in older adults than in young adults because the cardiovascular system needs to work harder to compensate for the increase in activity in participants older than 40 years, due to lower physical activity levels and suboptimal muscle condition. Thus, the SMA device may be more useful for reducing the HR during walking performed by healthy middle-aged individuals than by healthy young adults. The SMA device could potentially increase the gait distance without increasing HR during walking exercise performed by middle-aged individuals, and this may help increase overall health and motivation for walking exercises in this generation.

This study had several limitations. The sample size was small. However, as a result of the detailed experimental measurements performed on all participants, sufficient objective data for the intervention with the SMA device was collected. Additionally, the middle-aged participants were healthy, and their physical function was similar to that of the young subjects; therefore, the middle-aged participants may not have been representative of represent the general, middle-aged population because of sampling bias. Also, this study was performed under experimental conditions and the walking time was only 3 minutes. Because of this, the results may differ from those of studies examining longer walking distances. Further studies are needed to research the changes in the energy cost of participants walking over longer distances, and to monitor interventions involving participants of an older age. Although the subjects were blinded to the experimental conditions used in the present study, a validation test to determine whether or not they could feel the hip joint torque assistance provided by the SMA device was not conducted.

In conclusion, the results of this study suggest that the SMA device significantly improved step length and walk ratio, as well as the cadence the MID group, but not those of the YNG group. In both groups, the PCI significantly increased during the walking without SMA assistance; however, there was no change when SMA assistance was provided. In the comparison of conditions, the PCI of the MID group became significantly lower with SMA assistance than without it, but this was not observed in the YNG only in the MID group. This robotic-assisted method for walking exercise may be more suitable for middle-aged adults than healthy young females. If this device were used for long-term exercise, it might improve the gait function of middle-aged adults; however, only a short-term assessment was made in the present study. Nevertheless, it is possible that this device would improve not only the gait parameters and walking costs of patients with disability but also those of healthy middle-aged subjects, leading to health promotion in this age group.

Conflicts of interest

The authors have no conflicts of interest to disclose.

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