High-intensity interval walking training using internet of things (IoT): past and future

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Received: August 31, 2020 / Accepted: September 9, 2020

Abstract  Facing the rapid growth in the elderly population worldwide, the need for exercise prescriptions according to individual physical fitness has become increasingly apparent. Despite this, the training system broadly available has not been developed. Accordingly, we have developed a system with internet of things (IoT) for middle-aged and older people called “e-Health Promotion System”, based on interval walking training (IWT). IWT is a training regimen repeating 5 sets of fast walking at more than 70% peak aerobic capacity (VO2peak) and slow walking at ~40% VO2peak for 3 min each per day. The system is composed of a device that is equipped with a tri-axial accelerometer and a barometer, and connected to a central server. The server has a program for storing walking records transferred from the device through the internet, as well as for instructing participants regarding IWT in a feedback manner based on the server database. Using this system, we examined the effects of 5-month IWT in more than 8,700 middle-aged and older people, and found that the training increased VO2peak by 15%, improved lifestyle-related disease symptoms by 20%, and reduced healthcare costs by ~20% on average. We subsequently reported that the effects of IWT depended only on average fast walking time, rather than average slow or total walking time per week. Recently, we also developed a mobile application program to provide participants with this service on their smartphone so that we can examine the effects of IWT in a much larger population of people at the same time and across generations. The system has great potential to increase interdisciplinary studies between sports sciences and other fields of science to establish and promote a society for health and longevity.

Keywords: sensors for exercise intensity measurements, interval walking training, peak aerobic capacity, lifestyle-related diseases

Introduction

The rapid growth in the elderly population in many countries has highlighted the importance of exercise training for decreasing the likelihood of disability and age-associated diseases. In Japan, approximately 29% of the total population was over 65 years old in 2020, and according to National Institute of Population and Security Research projections from 2019, the figure will likely increase to over 31% by 2030. One of the serious problems resulting from the rapid increase in the number of older people is the related cost of healthcare. Japanese healthcare costs for people aged 65 and over were 25 trillion JPY (236 billion USD) in 2015, and estimates from the Ministry of Health and Welfare from 2019 are that costs will increase to 35 trillion JPY (330 billion USD) by 2025, an amount equivalent to 35% of the 2019 annual national budget.

Facing this national fiscal crisis, the Japanese government enacted a law in 2008 to reform the medical system to provide preventive medical care services by which people are obliged to receive health checkups for age- and lifestyle-related diseases (LSDs) when they reach 40 years of age. If abnormal results are indicated, people are encouraged to receive nutritional and/or exercise counseling at local healthcare institutions. While it is well known that an exercise prescription should conform to individual physical fitness in order to achieve specific effects, no relevant guidelines have been provided by the government, possibly because exercise prescriptions for individuals would cost more than standard walking training, and also because there has been little evidence to suggest...
that the cost of developing such exercise prescriptions for individuals would be less than the cost of current clinical expenditures.

Given these considerations, we have developed an exercise prescription system using the internet of things (IoT) for middle-aged and older individuals which can be run at low cost, and which achieves health outcomes that are at least equivalent to those of current standard exercise prescriptions carried out in gyms. While the details have been reported in our previous review articles 3-5), in the present review we focus on the history of the development of the system, we provide an up-to-date overview of the system and its current use, and we discuss the potential for future studies using the system.

**Brief history of interval walking training development**

One year prior to the 1998 Nagano Winter Olympic Games, Matsumoto City started a health promotion program of walking training for middle-aged and older people. Known as Matsumoto “Jukunen Taiikudaigaku”, this program was based on a proposal by the late Tadashi Aruga, a former mayor of the city. Since its inception, we have been engaged in the project, designing the initial program and examining the effects on health promotion of the participants. At the outset of the project in 1997, we instructed participants to perform walking training with a target of 10,000 steps per day, while having them report to us the steps measured with a pedometer. More than 30% of the roughly 100 participants walked more than 10,000 steps/day, more than 4 days/week, for a year. However, after our year-long program of intervention, we found little increase in peak aerobic capacity (VO2peak) and minimal improvement in LSD5.

The following year, we examined the effects of an exercise training program based on guidelines from the American College of Sports Medicine (ACSM)7). Participants in the program were recruited from those who had finished the walking training the previous year. They were instructed to perform running or cycling exercise at 60% or more of individual VO2peak in a gym, 30 min/day or more, 2-3 days/week, for 4 months or more. The results showed that VO2peak had increased by 10-20%, with marked improvements in the symptoms of LSDs, as envisaged by the ACSM guidelines7). However, we found that such training, implemented on a larger scale, would require considerable financial expenditure for establishing facilities and employing trainers, estimated at 300,000 JPY (2,830 USD) or more per participant per year, a potentially prohibitive amount3).

Recently, we examined the effects of IWT on VO2peak and LSD symptoms while focusing on exercise intensity and volume in middle-aged and older people10). We analyzed retrospectively how exercise intensity and volume of IWT affected the increase in VO2peak and the improvement of the LSD symptoms in 679 middle-aged and older people aged approximately 65 years, 196 men and 483 women, who had been instructed to perform IWT more than 30 min/day, more than 4 days/week, for 5 months. In case they did not have enough time for IWT on weekdays, we allowed them to perform the training in one session per week, i.e., on the weekend, provided their total fast walking time per week was 60 min or more.

During the 5-month IWT, some of the participants performed the training as instructed, with half of the total training time for fast walking and the remaining half for slow walking. Some participants, however, performed fast walking almost exclusively throughout the training period, while others performed only slow walking. Importantly, however, more than 95% of the total participants completed the program.

For the analyses, we divided the participants into small groups according to individual average fast (A), slow (B), and total (C) walking time per week and assessed the effects of respective walking time on changes in VO2peak from the baselines after the 5-month training (Fig. 1). As shown in panel A, we found that VO2peak increased linearly as average fast walking time per week increased up to 50 min; but above this time, it reached a plateau level. On the other hand, as shown in panels B and C, VO2peak did not increase as average slow or total walking time per
Fig. 1 The relationships between average fast (A), slow (B), and total (C) walking time per week vs the change in \( \Delta VO_2\text{peak} \) from the baseline, respectively, after 5-month IWT in middle-aged and older people. We calculated the average fast walking time and the corresponding average \( \Delta VO_2\text{peak} \) value, according to individual walking time per week, for each of the small groups into which all participants were divided. Calculations were performed for every 6-min increment of the walking time up to 60 min, every \( \sim \)30-min increment up to 180 min, every \( \sim \)60-min increment up to 240 min, and the values above this time. Similarly, we calculated the average slow walking time and the corresponding \( \Delta VO_2\text{peak} \) value up to 180 min as done for the fast walking time, and every \( \sim \)60-min increment up to 400 min and the values above this time. In addition, we calculated the average total walking time and the corresponding \( \Delta VO_2\text{peak} \) value every 10-min increment up to 200 min, every 50-min increment up to 500 min, every 100-min increment up to 600 min, and the values above this time. The closed circles and bars indicate the mean and standard error for each group, respectively. The open circles indicate the number of participants in each group. The *'s indicate the significant differences from the baseline before starting IWT. Redrawn from Masuki S et al., 2019[11].
week increased. These results suggest that the increase in VO2peak after the training depends on average fast walking time, but not on either average slow or total walking time per week. Furthermore, we found that at least 50 min/week of fast walking above a given exercise intensity was necessary to acquire the maximal increase in VO2peak.

Separately, as shown in panel A, we found that VO2peak marked the values below the baselines when fast walking time was less than 10 min, suggesting that less than this amount of time was not enough to prevent any reduction in VO2peak with aging. On the other hand, as shown in panel B, we found that the VO2peak marked the values above the baselines even around 0 min of slow walking time, suggesting that the participants in the relevant groups performed only fast walking with no slow walking during the training period.

Fig. 2 shows the effects of average fast (A), slow (B), and total (C) walking time per week on changes in the LSD score from baseline after the 5-month training period. The LSD score was calculated with reference to both Japanese and US healthcare guidelines, as previously described\(^{10,12}\). We added 1 point when a value met one of the following four criteria: (1) body mass index 25 kg/m\(^2\) or greater; (2) systolic blood pressure 130 mmHg or greater or diastolic blood pressure 85 mmHg or greater; (3) triglyceride level 150 mg/dl or greater, high-density lipoprotein cholesterol level less than 40 mg/dl, or low-density lipoprotein cholesterol level 130 g/dl or greater; and (4) blood fasting glucose level 110 mg/dl or greater. Therefore, the maximum total score was 4 points when all criteria were met. As seen in panel A in the figure, the LSD score decreased as average fast walking time increased up to 50 min; but above this time, the score reached a plateau. When we looked at the effects of average slow and total walking time per week on the LSD score, we found that the score did not decrease as average slow or total walking time per week increased. These results suggest that an improvement in LSD symptoms depends on average fast walking time, but not on average slow or total walking time per week. In other words, an improvement in LSD symptoms was closely associated with an increase in VO2peak, which was attained by exercise training above a given intensity relative to individual VO2peak, such as IWT fast walking.

Future directions

One of the problems with the present e-Health Promotion System is that the participants need to visit community offices near their homes once a month at a given time and date in order to transfer their walking records using a PC and the internet. While the system may be more readily available to older people whose schedules are relatively free after their retirement, it may not be as accessible to younger people who are working. To solve this problem, we have recently developed an application program specifically for mobile phones. The most recent model of mobile phone is equipped with a tri-axial accelerometer and a barometer. This development, made possible thanks to a 2017-2018 grant from the Japan Agency for Medical Research and Development (AMED), has allowed us to develop functions equivalent to those in the JD Mate\(^{(13)}\). Fig. 3 shows the quick response (QR) code which readers can use for trying out IWT with a sample of the application program.

To guarantee high adherence to training using the present system with JD Mate and a PC, we have also included 3 specific features in the application program: 1) Recognition of progress based on individual walking and health records returned to each individual from the server computer. Participants can recognize their achievements and training effects, which motivates them to continue IWT with confidence that their efforts have results; 2) Comparison with other participants – if participants recognize training achievements in the up-to-date histograms made from combined participant data, then this knowledge stimulates a competitive spirit; 3) Community promotion – if participants see an up-to-date ranking of the training achievements in their community, then they may encourage colleagues in their own community to elevate the ranking. We have conducted a validation study of participants divided into four groups – university students, company workers, retired older people, and hospital outpatients – by having them perform IWT for 5 months. As a result, we found that the adherence to and the effects of IWT using the application program were equivalent to those using the present system in each group of participants.

The development of an application program for mobile phones will enable us to examine the effects of exercise training for increasing physical fitness in a much larger population of people over multiple generations at the same time in the field by extending individualized training beyond gyms. Thereby, it will also enable us to explore new research areas of sports sciences in conjunction with other disciplines while focusing on exercise intensity in order to establish and promote a society for health and longevity by exercise training.

Conclusions

We developed a field training system to perform IWT according to individual VO2peak while continuously monitoring exercise intensity. Our findings suggest that high-intensity walking time during IWT is a key determinant for increasing VO2peak and improving LSD risk factors in middle-aged and older people. The system should significantly contribute to realizing a society that enjoys health and longevity.
Fig. 2  The relationships between average fast (A), slow (B), and total (C) walking time per week vs the change in the lifestyle-related disease (ΔLSD) score from the baseline, respectively, after 5-month IWT in middle-aged and older people. The procedure for dividing all participants into the small groups and the number of participants in each group are the same as in Fig. 1. The symbols are also the same as in Fig. 1. Redrawn from Masuki S et al., 201911.

Fig. 3  A quick response (QR) code for the iPhone application program developed under grants from AMED13.
Grants

This research was supported by the Ministry of Health Labor and Welfare of Japan (H17-Choju-Ippan-016), and the Japan Society for the Promotion of Science (18H04083, 18H03147). Preparation for this manuscript was partially supported by the SEI Group CSR Foundation (2020-2022).

Conflict of Interests

No conflict of interests, financial or otherwise, is declared by the authors.

Author Contributions

SM and MF prepared the figures. HN and SM drafted the manuscript. HN, MM, MF, and SM edited and revised the manuscript. HN, MM, MF, and SM approved the final version of the manuscript.

References


