Advanced Biomedical Engineering
12: 253–260, 2023.

Original Paper

DOI:10.14326/abe.12.253

A Novel Electronic Musical Instrument Used as an Aid in the Prevention of Dementia

Natsuki Asakura,* Yoshinobu Maeda,*,# Mamoru Iwaki,* Koji Tanaka,** Tomoko Ichinose,*** Ryuhei Okuno,† Kenzo Akazawa††,†††

Abstract The prevention of dementia is a pressing issue on a global scale. One of the most important recommendations in the World Health Organization's guidelines entitled "Risk reduction of cognitive decline and dementia" (PA guidelines) is to take part in physical activity, "maintaining at least 3 metabolic equivalents of task (METs) per exercise for at least 10 minutes". The authors believe that adding a musical performance to aerobic exercise makes the exercise more appealing, and provides the motivation to exercise and the encouragement to continue. The purpose of this study was to develop a new electronic musical instrument, Cymis-Foot, which has a built-in music score and has two functions. The first is that novices can play their favorite pieces easily using their feet to repeatedly push down onto a balloon, i.e. foot-stomping, while in a sitting position. When they do this, they force the pressure in the balloon to reach a threshold, and at a constant tempo the music is played smoothly. The second is that the PA guidelines can be easily satisfied with a performance of the Cymis-Foot. The METs can be calculated, as described in a previous report, by monitoring the heart rate during the performance and at rest. Eleven cognitively normal novices in their 20 s were able to perform pieces easily at between 40 and 160 bpm. The guidelines were still satisfied with foot-stomping from a greater height at a slower tempo, whereas five participants reported difficulty in satisfying the PA guidelines at 40 bpm.

Keywords: heart rate, METs, electronic music instrument, aerobic exercise.

Adv Biomed Eng. **12**: pp. 253–260, 2023.

1. Introduction

With nearly 10 million new cases of dementia reported each year, the prevention of dementia has become a top global priority for health and social care in the 21st century. Note that cognitive decline is due to lesions in the brain and progresses gradually from mild cognitive impairment to dementia, and that dementia is not a natural or inevitable consequence of aging. Although there is no curative treatment for dementia, it has been widely recognized that it is possible to delay the onset and progression of the disease through preventive management [1–3]. Recently the results of an 11-year follow-up study, in which 501,376 participants took part, showed a 35% lower risk of developing dementia for those who engage in regular, vigorous activity [4]. The World Health Organization (WHO) [1, 2] and the Ministry of Health, Labor and Welfare (MHJW) [3] have published the "Risk Reduction of Cognitive Decline and Dementia" guidelines, i.e., the PA guidelines. Among them, intervention through physical activity is strongly recommended for cognitively normal adults aged over 18 years to reduce the risk of cognitive decline and dementia. Simply stated, MHJW recommends that Japanese adults aged 18–64 years engage in aerobic exercise of at least 3 metabolic equivalents of task (METs) for at least 10 minutes at a time. This indicates that physical activity is recommended for the prevention of dementia not only in the elderly over

This study was presented at the Symposium on Biomedical Engineering 2023, Kumamoto, September, 2023.
Received on July 20, 2023; revised on October 17, 2023; accepted on October 25, 2023.

* Graduate School of Science and Technology, Niigata University, Niigata, Japan.
** Graduate School of Modern Society and Culture, Niigata University, Niigata, Japan.
*** School of Music, Mukogawa Women's University, Nishinomiya, Japan.
† Faculty of Science and Technology, Setsunan University, Neyagawa, Japan.
†† Social Welfare Organization Kibounoie, Takarazuka, Japan.
††† Professor Emeritus of Osaka University
# 8050 Ikarashi 2-no-cho, Nishi-ku, Niigata, Niigata 950–2181, Japan.
E-mail: maeda@eng.niigata-u.ac.jp

65 years of age, but also in young people over 18 years old. This corresponds to fast walking or physical activity of equivalent or greater intensity. The MET is defined as the oxygen uptake in ml/kg/min with one MET equal to the oxygen cost of sitting quietly.

It should be noted that one effective intervention for reducing the risk of dementia is taking part in a leisure activity, especially music. In cognitively normal subjects, playing a musical instrument has been reported to reduce the risk of dementia by 69% [5], and 64% [6], and to maintain or improve cognitive function [7, 8]. Furthermore, there are interventions for improving cognitive function, such as dancing, exercising to music, and playing percussion instruments [9, 10]. For these interventions, a large public space, an instructor, and other participants in the activity need to be prepared in advance. There is a pressing need therefore for a more practical personal system that allows novices to engage in musical performance more easily and with pleasure. As far as we know from our search of literature, there are no reports of such personal systems for dementia prevention. We believe that the addition of a leisure element, i.e., musical activity, will make exercise more attractive and motivate people to exercise and to keep exercising.

The authors have developed an electronic musical instrument, Cymis (cyber musical instrument with score), that allows novices to play their favorite pieces easily [11–13]. It has been recently applied to active music therapy for people with severe dementia [14]. For the present study, we have developed a new version of Cymis, Cymis-Foot, consisting of a computer, a pre-programmed score, and a user interface (rubber balloon and pressure sensor). To meet the above demands, it has the following two functions.

The first is that beginners can play their favorite pieces on Cymis-Foot by repeatedly pressing down with their feet while in a sitting position. By pressing on a balloon on the floor at a constant tempo, they can smoothly perform a musical piece. The second is that the PA guidelines can be easily met with Cymis-Foot.

The purpose of the present study was to develop Cymis-Foot and to demonstrate that the above two functions are satisfied. The participants in this study were 11 healthy cognitively normal males in their 20 s who were novice players (**Table 1**). They performed pieces at 40, 80, 120 and 160 bpm (beats per minute) with Cymis-Foot. We examined whether they were able to perform them easily and satisfy the PA guidelines.

Table 1 Participant's information.

	age	height (m)	weight (kg)	BMI
mean ± std	22 ± 1.0	1.7 ± 0.038	67 ± 14	22 ± 4.2

2. Method

2.1 Outline of Cymis

The structure of Cymis-Foot is shown in **Fig. 1**. The balloon sensor consists of a rubber balloon (Dip Sponge Sensor, Pacific Supply) and a differential pressure sensor SSCDRRN005PD2A5 (Honeywell, 34 kPa). The output is sent to an Arduino microcontroller as an I^2C digital signal, and in turn to the computer (Windows 10) via an USB. The pressure of the balloon is denoted by P_b. After processing the signal, the notes are sounded via the speaker.

The pressure signal generated when the participant repeatedly presses down on the balloon with the feet is

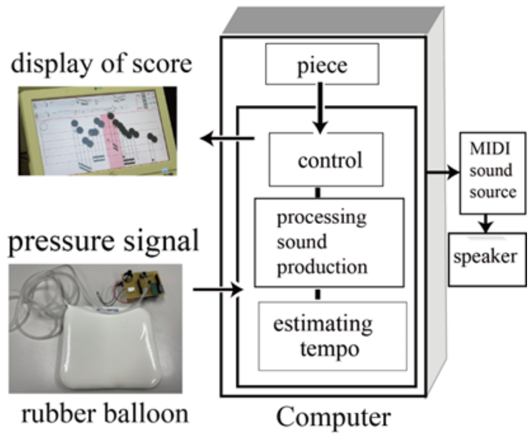


Fig. 1 Signal flow of Cymis-Foot.

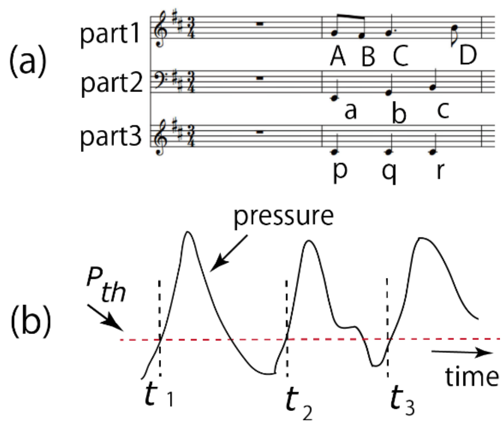


Fig. 2 Mechanism of sound production of Cymis-Foot.
(a) The built-in score in Cymis-Foot.
(b) t_1, t_2, and t_3 are the times when the pressure becomes higher than the threshold P_{th}.
At $t = t_1$, notes [p], [A] and [a] become note-on; at $t = t_2$, notes [q], [C] and [b] become note-on; at $t = t_3$, notes [r], [C] and [c] become note-on; [p], [q], [r] in part 3 are all silent.

shown schematically in **Fig. 2**. P_{th} is the threshold, and t_1, t_2, and t_3 are the times when the pressure P_b becomes greater than P_{th} (**Fig. 2b**). The piece in **Fig. 2a** is played as follows. At $t = t_1$, note [p] becomes active. Consequently, when $t_1 < t < t_2$, notes [A], [B] in part 1 and note [a] in part 2 become active (note-on) to produce sound. However, all notes in part 3 are silent. At $t = t_2$, the note [q] becomes active. As a result, note [C] of part 1 and [b] of part 2 become active at $t_2 < t < t_3$. This process continues.

In this study, all the notes in part 3 are quarter notes, so that the pace of the foot-stomping is equal to the tempo of the performance. The participants are instructed to keep their foot-stomping at a constant tempo by keeping time with a metronome. Hereinafter, the tempo of the piece is abbreviated as *tmp* (bpm).

2.2 Calculation of MET value

While there are advanced methods of estimating physical activity [15, 16], we use a simple method of calculating MET from the heart rate [17, 18]. When the MET value of physical activity is denoted by $MT(t)$, the heart rate during activity by $HRa(t)$, the heart rate at rest by HRr, and the heart rate index by $HRi(t)$, we obtain

$$MT(t) = 6\, HRi(t) - 5 \quad (1)$$

$$HRi(t) = \frac{HRa(t)}{HRr} \quad (2)$$

The heart rate is recorded at a sampling interval of 1 s with an optical heart rate sensor (Polar, Verity Sense) attached to the performer's forearm.

2.3 Performance experiments

2.3.1 Experimental procedure

The experimental procedure was as follows:
Step 1: Measurement of *HRr*
Step 2: Selection of the piece
Step 3: Set the height H_{ft}
Step 4: Set the threshold pressure, P_{th}
Step 5: Performance
Step 6: Psychological assessment
Step 7: Feedback of MET value

This study was approved by the Ethics Committee No. 2019–0247 of Niigata University and was conducted in accordance with the ethical principles of the Declaration of Helsinki.

2.3.2 Measurement of heart rate at rest

Step 1: The heart rate was measured at rest when the participant was sitting on a chair in a darkened room. First, the heart rate data measured during the last 5 minutes of the 10-minute period were divided into 10 equal parts of 30 seconds. Then, the mean value for each part was calculated. *HRr* was obtained as the average of the smallest and second smallest mean values; this procedure is based on the method of Kang et al. [18].

2.3.3 Protocol for performance experiments

Step 2: Each participant selected a favorite piece (such as Greensleeves and In the mood).
Step 3: The participant sat on a chair as shown in **Fig. 3**. He or she leaned against the back of the chair and put the hands at the side of the seat or held the seat. The seat height was set at 0.45 m from the floor. The linen cord was at height H_{ft} from the floor. The preset height was

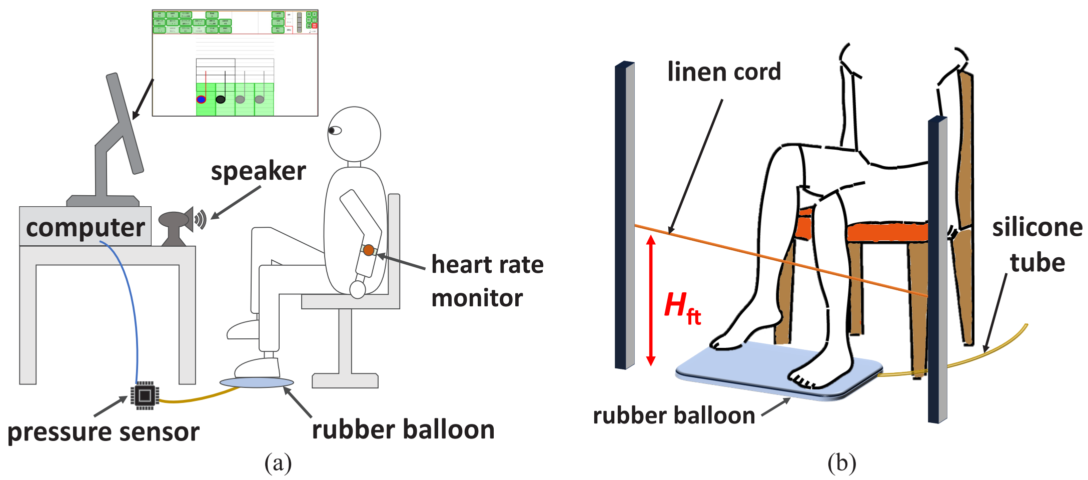


Fig. 3 Experimental set up of Cymis-Foot.
(a) The pressure of the balloon is monitored by the pressure sensor. The signal is then sent to the computer and the sound is produced from the speaker. The heart rate is monitored with an optical device.
(b) The linen cord is at height H_{ft} from the floor.

0.3 m for a piece at 40 bpm, 0.25 m for 80 bpm, 0.15 m for 120 bpm, and 0.1 m for 160 bpm.

Step 4: The pressure threshold P_{th} was set to either 3.6 kPa or 5.4 kPa based on the participant's feedback after short performances. The initial shape of the balloon was almost the same each time (approximately 0.25 kPa). The pressure varied almost linearly with the applied force (0.05 kPa/N).

Step 5: The participant was asked to stomp forcefully on the balloon to play and to lift the feet high enough such that the toes touched the linen cord (see **Fig. 3b**). The participant performed two pieces a day, in time with the electronic metronome. Each piece lasted 12 minutes. The order of the four pieces was chosen at random.

2.3.4 Psychological assessment using the Borg scale

Step 6: The intensity of physical activity was measured using the Borg scale [19], which is one of the measures of subjective exercise intensity. The scale measures rating of perceived exertion (RPE) and ranges from 6 to 20: very, very light = 7, very light = 9, fairly light = 11, somewhat hard = 13, hard = 15, very hard = 17, and very, very hard = 19. In addition, comments about the performance were collected from the participant.

2.3.5 Feedback of MET value to participants

Step 7: A record of $MT(t)$ (see **Fig. 6**) was presented to the participant after the performance. If the duration of $MT(t)$ above 3.0 was less than 10 minutes, the participant was asked to perform again on another day. Regarding re-performance, the participant was allowed to abstain from the experiment only when the duration of $MT(t)$ above 3.0 was not improved.

3. Results

3.1 Heart rate at rest

A typical record of the heart rate during rest is shown in **Fig. 4a** and **b**. The heart rate at rest, *HRr*, was approximately 76 bpm, and is shown as the red line in **Fig. 4a** and the red bar in the histogram of **Fig. 4b**.

3.2 Balloon pressure and heart rate during performance

Figure 5 shows a typical record of the balloon pressure P_b during the performance. The pressure changes sharply at the instant of pressing the balloon and exceeds the threshold, P_{th} without chattering. Furthermore, the tempo of the foot-stomping seems to be almost constant.

A typical record of *HRi* is shown in **Fig. 4c**. Using this record and Eq. (1), $MT(t)$ during the performance

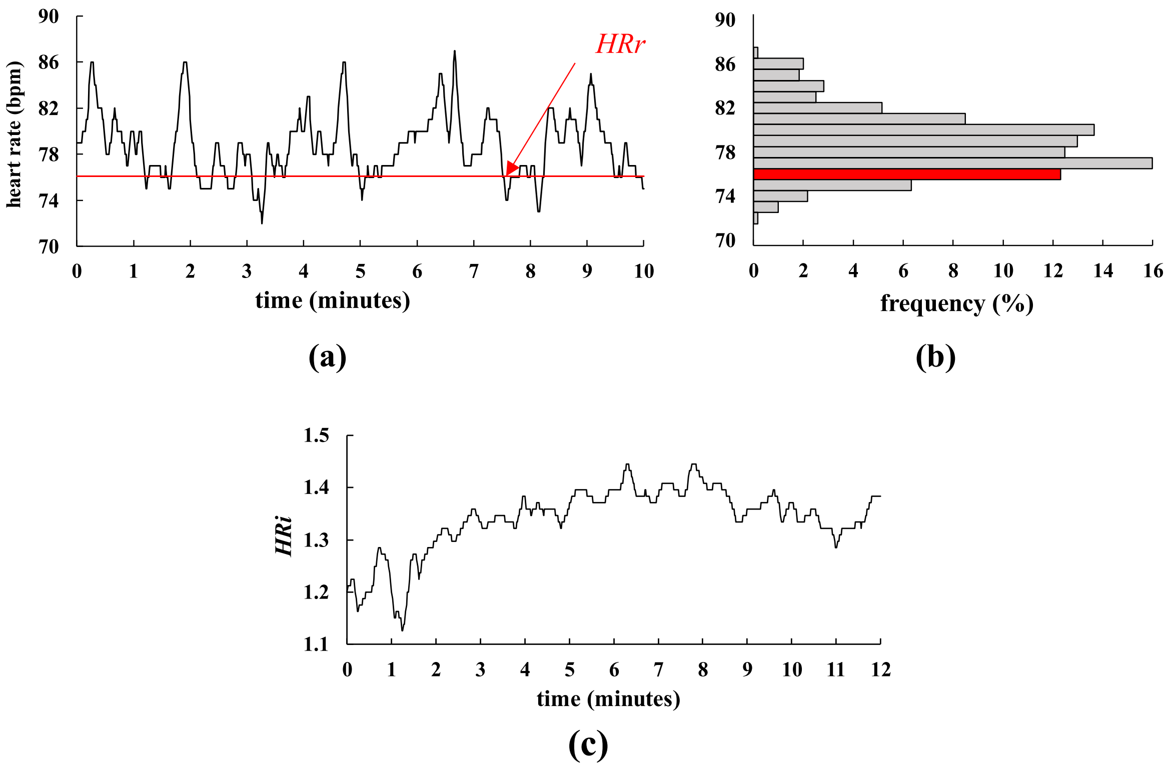


Fig. 4 Typical heart rate record.
(a) Time course of the heart rate at rest; the red line corresponds to *HRr*,
(b) Histogram of the heart rate record (a); the red bar corresponds to *HRr*,
(c) Time course of *HRi*.

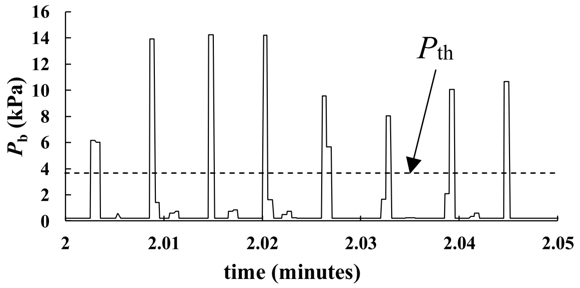


Fig. 5 Time course of the balloon pressure P_b caused by foot-stomping (*tmp* = 160 bpm).

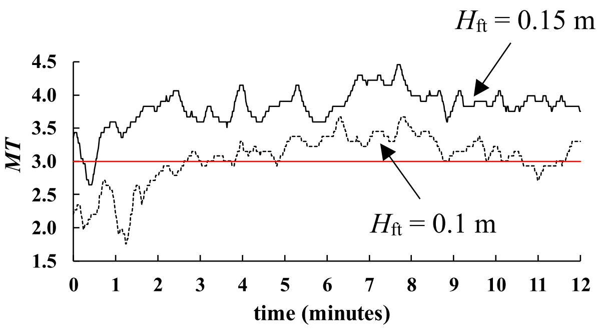


Fig. 6 Effect of H_{ft} on MET value.
Fine line, H_{ft} = 0.1 m; bold line, 0.15 m; *tmp*, 160 bpm.

was calculated (**Fig. 6**).

3.3 Results of MET record

Typical records of $MT(t)$ in performing the piece at 160 bpm are shown in **Fig. 6**. The fine line denotes the case when $H_{ft} = 0.1$ m, where the PA guidelines are not satisfied as seen from the figure; i.e. $MT(t)$ above 3.0 is not maintained for 10 minutes. On the other hand, the bold line denotes the case when $H_{ft} = 0.15$ m, which clearly satisfies the PA guidelines.

The results obtained from the 11 participants are summarized as follows. First, all the participants finally satisfied the PA guidelines in performing all the pieces at 80, 120, and 160 bpm, while seven failed in the first performance. Second, 5 of the 11 participants abstained and claimed that the 40 bpm performance was too slow to continue foot-stomping in order to meet the PA guidelines. This implies that a performance at 40 bpm is not suitable for this purpose.

3.4 Dependence of H_{ft} on tempo and METs

Since the height H_{ft} seems to be a key factor for meeting the PA guidelines, its dependence on tempo was examined. We calculated the mean value of $MT(t)$ averaged over 10 minutes, which is denoted by MT_{av}. We found that H_{ft} increased linearly with increasing MT_{av} at a fixed value of *tmp*. To simplify the analysis, this relationship was used.

First, there were nineteen performances of $3.0 \le MT_{av} < 4.0$. The height H_{ft} at MT_{av} was converted to the height at $MT_{av} = 3.5$, which is denoted by $\hat{H}(3.5)$ and given by

$$\hat{H}(3.5) = \frac{3.5 - 1.0}{MT_{av} - 1.0} H_{ft} \qquad (3)$$

This is because the value of MET is theoretically 1.0 at height = 0. A data set $\{MT_{av} = 3.5, tmp, \hat{H}(3.5)\}$ was obtained from nineteen performances. The height $\hat{H}(3.5)$ was plotted against *tmp* in **Fig. 7a1**. The height decreases with increasing tempo. This can be approximated by a straight line with $R^2 = 0.80$ by the equation

$$\hat{H}(3.5) = -1.7 \times 10^{-3}\, tmp + 0.42 \qquad (4)$$

This equation can be applied to preset the height H_{ft} before starting a performance.

Second, there were fifteen performances of $4.0 \le MT_{av} < 6.0$. A data set $\{MT_{av} = 5.0, tmp, \hat{H}(5.0)\}$ for $MT_{av} = 5.0$ was obtained from these performances with the following conversion:

$$\hat{H}(5.0) = \frac{5.0 - 1.0}{MT_{av} - 1.0} H_{ft} \qquad (5)$$

The height $\hat{H}(5.0)$ was plotted in **Fig. 7b1**. The relationship can be approximated by a straight line (R^2 = 0.68) as follows:

$$\hat{H}(5.0) = -1.7 \times 10^{-3}\, tmp + 0.45 \qquad (6)$$

and this is shown by the solid line in **Fig. 7b1**.

We assumed that the product of the tempo and the height reflect the work rate of the foot-stomping (see Discussion). The product of *tmp* and $\hat{H}(3.5)$ was plotted in **Fig. 7a2** and that of $\hat{H}(5.0)$ in **Fig. 7b2**. The mean and standard deviation of the products at 80, 120 and 160 bpm are 23.9 ± 5.8 m/min for $MT_{av} = 3.5$, and 28.4 ± 4.7 m/min for $MT_{av} = 5.0$, with a significant difference ($p < 0.05$) between the two. This result indicates that the work rate (the product) might be greater when the participants performed the physical activity (MT_{av}) at a higher intensity. Performances of 40 bpm were not included in calculating the mean.

3.5 Results of psychological assessment

The results of RPE on the Borg scale are shown in the box plot in **Fig. 8**. The RPE of all the participants ranges from 10 to 16 (very light to hard). This indicates that the foot-stomping in this study was not sufficiently excessive to cause motor impairment of the participants.

4. Discussion

4.1 Foot-stomping performance in accordance with WHO guidelines

WHO [1, 2] and MHJW [3] have stated that dementia prevention is possible through appropriate intervention. The PA guidelines provide the most important informa-

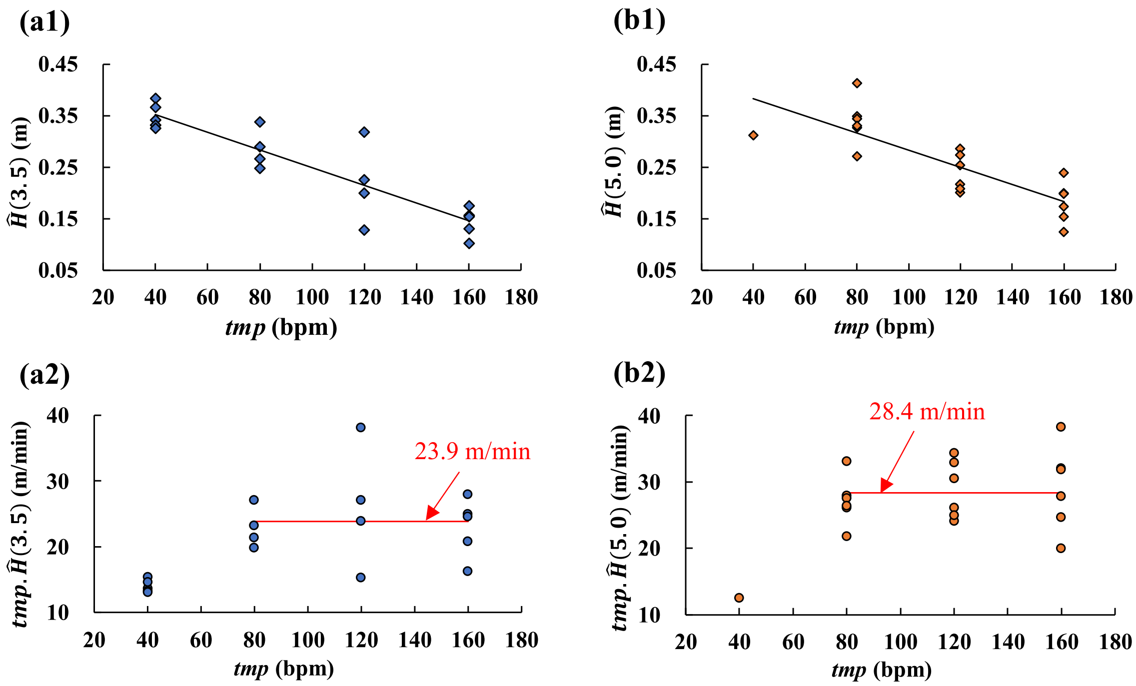


Fig. 7 Tempo-dependence of the height and the product of tempo and height.
(a1), (a2); $3.0 \leq MT_{av} < 4.0$, nineteen performances,
(a1) $\hat{H}(3.5)$, the height at $MT_{av} = 3.5$,
(a2) product of $\hat{H}(3.5)$ and tempo,
(b1), (b2); $4.0 \leq MT_{av} < 6.0$, fifteen performances,
(b1) $\hat{H}(5.0)$, the height at $MT_{av} = 5.0$,
(b2) product of $\hat{H}(5.0)$ and tempo.

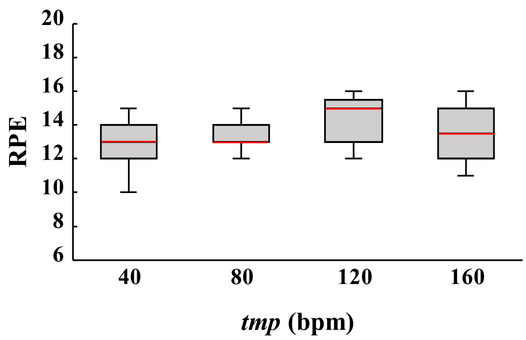


Fig. 8 Rating of perceived exertion (RPE) on the Borg scale of all participants at four different tempos.

tion to determine the direction of research and development. We believe that Cymis-Foot is a new system with the following features; novices can play a favorite piece of music by foot-stomping while seated and the activity during performance can satisfy the PA guidelines.

It is easy to play musical pieces with Cymis-Foot since stomping the feet is similar to walking. We found in a preliminary study that the time difference between the foot-stomping of one participant and the ideal time (the metronome sound) was 67.0 ± 53.7 ms for 90 bpm, and the maximum difference was 357 ms for all pieces at 60, 90, 120, and 180 bpm. Another two participants showed similar results. These differences in time were not large, suggesting a possibility that these participants may be able to play in an ensemble.

In this study, foot-stomping at a fixed tempo was used in quantitative evaluation, but a variable tempo is entirely possible. We found that novices could easily perform "Ravel's Bolero" with 760 notes at approximately 70 bpm by foot-stomping at different tempos.

4.2 Method for estimating MET from the heart rate

The MET is a measure of oxygen consumption during physical activity, and can be calculated by measuring the oxygen uptake (VO_2) using portable spirometers or metabolic analyzers. However, these devices are not suitable for routine use due to the high price, difficulty of operation, and potential to interfere with the exercise itself. Recently, there are reports of using small wearable sensors and machine learning algorithms to estimate VO_2, but this is still in the research stage [15, 16].

Wicks et al. [17] and Kang et al. [18] found a clear relationship between MET and heart rate index given by Eq. (1). These reports helped us in analyzing the data in this study. First, the heart rate can be measured with commercially available heart rate monitors, which is important from a practical point of view. Second, Eq. (1) was derived based on the results of 60 studies with various conditions, including the type of exercise and age [17]. A high correlation coefficient $R^2 = 0.99$ indicates that the equation is a highly reliable experimental formula.

Finally, Kang et al [18] studied 60 healthy individuals and showed no significant difference between the measured and estimated values of MET. They also showed a variation in the calculated values. For example, at 40% of $\dot{V}O_{2max}$, the measured value was 5.28 ± 0.98 METs while the calculated value from the heart rate was 5.53 ± 1.21 METs. The coefficient of variation (CV) of the calculated values was approximately 0.21.

4.3 Tempo and height

The product of tempo and H_{ft} plotted in **Fig. 7** is an index that may partly reflect the energy consumption rate. The following assumption was made for this calculation. The potential energy in foot-stomping is multiplied by three variables, m_{ft}, g, and H_{ft}, where they are the mass of the lower leg, the acceleration, and the height, respectively. The work rate is estimated by the product of m_{ft}, g, H_{ft} and the tempo. Let m_{ft} be proportional to the participant's weight. Then, the product of the four variables, represented by m_{ft}, g, H_{ft}, and tempo, divided by the weight is proportional to the product of H_{ft} and tempo. Note that normalization by weight was done using the commonly used formula: MET = kilocalories / (duration in hours) / weight in kilograms [20].

4.4 Psychological assessment

In the psychological assessments, there were no negative comments for the tempos of 80, 120 and 160 bpm. However, there were comments that 40 bpm was too slow and difficult to perform. Additionally, five of the eleven participants found it difficult to achieve 3 METs at 40 bpm. The tempo at 40 bpm was probably too slow to consume sufficient energy. Pieces at faster tempos are recommended.

4.5 Future outlook on research

The results of this study were obtained from 11 participants in their 20 s. However, the PA guidelines are recommended for adults over 18 years of age, and the participants in this study constitute only a part of the recommended population. Therefore, we plan to perform the performance adopted in this study in cognitively normal participants in their 30 s to 60 s, and to examine the tempo and H_{ft} required to satisfy the PA guidelines.

Furthermore, we plan to develop a system that takes into account fun and attractiveness of music performance. Since the electronic instrument Cymis can play 16 parts simultaneously, a player can play his or her favorite piece at his or her own tempo in an orchestral style. Experiments are planned to evaluate the enjoyment and PA guidelines. We are also considering building a system that allows multiple players to play in an ensemble while maintaining the tempo.

Conflict of Interest Discloser

We have no conflict of interest with any company or commercial organization.

Acknowledgement

Part of this research was supported by a Grant-in-Aid for Scientific Research (Substrate C, Proposal No. 20k00241).

References

1. World Health Organization: Risk reduction of cognitive decline and dementia: WHO guidelines 1 January 2019.
2. World Health Organization: Global recommendations on Physical Activity for Health. WHO 1 January 2010.
3. Ministry of Health, Labour and Welfare, 2013: https://www.mhlw.go.jp/stf/houdou/2r9852000002xple.html
4. Zhu J,Ge F,Zeng Y,Qu Y, Chen W, Yang H, Yang L, Fang F, Song H:Physical and mental activity, disease susceptibility, and risk of dementia. A prospective cohort study based on UK Biobank. Neurology. **99**(8), e799-e813, 2022.
5. Verghese J, Lipton R B, Katz M J, Hall C B, Derby C A, Kuslansky G, Ambrose A F, Sliwinski M, Buschke H: Leisure activities and the risk of dementia in the elderly. N Engl J Med. **348**(25), 2508–2516, 2003.
6. Balbag MA,Pedersen NL, Gatz M: Playing a musical Instrument as a protective factor against dementia and cognitive impairment: A population-based twin study. Int J Alzheimer's Dis. **2014**, 836748, 2014.
7. Walsh S, Luben R, Hayat S, Brayne C: Is there a dose-response relationship between musical instrument playing and later-life cognition? A cohort study using EPIC-Norfolk data. Age Ageing. **50**(1), 220–226, 2021.
8. Mansky R, Marzel A, Orav, Chocano-Bedoya PO, Grünheid P, Mattle M, Freystätter G, Stähelin HB, Egli A, Bischoff-Ferrari HA: Playing a musical instrument is associated with slower cognitive decline in community-dwelling older adults. Aging Clin Exp Res. **32**(8), 1577–1584, 2020.
9. Satoh M, Ogawa J, Tokita T, Nakaguchi N, Nakao K, Kida H, Tomimoto H: The effects of physical exercise with music on cognitive function of elderly people: Mihama-Kiho Project. PLoS One. **9**(4): e95230, 2014.
10. Doi T, Verghese J, Makizako H, et al. Effects of cognitive leisure activity on cognition in mild cognitive impairment: results of a randomized controlled trial. J Am Med Dir Assoc **18**, 686, 2017.
11. Takahashi R, Maeda Y, Tanaka K, Ichinose T, Okuno R, Akazawa K: Development of a novel breath-touch electronic instrument that enables beginners to engage in ensemble playing.Adv Biomed Eng. **12,** 64–73, 2023.
12. Akazawa K, Ichinose T, Matsumoto K, Ichie M, Masuko T, Okuno R: Novel electronic musical instrument with pre-programmed

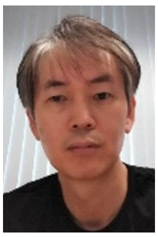
score for the disabled to enjoy playing music. Adv Biomed Eng. **6**, 1–7, 2017.

13. Ichinose T, Takehara N, Matsumoto K, Aoki T, Yoshizato T, Okuno R, Watabe S, Sato K, Masuko T, Akazawa K: Development of a system combining a new musical instrument and Kinect: Application to music therapy for children with autism spectrum disorders. Int J Tech Inclusive Educ. **3**(1), 938–947, 2016.
14. Kondo E, Tabei K, Okuno R, Akazawa K: Case Report: Accessible digital musical instrument can be used for active music therapy in a person with severe dementia and worsening behavioral and psychological symptoms: A case study over a year and a half. Front Neurol. **13**, 831523, 2022.
15. Zignoli A, Fornasiero A, Ragni M, Pellegrini B, Schena F, Biral F, Laursen PB: Estimating an individual's oxygen uptake during cycling exercise with a recurrent neural network trained from easy-to-obtain inputs: A pilot study. PLoS One. **15**(3), e0229466, 2020.
16. Pavel Davidson 1, Huy Trinh 1, Sakari Vekki 2, Philipp Müller:-Surrogate modelling for oxygen uptake prediction using LSTM neural network. Sensors (Basel). **23**(4), 2249, 2023.
17. Wicks JR, Oldridge NB, Nielsen LK, Vickers CE: HR index--a simple method for the prediction of oxygen uptake. Med Sci Sports Exerc. **43**(10), 2005–2012, 2011.
18. Kang J, Ratamess NA, Faigenbaum AD, Bush JA, Roser C, Montemarano D, Mercado H, Choma M, Mendez C, Pollock M: Use of heart rate index to predict oxygen uptake - A validation study. Int J Exerc Sci. **13**(7), 1705–1717, 2020.
19. Borg G: Psychophysical scaling with applications in physical work and the perception of exertion. Scand J Work Environ Health. **16**(Suppl 1), 55–58,1990.
20. Ainsworth BE, Haskell WL, Herrmann SD, Meckes N, Bassett DR Jr, Tudor-Locke C, Greer JL, Vezina J, Whitt-Glover MC, Leon AS: 2011 Compendium of physical activities: A second update of codes and MET values. Med Sci Sports Exerc. **43**(8), 1575–1581, 2011.

Natsuki Asakura

Natsuki Asakura received a B.E. (2022) in Faculty of Engineering from Niigata University. He is currently studying in Graduate School of Science and Technology, Niigata University. His research fields are human interface designs in assistive technologies.

Yoshinobu Maeda



Yoshinobu Maeda received a M.E. (1995) and a Ph.D. (1998) in Graduate School of Engineering Science from Osaka University. He was JSPS Research Fellow in Osaka University (1995–98), Research Associate in Niigata University (1998–2005), Associate Professor in Niigata University (2005–15), and presently, Professor in Graduate School of Science and Technology, Niigata University. His research fields are analyses of neuro-dynamics and socio-dynamics, human interface designs in assistive technologies, etc. He is a regular member of JSMBE, JSWSAT, IEE of Japan, and a senior member of IEICE.

Mamoru Iwaki

Mamoru Iwaki received a M.E. (1991) and a Dr. Eng. (1994) in electronic and information engineering from the University of Tsukuba. He was Research Associate in School of Information Science, Japan Advanced Institute of Science and Technology (1994–1998), and presently, Associate Professor in Graduate School of Science and Technology, Niigata University. His research interests include speech signal processing, human auditory systems and information processing. He is a regular member of IEICE, ASJ, JSWSAT, and IEEE.

Koji Tanaka

Koji Tanaka received a U.M. (1992) in Sweelinck Concervatoru in Amsterdam, and received a M.M. (1993) in Graduate School of Music from Tokyo National University of Fine Arts and Music. He was Assistant in Niigata University (1993–94), Lecturer in Niigata University (1994–1997), Associate Professor in Niigata University (1997–2019), and presently, Professor in Graduate School of Modern Society and Culture, Niigata University. His research fields are piano performance and music education, piano education, music management, etc. He is a regular member of JMES, JPTA, JAAM.

Tomoko Ichinose

Tomoko Ichinose received her PhD from the Graduate School of Educational Informatics, Tohoku University in 2017. Associate Professor (2011–17) and presently, Professor of the School of Music, Mukogawa Women's University. Her specialty is in music therapy. Board-certified music therapist (Japan) (U.S.A).

Ryuhei Okuno

Ryuhei Okuno received a Ph. D. (1997) in Graduate school of Science and Technology from Kobe University. He was an Assistant Professor in Kobe University (1997–2000), Assistant Professor in Osaka University (2000–2008), Associate Professor in Setsunan University (2008–2013) and currently, Professor in Department of Electrical and Electronic Engineering, Setsunan University. His research interests include the myoelectric prosthetic hand, measuring and analysis of electromyogram. He is a regular member of JSMBE, SOBIM Japan and IEEE.

Kenzo Akazawa

Kenzo Akazawa received his B.E, M.E. and D. Eng. degrees in electrical engineering from Osaka University, Japan, in 1965, 1967, and 1974, respectively. He was a Jyoshu (assistant professor) of Osaka University in 1971, a Professor of Kobe University in 1990, and Osaka University in 2000 and Osaka Institute of Technology in 2006. He was a Research Associate of University of Alberta in 1980. He is a Professor Emeritus of Osaka University and a Director, Advanced Applied Music Institute, Kibounoie Takarazuka. He was an Associate Editor, Rehabilitation Eng. IEEE in1996, and a Vice President of JSMBE in 2002.His research interests include biomedical engineering on muscle and music-supported assistive technology.