Kobe University Repository : Kernel

PDF issue: 2026-11-19

Exercising Alone or Exercising With Others and Mental Health Among Middle-Aged and Older Adults: Longitudinal Analysis of Cross-Lagged and Simultaneous Effects

Harada, Kazuhiro

Masumoto, Kouhei

Kondo, Narihiko

(Citation)
Journal of Physical Activity and Health,16(7):556-564

(Issue Date)
2019-07

(Resource Type)
journal article

(Version)
Accepted Manuscript

(Rights)
Accepted author manuscript version reprinted, by permission, from [Journal of Physical Activity and Health, 2019, 16(7): pp556-pp564, https://doi.org/10.1123/jpah.2018-0366.
© Human Kinetics, Inc.

(URL)
https://hdl.handle.net/20.500.14094/90006238

KOBE UNIVERSITY

Exercising alone or exercising with others and mental health among middle-aged and older adults: longitudinal analysis of cross-lagged and simultaneous effects

Running head: Exercise and mental health

Manuscript type: Original Research

Key words: accelerometry; aging; exercise; mental health; physical activity

Abstract word count: 192 words

Manuscript word count: 5006 words

Date of manuscript submission: 13 March 2019

Abstract

Background: Although the beneficial effects of physical activity and exercise on mental health are well-known, the optimal conditions for them for benefitting mental health are still unclear. Engaging in exercise with others might have more desirable effects on mental health than engaging in exercise alone. This study examined the associations between exercising alone, exercising with others, and mental health among middle-aged and older adults.

Methods: Baseline and one-year follow-up surveys were conducted with 130 individuals. Time spent exercising alone or with others was measured using a 7-day diary survey. Total physical activity was objectively measured using an accelerometer. Mental well-being was assessed using the simplified Japanese version of the World Health Organization Five Well-Being Index, and mental distress was assessed using the Japanese version of the Kessler Distress Scale (K6).

Results: Cross-lagged and simultaneous effects models revealed that exercising with others positively influenced mental well-being. Exercising alone and total physical activity did not significantly influence mental well-being. Neither total physical activity, exercising alone, nor exercising with others was significantly associated with mental distress.

Conclusions: Engaging in exercise with others could be effective in improving mental well-being relative to engaging in exercise alone.

Keywords: accelerometry; aging; exercise; mental health; physical activity

Introduction

Maintaining and improving mental health is a public health priority. It is estimated that neuropsychiatric disorders, mostly due to mental health problems, account for approximately 14% of the global burden of disease, and that mental health problems are an important risk factor for suicide[1]. The Japanese Ministry[2] estimated that in 2014 there were approximately 5.2 million patients with mental and behavioral disorders in Japan, and that the total numbers of patients with such disorders was highest among middle-aged to older adults aged 60 to 69 (approximately 1.1 million patients). Thus, mental health problems among middle-aged to older adults is a substantive issue in Japan. Previous studies have proposed that engaging in physical activity is an effective strategy to maintain and improve mental health. Systematic reviews and meta-analyses have concluded that physical activity has desirable effects on mental health variables such as depression[3,4], anxiety[5], and mental well-being[6].

However, despite these previous investigations of the relationships between physical activity and mental health, it remains unclear what specific conditions of physical activity are optimal for benefitting mental health. The identification of such optimal conditions is essential for establishing more effective strategies to promote mental health through engagement in physical activity. Domains of physical activity could be a key factor for identifying the optimal conditions for physical activity. The four common domains of physical activity are occupation, transportation, household, and leisure time[7]. A recent meta-analysis[8] showed that physical activity performed in leisure time has more desirable effects on metal heath than physical activities performed in other domains. The major component of leisure-time physical activity is exercise[7,9]. Exercise is conceptualized as physical activity that is planned, structured, repetitive, and designed to promote physical fitness and health[7,9]. Desirable effects of exercise on mental health status, such as depression[10], anxiety[11,12], and mental well-being[13], have been confirmed by systematic reviews and meta-analyses.

The effects of exercise on mental health might be modulated by social context. In particular, according to the social interaction hypothesis, engaging in exercise with others might have more desirable effects on mental health than engaging in exercise alone. The social interaction hypothesis has been proposed as one potential mechanism to explain exercise and mental-health relationships[14]. This hypothesis suggests that exercise can provide more opportunities to interact with others, and that increases in such opportunities causes desirable changes in mental health[14,15]. Several population-based studies have revealed that engaging in exercise with others is associated with better self-rated health[16] and mental health status[17], but that engaging in exercise alone is not significantly associated with them. However, one of these studies was cross-sectional[16] and neither[16,17] considered bidirectional associations of exercise and mental health, something that previous studies[18,19] suggest may exist. To establish additional effects of exercise with others, further longitudinal investigations are necessary.

The purpose of the present study was to examine the longitudinal associations between exercising alone, exercising with others, and mental health among middle-aged and older adults. It was hypothesized that exercising with others would be more closely associated with mental health than would exercising alone.

Methods

Participants and Procedures.

The present study targeted middle-aged and older populations living in four areas located in Xxxxx Prefecture (deleted for blinded review process), Japan: Xxxx Ward of Xxxx City; Xxxxxxxx City; Xxxx City; and Xxxx City. There are approximately 135 thousand people in Xxxx Ward of Xxxx City (4684 per km^2), 90 thousand people in Xxxxxxx City (2645 per km^2), 77 thousand people in Xxxx City (437 per km^2), and 37 thousand people in

Xxxxx City (57 per km^2). From the official basic resident register of the four areas, 540 men aged 59, 64, or 69 in April of 2016 (135 men per area) and their 540 wives were randomly selected. The recruitment document was sent to 540 couples to invite them to participate in our accelerometer and diary survey for seven consecutive days, along with our questionnaire survey. One hundred and fifty-eight people (79 couples) agreed to participate in the survey (*wave 1*). Book coupons worth 5000 Japanese yen were provided as incentives for each couple. The reason for recruiting couples was that the survey was part of a larger study with additional objectives; we examined spousal concordance of total physical activity among couples. Our previous work[20] reported that spousal concordance for objectively measured total physical activity was unclear.

After one year, we asked the 158 original participants (79 couples) to participate in a follow-up survey. Among them, 138 individuals (69 couples) agreed to participate (*wave 2*). The content of the one-year follow-up survey was the same as the baseline survey.

Among the 138 participants of the follow-up, 130 individuals met the inclusion criteria for the physical activity data (detailed below). Among them, one individual who had been diagnosed with clinical depression was excluded. Thus, the present study analyzed the data of 129 individuals.

Informed consent was obtained from all individual participants included in the study. The present study received prior approvals (baseline survey, No. 209; 1-year follow-up survey, No.286) from the Ethical Committee in the Graduate School of Xxxxxxxxx Xxxxxx xx Xxxxx Xxxxxxxxx xxx Xxxxxxxx, Xxxx University.

Measures.

Total physical activity.

The present study examined total physical activity as an important potential confounder in the relationships between exercise alone, exercise with others, and variables

relating to mental health. A triaxial accelerometer (HJA-750C, Active Style Pro, Omron Healthcare Co., Ltd., Kyoto, Japan) was used to measure the amount of time participants engaged in locomotive light physical activity, household light physical activity, locomotive moderate-to-vigorous physical activity, and household moderate-to-vigorous physical activity. Following Pate et al.[21], the present study defined moderate-to-vigorous physical activity as activities involving ≥ 3 metabolic equivalents, and light physical activity as activities involving 1.6 to 2.9 metabolic equivalents. The accelerometer can classify physical activity into locomotive and household activities through a validated algorithm[22]. Examples of locomotive activities are walking, jogging, and climbing stairs, whilst examples of household activities are laundry, moving a small load, and vacuuming[22].

The period of the accelerometer survey was seven consecutive days. The participants were asked to wear the accelerometer on their waists all day, except when bathing and sleeping, and to go about their normal routines. The monitored results were blinded, so that the individual participants could not check their recorded data themselves. The algorithm of the accelerometer used in this study (HJA-750C) is identical to that of the older model (HJA-350IT) used in previous studies, although the body size and data-download system differ between the newest and older models. The validity of the measurements provided by the HJA-350IT has been confirmed[23], and compared with other types of accelerometers available in Japan, the HJA-350IT provides the most accurate estimate of total energy expenditure in free-living conditions compared to the doubly labeled water method[24].

Wearing time was calculated by subtracting the non-wearing time from 24 hours. A period of at least 60 minutes in which accelerometer data were not recorded was defined as non-wearing time. The epoch length of the accelerometer was set at 10 seconds. An eligible day was defined as wearing the accelerometer for between 10 and 20 hours over a one-day period. Previous studies[25] have typically used wearing time ≥ 10 hours per day as an inclusion

criterion. Although we asked individuals to take off the accelerometer when sleeping, the data indicated that a few individuals wore it when sleeping. Thus, we excluded data that were collected on days when the wearing time was ≥ 20 hours. Following the criteria used in other studies[25], participants needed to have at least 4 eligible days for their data to be included in the study for further analysis.

Similar to previous studies[26,27,28], the daily data on physical activity were divided by total accelerometer wearing time to eliminate the effects of wearing time itself. Thus, the average time engaged in each behavior per hour of wearing time was analyzed in the present study.

Exercise alone or with others.

Exercise behavior was measured by the diary survey. The period of the diary survey was seven consecutive days, which were same days as the accelerometer survey. Because the term exercise is common in Japan, the present study did not provide a specific definition of exercise. Instead, we listed walking for exercise, calisthenics, and sports, as examples of exercise. Participants were asked to record the time spent on exercise and whether they exercised with others or alone, before going to bed each day. From the records of the dairy survey, the average time spent exercising alone each day, and the average time spent engaging in exercise with others each day, were calculated and analyzed in the present study.

Mental health.

Mental well-being and mental distress were measured by questionnaire survey as indices of mental health. Mental well-being and mental distress represent positive and negative aspects of mental health, respectively. To measure mental well-being, the simplified Japanese version of the World Health Organization Five Well-Being Index (WHO-5)[29], was utilized. This index consists of five items, with participants responding to each item on a four-point Likert scale (scored 0–3). Scores were summed across the four items, giving a range of

values of 0–15, with higher scores indicating greater mental well-being.

Mental distress was measured by the Japanese version of the Kessler Distress Scale (K6)[30]. This scale consisted of six items, with participants responding to each item on a five-point Likert scale (scored 0–4). Scores were summed across the six items, giving a range of values of 0–24, with higher scores indicating greater mental distress.

Basic demographic factors.

Gender, age, educational background (junior high/high school, beyond high school) were measured by the questionnaire survey as basic demographic factors.

Analyses

Among the 129 individuals who met the inclusion criteria of wearing status for the accelerometer, one individual had missing data for mental well-being at wave 2, and another individual had missing data for mental distress at wave 2. The missing data of these two individuals were treated by pair-wise deletion.

The Pearson's correlations of basic demographic factors with total physical activity, exercise, and mental health variables at wave 1 were calculated. Gender (men = 0, women = 1 and educational background (junior high/high school = 0, beyond high school = 1) were treated as dummy variables. Paired t-tests were conducted to examine longitudinal changes in total physical activity, exercise, and mental health variables from wave 1 to wave 2.

Path analyses were then conducted to examine bidirectional longitudinal associations of total physical activity and exercise variables with mental health. Similar to previous studies for bidirectional longitudinal associations[31,32,33], both cross-lagged and simultaneous effects models were examined to confirm robustness of the associations. The dependent variables were mental well-being and distress. Thus, the present study examined four models in total: (a) a cross-lagged effects model for mental well-being; (b) a simultaneous effects model for mental well-being; (c) a cross-lagged effects model for mental distress; and (d) a simultaneous

effects model for mental distress. The absolute values of the Pearson's correlation coefficients between basic demographic factors, total physical activity, and exercise variables, ranged from 0.03 to 0.61, which is lower than the benchmarks for considering multicollinearity: 0.70[34] and 0.85[35]. Thus, multicollinearity was not considered a serious issue when examining these models.

In the cross-lagged effects model, there are mainly three types of paths. The first type are the autoregressive paths from wave 1 to wave 2 for total physical activity, exercise alone or with others, and the mental health variables. The autoregressive paths represent the longitudinal stability of each variable. The second type are the cross-lagged paths from total physical activity and exercise variables at wave 1 to mental health variables at wave 2. The third type of path are cross-lagged paths from mental health variables at wave 1 to total physical activity and exercise variables at wave 2. By including both types of cross-lagged paths, the bidirectional relationships of mental health with total physical activity, exercise alone, and exercise with others can be estimated. In the cross-lagged effects model, the cross-sectional correlations among each physical activity and exercise variables at both wave 1 and wave 2, and the cross-sectional correlations of total physical activity and exercise variables with mental health variables at wave 1, were included. Furthermore, to adjust for potential confounding effects of the basic demographic factors, the paths from the basic demographic factors to total physical activity, exercise alone or with others, and mental health variables at wave 1 were added to the model if significant Pearson's correlations were observed for these demographic variables.

Similar to the cross-lagged effects model, the simultaneous effects model has three main types of paths. The first type are autoregressive paths from wave 1 to wave 2 for each variable. The second type are cross-sectional paths from total physical activity and exercise variables at wave 2 to mental health variables at wave 2. The third type of path are cross-

sectional paths from mental health variables at wave 2 to total physical activity and exercise variables at wave 2. In the simultaneous effects model, the cross-sectional correlations among each physical activity and exercise variable at both wave 1 and wave 2, and the cross-sectional correlations of total physical activity and exercise variables with mental health variables at wave 1, were included. As described for the cross-lagged effects model, potentially confounding paths from the basic demographic factors were also added, as indicated by Pearson's correlations. Thus, in summary, while the cross-lagged effects model examines bidirectional relationships among the variables over time, the simultaneous effects model examines the synchronous relationships among them.

The goodness of fit index (GFI), comparative fit index (CFI), and root mean square error of approximation (RMSEA), were used as indices of model fit. Statistical significance was set at $p<0.05$. All statistical analyses were carried out using SPSS (version 21.0; IBM Japan, Ltd., Tokyo, Japan) and AMOS (version 21.0; IBM Japan, Ltd., Tokyo, Japan) software packages.

Results

Characteristics of Participants

Among the 129 participants of the present study, 66 of them (51.2%) were men, and 63 of them (48.8%) were women. At wave 1, their mean age was 63.1 years old (standard deviation, 4.7). Sixty-eight individuals (52.7%) graduated from junior-high or high school, and 61 individuals (47.3%) were educated beyond high school.

Pearson's correlations showed that being a woman was significantly correlated with younger age ($r = –0.30$, $p = 0.001$), higher levels of household light physical activity ($r = 0.48$, $p < 0.001$), lower levels of locomotive moderate-to-vigorous physical activity ($r = –0.29$, $p = 0.001$), higher levels of household moderate-to-vigorous physical activity ($r = 0.32$, $p <$

0.001), and lower levels of exercising alone ($r = –0.27$, $p = 0.002$). Age was significantly correlated with exercise alone ($r = 0.27$, $p = 0.002$). These significant correlations led to the inclusion of these factors in the path analyses. Gender and age were not significantly correlated with mental health variables. There were no significant correlations of educational background with gender, age, total physical activity, exercise alone or with others, or mental health variables.

Associations between Total Physical Activity Levels, Exercising Alone or with Others, and Mental Health

The means and standard deviations of total physical activity, exercise alone and with others, and mental health variables at wave 1 and wave 2 are shown in Table 1. Paired t-tests indicated that none of these variables were significantly changed from wave 1 to wave 2.

The results of the cross-lagged and simultaneous effects models for mental well-being are presented in Figure 1 and Figure 2, respectively. In both models, more time spent exercising with others positively influenced mental well-being, and better mental well-being positively influenced time spent exercising alone. The converse relationships among these variables were non-significant in both models. None of the physical activity variables were significantly associated with mental well-being.

Figure 3 and Figure 4 represent the results of the cross-lagged and simultaneous effects models for mental distress, respectively. None of the paths from total physical activity and exercise variables to mental distress, or their converse paths, were significant.

Discussion

The present study found that more self-reported exercise time with others reflected better mental well-being among middle-aged and older adults. However, self-reported levels of exercising alone were not significantly associated with better mental well-being. These

results indicate that engaging in exercise with others would be more effective for improving mental well-being than engaging in exercise alone. As far as we know, this is the first study to show the effects of exercise with others on mental health after adjustments for objectively measured total physical activity and after the examination of the bidirectional relationships between these variables. Takeda et al.[17] revealed that while exercise with others at baseline was a predictor of mental health status at 5-year follow-up after adjustment for mental health status at baseline and other potential confounders, exercise alone at baseline was not a significant predictor of mental health status. However, Takeda et al.[17] did not consider longitudinal changes in exercise behavior and bidirectional relationships to mental health. Thus, after addressing this methodological weakness of the previous study[17], the present findings suggest that the influence of exercise on mental health is different for exercising with others or alone. Although it has been reported that engaging in social activity has beneficial effects on mental health[36,37], no previous studies have compared the relative impacts of exercise with others (i.e., physically-active social activity), exercise alone, and sedentary social activities, on mental health. Further well-designed experiments are necessary to determine the relative impacts of these behaviors.

Whilst several mechanisms have been proposed to explain the influences of physical activity and exercise on mental health, according to the findings of the present study, the social interaction hypothesis could play a dominant role. The underlying mechanisms for this are not fully understood. Potential mechanisms include physiological, psychological, and social factors. Examples of physiological factors are those relating to neuroendocrine, neurotrophic, inflammatory, and oxidative stress effects[38]. As for psychological factors, distraction, self-efficacy, and mastery are described as important contributors[15]. However, our data does not support hypotheses based on physiological and psychological factors because total physical activity and exercise alone were not significantly associated with mental well-

being. A meta-analysis[8] proposed that psychological or social pathways, rather than physiological pathways, would offer an effective explanatory framework to link physical activity to mental health. Moreover, for physiological pathways, previous reviews[3,6] have not supported the dose-response relationships between quantitative amounts of physical activity and mental health variables. Instead, the social interaction hypothesis, which proposes that social relationships and support during exercise lead to better mental health[14,15], is sufficient to understand the results of the present study. Supporting the social interaction hypothesis, previous studies[39,40] examining acute effects of exercise have shown that engaging in exercise with others can induce better affective responses than exercising alone.

However, contrary to the findings for mental well-being, a significant relationship between time spent exercising with others and mental distress was not observed in either the cross-lagged or simultaneous effects models. These results indicate that exercise with others might have greater influence on positive than on negative aspects of mental health status. A positive state of mental health and mental illness are not necessarily on the same dimension[41] and it would be reasonable to consider that the effects of exercise are different for positive and negative aspects of mental health status. For the results of the present study, it could be speculated that social interactions during exercise might increase positive feelings rather than reduce negative feelings. However, further research is necessary to confirm this and to determine whether exercise with others has differential influences upon positive and negative states of mental health.

For the bidirectional relationships between exercise and mental health, both cross-lagged and simultaneous effects models revealed that exercising alone was not a significant predictor of mental well-being, but that mental well-being was a significant predictor of exercising alone. These results should be interpreted carefully because there is a possibility that their association was spuriously caused by confounding factors that the present study did

not examine. Nonetheless, a systematic review[18] has previously suggested that depression is a risk factor for further decline in physical activity and exercise. Similar to the present study, Teychenne et al.[42] found that stronger depressive symptoms at baseline predicts decline in leisure-time physical activity over time, but that leisure-time physical activity did not predict longitudinal changes in depressive symptoms. The present and previous studies[18,42] together emphasize the importance of considering the bidirectional associations of physical activity and exercise with mental health.

After adjusting for exercise variables, the present study did not find significant relationships between objectively measured total physical activity and mental health. Similarly, a previous study[43] conducted in Singapore reported that objectively measured moderate-to-vigorous physical activity is not associated with mental health variables. Alternatively, this previous study[43] showed that more time spent engaging in leisure-time physical activity was associated with better mental health status. A meta-analysis[10] indicated that physical activity performed in leisure time had more desirable effects on mental health than physical activity performed in non-leisure time. As the concept of exercise substantially overlaps with leisure-time physical activity[7,9], both the present study and previous findings[10,43] indicate that increasing the total volume of physical activity might have less impact on mental health than engaging in leisure-time activities such as exercise.

The examinations of both cross-lagged and simultaneous effects models are the strengths of the present study. Concordance of both models emphasizes the robustness of the findings. The use of the accelerometer and the diary method are other strengths. Their use can provide more accurate data than that obtained through traditional questionnaire surveys. However, the present study had several limitations. First, the sample size was small. Second, the diary survey did not give the participants a specific definition of the term exercise. Although this term is commonly and frequently used in Japan, it is unclear whether

interpretations of this term were equivalent across the participants. Third, a sampling bias may exist: those participating in mail-based accelerometer surveys are likely to have walking habits during their leisure time[44] and so the participants in the present study might be more physically active than typical non-participants. Moreover, the present study targeted only married couples. It is unclear whether the findings from our sample could generalize to people who are not married. Thus, further longitudinal investigation using larger and more representative samples would be necessary to provide more definitive findings. Nonetheless, the present study contributes to a better understanding of the influences of physical activity and exercise on mental health.

In conclusion, from both cross-lagged and simultaneous effects analyses, the present study found that exercising with others, but not exercising alone, was associated with better mental well-being among middle-aged and older adults. A practical implication of these findings is that promoting exercise with others might be more successful for improving mental well-being than promoting exercising alone. Current physical activity guidelines[7] recommend both exercise and physical activity equally, and do not stress the social contexts of them. When improving physical health, the difference between exercise and physical activity and their social contexts might not be what matters. However, according to the findings of the present study, such differences and the social context might be essential considerations when improving mental health: exercising with others may result in better mental health. Based on our findings, further interventional research examining the optimal types of physical activity to improve mental health is recommended.

Funding Source

This work was supported by xxxxxx (deleted for blinded review process).

326 **References**

327 1. Prince M, Patel V, Saxena S, et al. No health without mental health. *Lancet*.
328 2007;370(9590):859-877.
329 2. Ministry of Health, Labour and Welfare. Patient Survey in 2014. (in Japanese)
330 https://www.e-stat.go.jp/stat-
331 search/files?page=1&layout=datalist&toukei=00450022&tstat=000001031167&cycle=7
332 &tclass1=000001077497&tclass2=000001077500&stat_infid=000031349522&second2=
333 1 (accessed 10 January 2019).
334 3. Mammen G, Faulkner G. Physical activity and the prevention of depression: A systematic
335 review of prospective studies. *Am J Prev Med*. 2013;45(5):649-657.
336 4. Schuch FB, Vancampfort D, Firth J, et al. Physical activity and incident depression: A
337 meta-analysis of prospective cohort studies. *Am J Psychiatry*. 2018:1-18.
338 5. Mochcovitch MD, Deslandes AC, Freire RC, Garcia RF, Nardi AE. The effects of regular
339 physical activity on anxiety symptoms in healthy older adults: a systematic review. *Rev*
340 *Bras Psiquiatr*. 2016;38(3):255-261.
341 6. Netz Y, Wu M-J, Becker BJ, Tenenbaum G. Physical activity and psychological well-
342 being in advanced age: a meta-analysis of intervention studies. *Psychol Aging*.
343 2005;20(2):272-284.
344 7. 2018 Physical Activity Guidelines Advisory Committee. 2018 Physical Activity
345 Guidelines Advisory Committee Scientific Report. Washington, DC: U.S. Department of
346 Health and Human Services, 2018.
347 8. White RL, Babic MJ, Parker PD, Lubans DR, Astell-Burt T, Lonsdale C. Domain-specific
348 physical activity and mental health: A meta-analysis. *Am J Prev Med*. 2017;52(5):653-
349 666.
350 9. Caspersen CJ, Powell KE, Christenson GM. Physical activity, exercise, and physical

fitness: definitions and distinctions for health-related research. *Public Health Rep*. 1985;100(2):126-131.

10. Cooney GM, Dwan K, Greig CA, et al. Exercise for depression. *Cochrane database Syst Rev*. 2013;9(9):CD004366.
11. Jayakody K, Gunadasa S, Hosker C. Exercise for anxiety disorders: systematic review. *Br J Sports Med*. 2014;48(3):187-196.
12. Stonerock GL, Hoffman BM, Smith PJ, Blumenthal JA. Exercise as treatment for anxiety: Systematic review and analysis. *Ann Behav Med*. 2015;49(4):542-556.
13. Windle G, Hughes D, Linck P, Russell I, Woods B. Is exercise effective in promoting mental well-being in older age? A systematic review. *Aging Ment Health*. 2010;14(6):652-669.
14. Ransford CP. A role for amines in the antidepressant effect of exercise: a review. *Med Sci Sports Exerc*. 1982;14(1):1-10.
15. Paluska SA, Schwenk TL. Physical activity and mental health: current concepts. *Sports Med*. 2000;29(3):167-180.
16. Kanamori S, Takamiya T, Inoue S, Kai Y, Kawachi I, Kondo K. Exercising alone versus with others and associations with subjective health status in older Japanese: The JAGES Cohort Study. *Sci Rep*. 2016;6(1):39151.
17. Takeda F, Noguchi H, Monma T, Tamiya N. How possibly do leisure and social activities impact mental health of middle-Aged adults in Japan?: An evidence from a national longitudinal survey. *PLoS One*. 2015;10(10):1-10.
18. Roshanaei-Moghaddam B, Katon WJ, Russo J. The longitudinal effects of depression on physical activity. *Gen Hosp Psychiatry*. 2009;31(4):306-315.
19. Steinmo S, Hagger-Johnson G, Shahab L. Bidirectional association between mental health and physical activity in older adults: Whitehall II prospective cohort study. *Prev*

376 *Med*. 2014;66:74-79.
377 20. Xxxxxx X, Xxxxxxxx X, Xxxx X. (deleted for blinded review process).
378 21. Pate RR, O'Neill JR, Lobelo F. The evolving definition of "sedentary". *Exerc Sport Sci*
379 *Rev*. 2008;36(4):173-178.
380 22. Oshima Y, Kawaguchi K, Tanaka S, et al. Classifying household and locomotive activities
381 using a triaxial accelerometer. *Gait Posture*. 2010;31(3):370-374.
382 23. Ohkawara K, Oshima Y, Hikihara Y, Ishikawa-Takata K, Tabata I, Tanaka S. Real-time
383 estimation of daily physical activity intensity by a triaxial accelerometer and a gravity-
384 removal classification algorithm. *Br J Nutr*. 2011;105(11):1681-1691.
385 24. Murakami H, Kawakami R, Nakae S, et al. Accuracy of wearable devices for estimating
386 total energy expenditure: Comparison with metabolic chamber and doubly labeled water
387 method. *JAMA Intern Med*. 2016;176(5):702-703.
388 25. Gorman E, Hanson HM, Yang PH, Khan KM, Liu-Ambrose T, Ashe MC. Accelerometry
389 analysis of physical activity and sedentary behavior in older adults: A systematic review
390 and data analysis. *Eur Rev Aging Phys Act*. 2014;11(1):35-49.
391 26. Healy GN, Wijndaele K, Dunstan DW, et al. Objectively measured sedentary time,
392 physical activity, and metabolic risk. *Diabetes Care*. 2008;31(2):369-371.
393 27. Helmerhorst HJF, Wijndaele K, Brage S, Wareham NJ, Ekelund U. Objectively measured
394 sedentary time may predict insulin resistance independent of moderate- and vigorous-
395 intensity physical activity. *Diabetes*. 2009;58(8):1776-1779.
396 28. Spittaels H, Van Cauwenberghe E, Verbestel V, et al. Objectively measured sedentary
397 time and physical activity time across the lifespan: a cross-sectional study in four age
398 groups. *Int J Behav Nutr Phys Act*. 2012;9(1):149. 1.
399 29. Inagaki H, Ito K, Sakuma N, Sugiyama M, Okamura T, Awata S. [Reliability and validity
400 of the simplified Japanese version of the WHO-Five Well-being Index (S-WHO-5-J)].

401 *Nihon Koshu Eisei Zasshi*. 2013;60(5):294-301. (in Japanese)
402 30. Furukawa TA, Kawakami N, Saitoh M, et al. The performance of the Japanese version of
403 the K6 and K10 in the World Mental Health Survey Japan. *Int J Methods Psychiatr Res*.
404 2008;17(3):152-158.
405 31. Boujut E, Gana K. Relationship between depressive mood and eating disorders in a non-
406 clinical young female sample: a one-year longitudinal analysis of cross-lagged and
407 simultaneous effects. *Eat Behav*. 2014;15(3):434-440.
408 32. Gana K, Bailly N, Saada Y, et al. Relationship between life satisfaction and physical
409 health in older adults: a longitudinal test of cross-lagged and simultaneous effects. *Health*
410 *Psychol*. 2013;32(8):896-904. doi:10.1037/a0031656.
411 33. Monma T, Takeda F, Okura T. Physical activities impact sense of coherence among
412 community-dwelling older adults. *Geriatr Gerontol Int*. 2017;17(11):2208-2215.
413 34. Dormann CF, Elith J, Bacher S, et al. Collinearity: a review of methods to deal with it and
414 a simulation study evaluating their performance. *Ecography (Cop)*. 2013;36(1):27-46.
415 35. Schroeder MA. Diagnosing and dealing with multicollinearity. *West J Nurs Res*.
416 1990;12(2):175-84.
417 36. Choi Y, Park E-C, Kim J-H, Yoo K-B, Choi J-W, Lee K-S. A change in social activity and
418 depression among Koreans aged 45 years and more: analysis of the Korean Longitudinal
419 Study of Aging (2006-2010). *Int psychogeriatrics*. 2015;27(4):629-637.
420 37. Shiba K, Kondo N, Kondo K, Kawachi I. Retirement and mental health: Dose social
421 participation mitigate the association? A fixed-effects longitudinal analysis. *BMC Public*
422 38. Dietrich A, McDaniel WF. Endocannabinoids and exercise. *Br J Sports Med*.
423 2004;38(5):536-541.
424 39. McAuley E, Blissmer B, Katula J, Duncan TE. Exercise environment, self-efficacy, and
425 affective responses to acute exercise in older adults. *Psychol Health*. 2000;15(3):341-355.

426 40. Johansson M, Hartig T, Staats H. Psychological benefits of walking: Moderation by
427 company and outdoor environment. *Appl Psychol Heal Well-Being*. 2011;3(3):261-280.
428 41. Keyes CLM. Mental illness and/or mental health? Investigating axioms of the complete
429 state model of health. *J Consult Clin Psychol*. 2005;73(3):539-548.
430 42. Teychenne M, Abbott G, Lamb KE, Rosenbaum S, Ball K. Is the link between movement
431 and mental health a two-way street? Prospective associations between physical activity,
432 sedentary behaviour and depressive symptoms among women living in
433 socioeconomically disadvantaged neighbourhoods. *Prev Med*. 2017;102:72-78.
434 43. Chu AHY, van Dam RM, Biddle SJH, Tan CS, Koh D, Müller-Riemenschneider F. Self-
435 reported domain-specific and accelerometer-based physical activity and sedentary
436 behaviour in relation to psychological distress among an urban Asian population. *Int J*
437 *Behav Nutr Phys Act*. 2018;15(1):1-14.
438 44. Inoue S, Ohya Y, Odagiri Y, et al. Characteristics of accelerometry respondents to a mail-
439 based surveillance study. *J Epidemiol*. 2010;20(6):446-452.

Figure Captions

Figure 1. Cross-lagged effects model for the associations of total physical activity and exercise with mental well-being. Bold lines represent significant paths. All path coefficients were standardized. For clarity, cross-sectional correlations among physical activity and exercise variables at wave 1 and wave 2 are not depicted in this figure. Paths from gender and age to physical activity and exercise variables were included because of significant Pearson's correlation coefficients for these variables. Gender was treated as a dummy variable (men = 0, women = 1). Educational background was excluded because it was not significantly correlated with physical activity, exercise, and mental well-being. LPA, light physical activity; MVPA, moderate-to-vigorous physical activity. $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$. GFI=0.939, CFI=0.980, RMSEA=0.054.

Figure 2. Simultaneous effects model for the associations of total physical activity and exercise with mental well-being. Bold lines represent significant paths. All path coefficients were standardized. For clarity, cross-sectional correlations among physical activity and exercise variables at wave 1 and wave 2 are not depicted in this figure. Paths from gender and age to physical activity and exercise variables were included because of significant Pearson's correlation coefficients for these variables. Gender was treated as a dummy variable (men = 0, women = 1). Educational background was excluded because it was not significantly correlated with physical activity, exercise, and mental well-being. LPA, light physical activity; MVPA, moderate-to-vigorous physical activity. $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$. GFI=0.939, CFI=0.981, RMSEA=0.054.

Figure 3. Cross-lagged effects model for the associations of total physical activity and exercise with mental distress. Bold lines represent significant paths. All path coefficients were standardized. For clarity, cross-sectional correlations among physical activity and exercise variables at wave 1 and wave 2 are not depicted in this figure. Paths from gender and age to

physical activity and exercise variables were included because of significant Pearson's correlation coefficients for these variables. Gender was treated as a dummy variable (men = 0, women = 1). Educational background was excluded because it was not significantly correlated with physical activity, exercise, and mental distress. LPA, light physical activity; MVPA, moderate-to-vigorous physical activity. $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$. GFI=0.941, CFI=0.984, RMSEA=0.050.

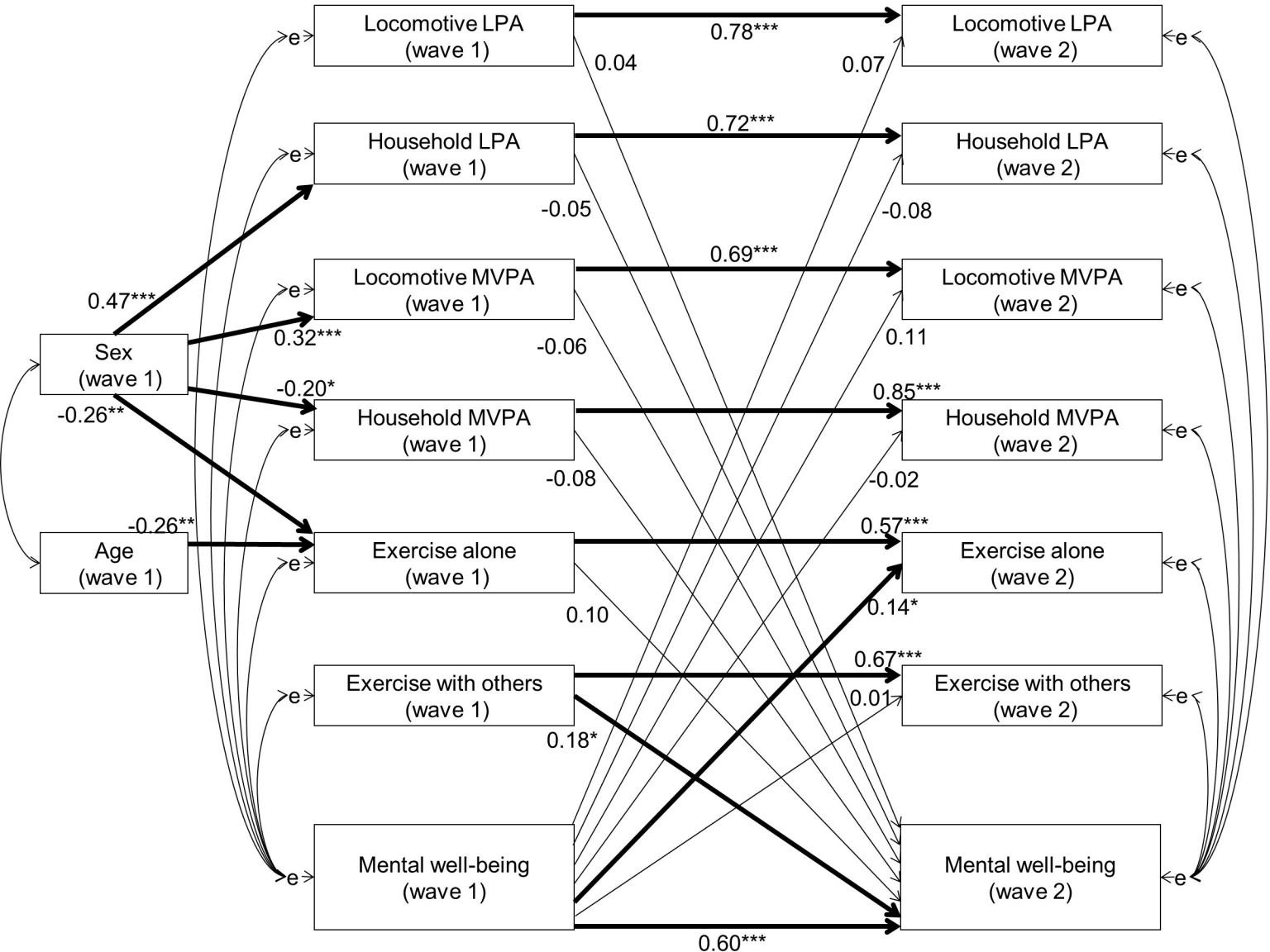
Figure 4. Simultaneous effects model for the associations of total physical activity and exercise with mental distress. Bold lines represent significant paths. All path coefficients were standardized. For clarity, cross-sectional correlations among physical activity and exercise variables at wave 1 and wave 2 are not depicted in this figure. Paths from gender and age to physical activity and exercise variables were included because of significant Pearson's correlation coefficients for these variables. Gender was treated as a dummy variable (men = 0, women = 1). Educational background was excluded because it was not significantly correlated with physical activity, exercise, and mental distress. LPA, light physical activity; MVPA, moderate-to-vigorous physical activity. $^{*}p<0.05$, $^{**}p<0.01$, $^{***}p<0.001$. GFI=0.941, CFI=0.983, RMSEA=0.051.

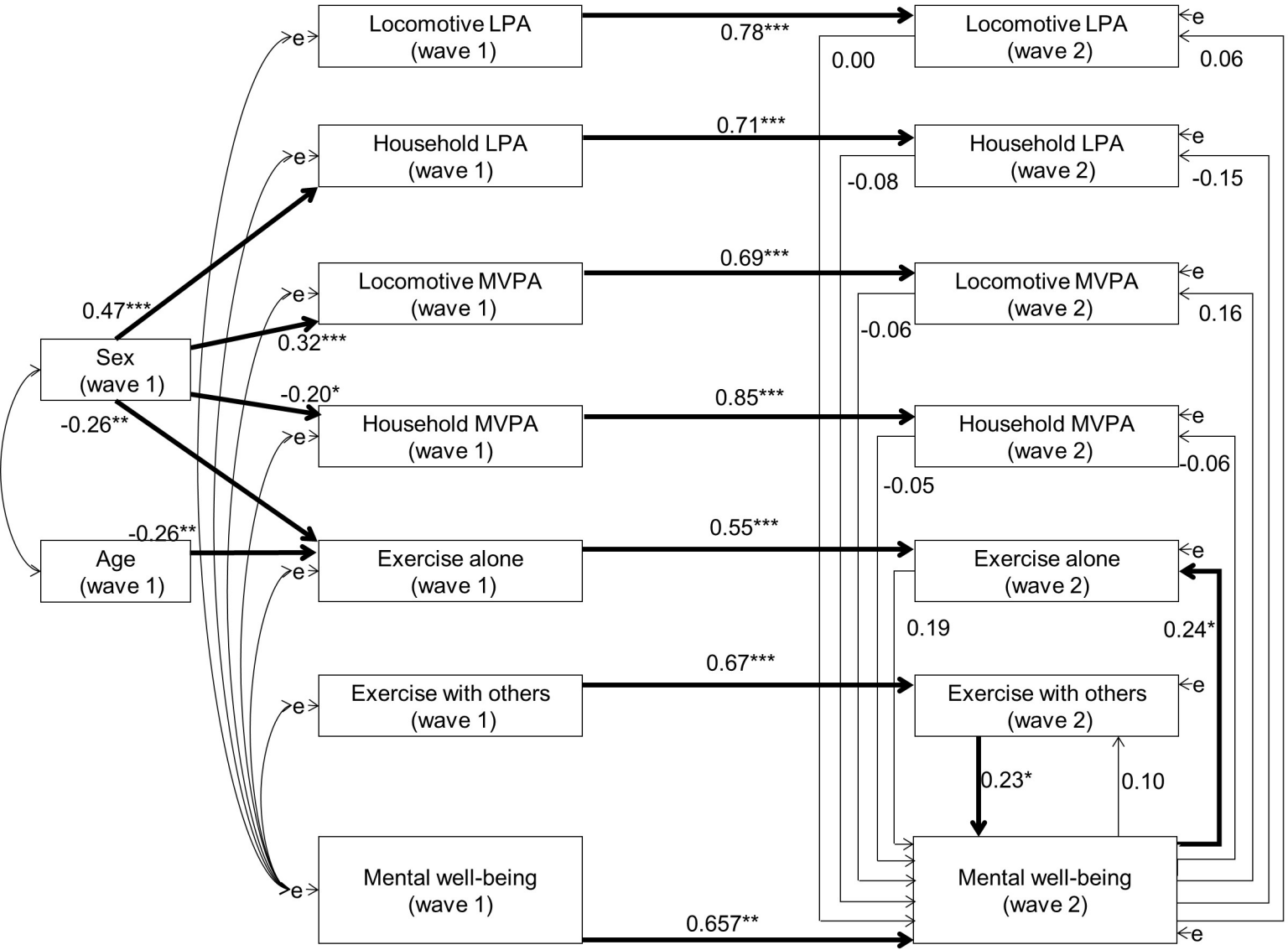
Table 1

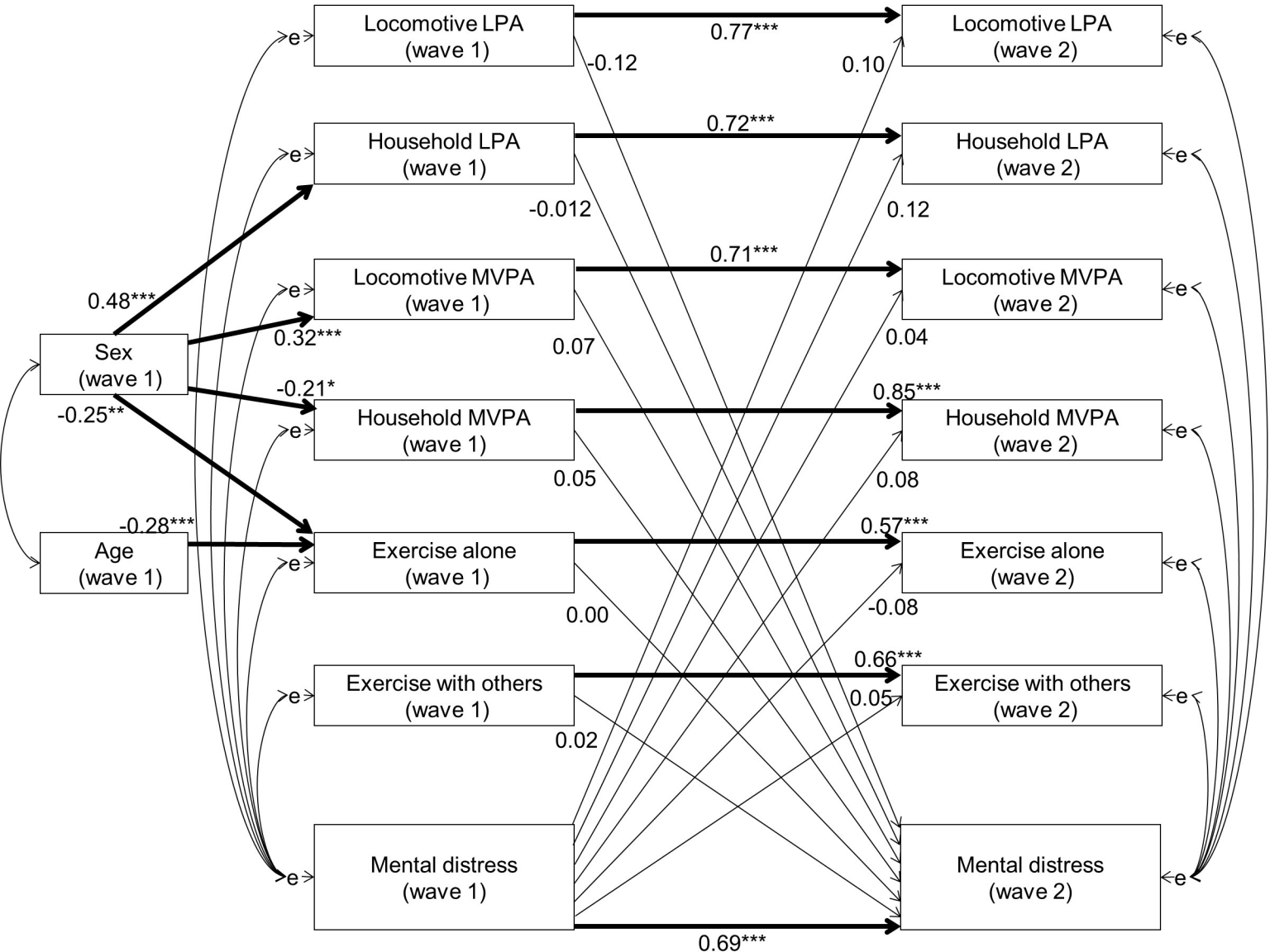
Descriptive statistics and paired t-tests for physical activity, exercise, and mental health

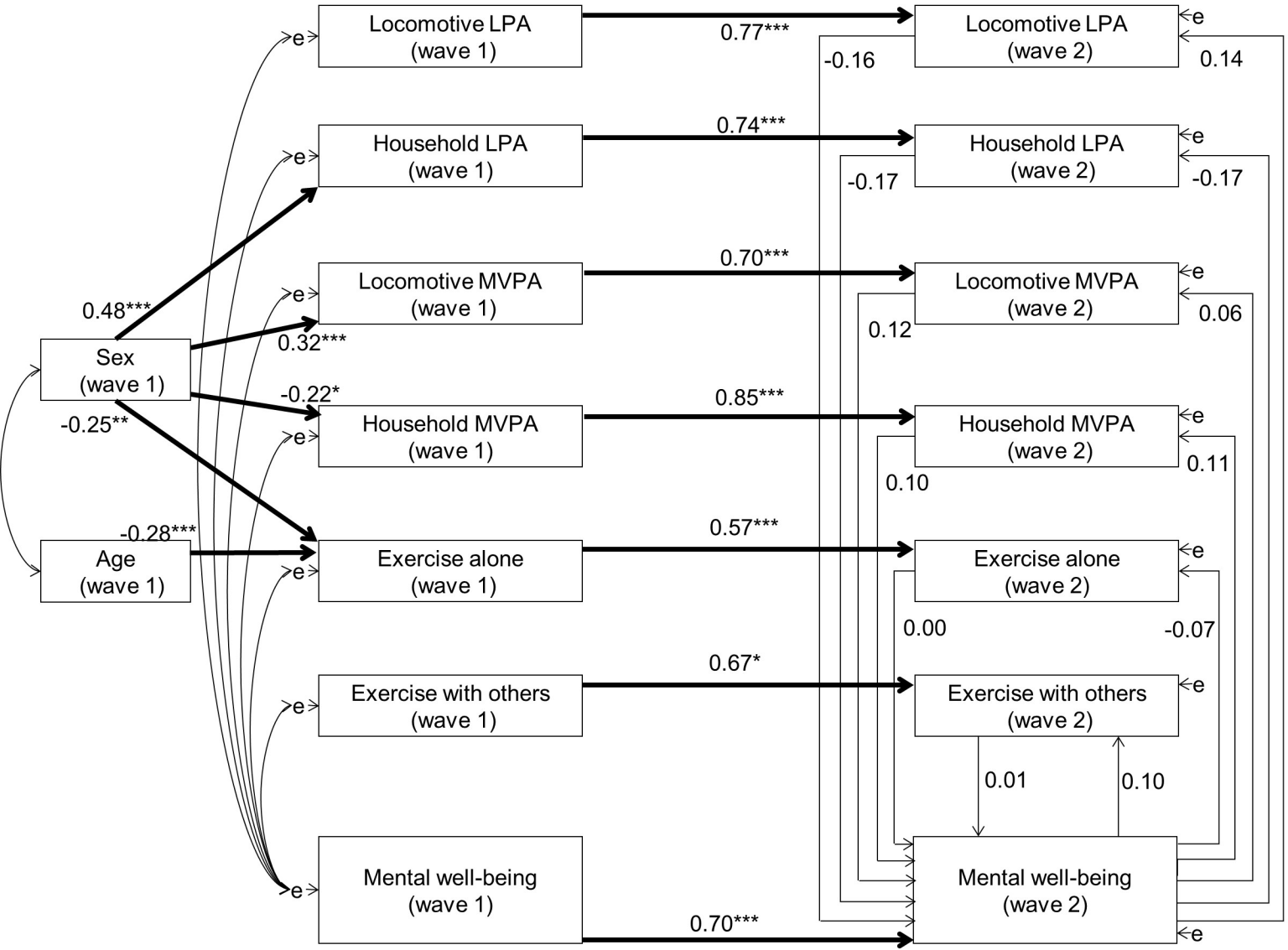
		Wave 1		Wave 2		Paired t-test		
	n	Mean	SD	Mean	SD	t-value	Cohen's d	p-value
Locomotive LPA (time per hour of wearing time)	129	0:03:49	0:01:37	0:03:52	0:01:48	0.48	0.03	0.634
Household LPA (time per hour of wearing time)	129	0:16:06	0:04:39	0:16:12	0:04:33	0.38	0.01	0.702
Locomotive MVPA (time per hour of wearing time)	129	0:02:29	0:01:37	0:02:28	0:01:44	0.25	0.02	0.801
Household MVPA (time per hour of wearing time)	129	0:03:46	0:01:59	0:03:53	0:02:03	1.20	0.06	0.231
Exercise alone (time per day)	129	0:13:58	0:21:33	0:12:15	0:18:52	1.07	0.09	0.289
Exercise with others (time per day)	129	0:14:07	0:25:45	0:15:40	0:31:42	0.74	0.05	0.462
Mental well-being (score, WHO-5)	128	9.3	2.7	9.1	2.5	1.19	0.09	0.238
Mental distress (score, K6)	128	3.5	3.6	3.7	3.7	1.01	0.07	0.315

Note: LPA, light physical activity; MVPA, moderate-to-vigorous physical activity; WHO-5, simplified Japanese version of the WHO—Five Well-Being Index; K6, Japanese version of the K6


Locomotive LPA (wave 1)
Household LPA (wave 1)
Locomotive MVPA (wave 1)
Household MVPA (wave 1)
Exercise alone (wave 1)
Exercise with others (wave 1)
Mental well-being (wave 1)
Locomotive LPA (wave 2)
Household LPA (wave 2)
Locomotive MVPA (wave 2)
Household MVPA (wave 2)
Exercise alone (wave 2)
Exercise with others (wave 2)
Mental well-being (wave 2)
Sex (wave 1)
Age (wave 1)
e
0.78***
0.72***
0.69***
0.85***
0.57***
0.67***
0.60***
0.04
0.07
-0.05
-0.08
-0.06
0.11
-0.08
-0.02
0.10
0.14*
0.18*
0.01
0.47***
0.32***
-0.20*
-0.26**
-0.26**


Locomotive LPA (wave 1)
Household LPA (wave 1)
Locomotive MVPA (wave 1)
Household MVPA (wave 1)
Exercise alone (wave 1)
Exercise with others (wave 1)
Mental well-being (wave 1)
Sex (wave 1)
Age (wave 1)
Locomotive LPA (wave 2)
Household LPA (wave 2)
Locomotive MVPA (wave 2)
Household MVPA (wave 2)
Exercise alone (wave 2)
Exercise with others (wave 2)
Mental well-being (wave 2)
e
0.78***
0.71***
0.69***
0.85***
0.55***
0.67***
0.657**
0.47***
0.32***
-0.20*
-0.26**
-0.26**
0.00
0.06
-0.08
-0.15
-0.06
0.16
-0.05
-0.06
0.19
0.24*
0.23*
0.10


Locomotive LPA (wave 1)
Household LPA (wave 1)
Locomotive MVPA (wave 1)
Household MVPA (wave 1)
Exercise alone (wave 1)
Exercise with others (wave 1)
Mental distress (wave 1)
Locomotive LPA (wave 2)
Household LPA (wave 2)
Locomotive MVPA (wave 2)
Household MVPA (wave 2)
Exercise alone (wave 2)
Exercise with others (wave 2)
Mental distress (wave 2)
Sex (wave 1)
Age (wave 1)
e
0.77***
0.72***
0.71***
0.85***
0.57***
0.66***
0.69***
-0.12
0.10
-0.012
0.12
0.07
0.04
0.05
0.08
0.00
-0.08
0.02
0.05
0.48***
0.32***
-0.21*
-0.25**
-0.28***


Locomotive LPA (wave 1)
Household LPA (wave 1)
Locomotive MVPA (wave 1)
Household MVPA (wave 1)
Exercise alone (wave 1)
Exercise with others (wave 1)
Mental well-being (wave 1)
Sex (wave 1)
Age (wave 1)
Locomotive LPA (wave 2)
Household LPA (wave 2)
Locomotive MVPA (wave 2)
Household MVPA (wave 2)
Exercise alone (wave 2)
Exercise with others (wave 2)
Mental well-being (wave 2)
e
0.77***
0.74***
0.70***
0.85***
0.57***
0.67*
0.70***
0.48***
0.32***
-0.22*
-0.25**
-0.28***
-0.16
-0.17
0.12
0.10
0.00
0.01
0.10
0.14
-0.17
0.06
0.11
-0.07