Tracking of cardiorespiratory fitness in Japanese men

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Abstract The stability of the relative order of cardiorespiratory fitness (CRF) during adulthood has not been sufficiently investigated. This study investigated the tracking of CRF over a 7-year follow-up period in Japanese male adults aged 18-53 years. A total of 3,718 male workers who underwent three submaximal exercise tests (a first test and again 3 and 7 years later for a second and third test) were included. CRF was defined as the maximal oxygen uptake estimated from a submaximal exercise test using a cycle ergometer. Spearman correlation coefficients for CRF in the first and second tests, the second and third tests and the first and third tests were 0.61, 0.62 and 0.54, respectively. A moderate kappa coefficient, indicating the degree of agreement for quartiles, was obtained for all follow-up periods (kappa coefficient = 0.43-0.53). The changes in quartiles for all three time measurements indicated that approximately 70% of participants had stable (participants in the same quartile for all three measurements) or moderately stable (participants who exhibited changes varying by one quartile from the initial quartile) CRF levels. These findings showed moderate CRF tracking during adulthood over a period of up to 7 years.

Keywords: stability, physical activity, cohort study, regression dilution bias

Introduction Cardiorespiratory fitness (CRF) is an objective measure that reflects habitual physical activity1). Many previous cohort studies have reported negative correlations between high CRF and various health conditions2,3). Most of these cohort studies involving CRF exposure have measured CRF only once at baseline and evaluated the association of this measurement with the health outcome of interest2,3). The assumption made is that the CRF of an individual measured only once at baseline is a good reflection of the CRF level. However, it may be possible to more accurately evaluate the results of cohort studies by understanding CRF changes owing to lifestyle modifications throughout the follow-up period and the extent of the underestimation of the outcome because of regression dilution bias. Previously, we conducted a 14-year follow-up study with participants classified into quartiles using the degree of change in CRF over 7 years (regression coefficient of the primary regression equation) as an index and investigated the effect of the degree of change in CRF on type 2 diabetes patients4). The results in that study revealed a clearer dose-response relationship than those in studies in which CRF was measured only once at baseline and was used to examine the association of CRF with diabetes5). This suggests that changes in CRF during the follow-up period and regression dilution bias are the source of underestimation of the results. Similarly, other similar cohort studies suggested a strong relationship between CRF change and morbidity or mortality6-10).
Generally, the relative order of individual physical activity and physical fitness in a population is believed to remain stable over the long term, and this phenomenon is referred to as tracking\textsuperscript{11}. Several previous studies have investigated the stability of the absolute value of CRF\textsuperscript{8,10,12,13}. However, to the best of our knowledge, the relative order of CRF in adults has not been sufficiently investigated. Although many previous studies have investigated CRF tracking during childhood\textsuperscript{14-17} and from childhood to adulthood\textsuperscript{18-21}, we were able to locate only two reports, that by Lefevre et al.\textsuperscript{22} and Mertens et al.\textsuperscript{23}, investigating CRF tracking during adulthood. Moreover, the study by Lefevre et al.\textsuperscript{22} had a small sample size (n = 130) and only investigated CRF tracking in the age range of 30-35 and 35-40 years. Both studies only measured CRF at two points. A detailed investigation of CRF tracking during adulthood can provide important insights for interpreting the results of cohort studies that have only measured CRF once at baseline and for formulating future study designs. Therefore, the purpose of the present study was to investigate CRF tracking over a 7-year follow-up period, used as follow-up period in several tracking studies\textsuperscript{24-26}, using data measured three times in a large sample of Japanese male adults aged 18-53 years.

Materials and Methods

Participants. A total of 6,082 men (age in 1979, 18-53 years) who were free from diabetes, tuberculosis, any digestive system disorder or cardiovascular disease, including hypertension, at a health check-up in 1979, had undergone a submaximal exercise test at a metropolitan gas company with a base in Tokyo. Most of these participants also underwent another submaximal exercise test of their own volition in 1982 (n = 4,642). Of these, 3,718 men underwent a third test of their own volition in 1986. The 3,718 individuals who underwent all submaximal exercise tests (in 1979, 1982 and 1986) were included as participants.

The clinical examinations were performed and CRF measurements were taken in accordance with the Japanese Industrial Safety and Health Law. Therefore, written informed consent was not required in Japan. This study was approved by the Research Ethics Review Committee of the National Institute of Health and Nutrition of Japan (approval number nibiohn-20-20151222-290-1).

Health check-ups. The participants underwent regular health check-ups that are required by the Industrial Safety and Health Act in Japan. Height and weight measurements from these health check-ups were used in our analysis; the body mass index (BMI) was calculated from these measurements.

CRF measurement. The CRF of the participants was evaluated according to the maximum oxygen uptake estimated with a submaximal exercise test using a cycle ergometer. The exercise test had a maximum of three levels, each of which lasted for 4 min. The load gradually increased as the levels progressed. The load at the start of the test was 98 W for participants aged 18-29 years, 86 W for those aged 30-39 years, 73 W for those aged 40-49 years and 61 W for those aged 50-59 years. The heart rate was measured using the R-R interval from electrocardiograms. The target heart rate was set at 85% of the maximum heart rate, which was estimated on the basis of age (220 – age). The exercise load was increased at each level by 37 W until the target heart rate or the third level was reached. Pedal revolutions were set at 50 rpm. On the basis of the heart rate of each participant for the final minute of the final stage, the maximum oxygen uptake was estimated using the Åstrand-Ryhming nomogram\textsuperscript{27} and Åstrand age correction factor\textsuperscript{28}.

Statistical analysis. The widely-used indicators for tracking are Spearman’s rank order correlation and kappa value because tracking is the tendency of individuals to maintain their rank or position within a group over time\textsuperscript{11}. In addition, CRF levels are often categorized using quartiles in cohort studies examining the associations of CRF with health outcomes. Therefore, the following three different methods were used to investigate CRF tracking.

The first method involved the Spearman correlation coefficient for CRF in the first and second tests, the second and third tests and the first and third tests. Malina\textsuperscript{11} defined the degrees of tracking using the Spearman correlation coefficient as follows: low (below 0.3), moderate (0.3-0.59) and high (0.6 or higher). Bloom\textsuperscript{29} reported that for measurements taken at an interval of 1 year or longer, a correlation coefficient of 0.5 or higher indicated high tracking. In the present study, we evaluated CRF tracking using these values as a reference.

In the second method, the participants were divided into three groups according to their age in the first test: 18-29, 30-39 and 40-53 years old. Next, the age group-specific quartiles individuals belonged to for each year were determined (in the first, second and third tests). The degree of agreement for the quartiles to which the individuals belonged to in the first and second tests, the second and third tests and the first and third tests using the weighted kappa statistics was then investigated. The kappa weights were applied using Fleiss–Cohen weighting\textsuperscript{30}. The degree of agreement, according to the kappa statistics, was defined as “fair agreement” for below 0.2, “moderate agreement” for 0.21-0.45, “substantial agreement” for 0.46-0.75 and “almost perfect agreement” for 0.76-1.0\textsuperscript{31}. In addition, we calculated the Fleiss’ kappa coefficient for the degree of agreement for the quartiles to which the individuals belonged among the three tests.

In the third method, a descriptive approach was used to investigate CRF changes in the first, second and third tests. With regards to the aforementioned quartiles, par-
Participants in the same quartile for all three measurements were described as “stable”; those who exhibited changes varying by one quartile from the initial quartile (e.g., first measurement: second quartile, second measurement: first quartile, third measurement: third quartile) were considered “moderately stable”; those who exhibited changes varying by two quartiles (e.g., first measurement: second quartile, second measurement: second quartile, third measurement: fourth quartile, third measurement: first quartile) were grouped as “moderately unstable”; and those who exhibited changes varying three quartiles (e.g., first measurement: first quartile, second test and third test) were described as “unstable”. The percentage of participants in each stability group was calculated.

IBM SPSS Statistics Version 25 (IBM Corp, Armonk, NY) was used for statistical analysis, and the level of statistical significance was set at p < 0.05. All p values provided are from two-sided tests.

Results

The age of the participants in the first, second and third tests, as well as their height, weight, BMI and CRF, are presented in Table 1. Weight and BMI tended to increase from the first to second and third tests. CRF was lower in the second and third compared to the first tests, and was the lowest in the second test.

The correlation coefficients for CRF in the first and second tests, the second and third tests and the first and third tests were 0.61, 0.62 and 0.54, respectively (Table 2). When investigated according to age, no marked differences were observed for the rank correlation coefficients during the entire follow-up period (Table 2).

Table 3 shows the joint distribution of the participants in quartiles between the first and second tests, the second and third tests and the first and third tests. In each comparison, approximately 50% of the participants in the first or fourth quartile at baseline were in the same quartile during the follow-up. Approximately 30% of the participants in the second or third quartile at baseline were in the same quartile. The percentage of participants who changed two or more quartiles from baseline to a subsequent follow-up was 21.8% (first-second test), 15.0% (second-third test) and 23.3% (first-third test) of participants in the first quartile at baseline. For participants in the second, third and fourth quartiles at baseline, the percentages were 12.7%-16.8%, 14.9%-20.2% and 19.8%-23.3%, respectively. Thus, the quartile in which a participant was initially ranked at baseline did not markedly affect these figures. The weighted kappa coefficients for first-second test, second-third test and first-third test were 0.47, 0.53 and 0.43, respectively. The Fleiss’ kappa coefficient for the three tests was 0.22 (95% Confidence Interval: 0.21-0.23).

Table 4 shows the changes in quartile distribution at the three measurements. For the three measurements, values were stable for 22.1% of the participants, moderately stable for 47.5%, moderately unstable for 23.7% and unstable for 6.6%. Thus, values were stable or moderately stable (as defined for this study) for approximately 70% of the participants.

Discussion

In the present study, CRF tracking over a period of 7 years was investigated in Japanese male adults. The results indicated relatively high rank correlation coefficients for CRF values. Moderate values were also achieved for the kappa coefficient, indicating the degree of agreement for quartiles in the follow-up period. Our investigation of changes in quartiles at the three time points of the first, second and third tests indicated that approximately 70% of the participants had stable or moderately stable CRF levels. These findings showed moderately good CRF tracking in Japanese male adults. The results of this study suggest that the CRF values, from only one measurement at baseline in cohort studies, reflect the relative rankings over a period of up to 7 years reasonably well in this population.

In a study tracking 5-year CRF in males aged 30-35 and 35-40 years, Lefevre et al.27) reported a Pearson correlation coefficient of 0.58 in both periods. In a study tracking 10-year CRF in males, Mertens et al.28) reported a Pearson correlation coefficient of 0.66. The present study also demonstrated a Spearman’s rank order correlation coefficient of the same level. In cohort studies, CRF levels are often categorized using quartiles. Therefore, in the present study, we investigated the degree of coincidence for quartiles within the follow-up period, with results indicating moderately good kappa coefficients. CRF is an objective measure that reflects habitual physical activity11. To the authors’ knowledge, only two previous studies have investigated physical activity tracking using an objective method in adulthood32,33). In a study tracking 1-year daily step count in Western Australian adult males who relocated, Tudor-Locke et al.32) reported a Spearman’s rank order correlation coefficient of 0.57. In a study tracking 8-year daily step count in Japanese elderly males, Yamamoto et al.33) reported a Spearman’s rank order correlation coefficient of 0.67. The degree of tracking CRF in the present study is the same as the levels in the previous objectively measured physical activity studies. Several previous studies have investigated physical activity tracking using a questionnaire34). According to Telama34, who reviewed these studies, tracking coefficients (rank correlation coefficient, correlation coefficient or intraclass correlation coefficient) in adult participants vary depending on the follow-up duration and participant age, but have rarely been reported to exceed 0.5, with most results ranging between 0.2 and 0.4. Furthermore, Morseth et al.35), who investigated the 7-year degree of coincidence with the kappa coefficient for physical activ-
## Table 1. Characteristics of participants in the first, second and third tests.

|                      | First test | Second test | Third test |
|----------------------|------------|-------------|------------|
|                      | Mean       | SD          | Mean       | SD          | Mean       | SD          |
| **ALL (n=3718)**     |            |             |            |             |            |             |
| Age (years)          | 31.7       | 8.4         | 34.7       | 8.4         | 38.7       | 8.4         |
| Height (cm)          | 168.1      | 5.5         | 168.1      | 5.5         | 168.2      | 5.5         |
| Weight (kg)          | 63.2       | 7.8         | 64.2       | 7.8         | 65.9       | 8.2         |
| BMI (kg/m²)          | 22.4       | 2.5         | 22.7       | 2.4         | 23.3       | 2.5         |
| VO₂max (mL/kg/min)   | 40.0       | 7.9         | 37.4       | 6.6         | 39.0       | 7.8         |

| **Aged 18-29 yrs (n=1803)** |            |             |            |             |            |             |
| Age (years)           | 24.6       | 2.7         | 27.6       | 2.7         | 31.6       | 2.7         |
| Height (cm)           | 169.3      | 5.4         | 169.3      | 5.3         | 169.4      | 5.3         |
| Weight (kg)           | 62.8       | 7.7         | 64.3       | 7.9         | 66.4       | 8.4         |
| BMI (kg/m²)           | 21.9       | 2.4         | 22.4       | 2.5         | 23.1       | 2.6         |
| VO₂max (mL/kg/min)    | 43.5       | 7.6         | 39.9       | 2.7         | 41.2       | 7.9         |
| 1st quartile (mL/kg/min) | <38.2     | <35.5       | <35.5       |             |             |             |
| 2nd quartile (mL/kg/min) | 38.2-42.6 | 35.5-39.0   | 35.5-39.9   |             |             |             |
| 3rd quartile (mL/kg/min) | 42.7-48.1 | 39.1-43.5   | 40.0-45.4   |             |             |             |
| 4th quartile (mL/kg/min) | >48.1     | >43.5       | >45.4       |             |             |             |

| **Aged 30-39 yrs (n=1172)** |            |             |            |             |            |             |
| Age (years)           | 34.0       | 3.0         | 168.2      | 5.3         | 168.2      | 5.3         |
| Height (cm)           | 168.2      | 5.3         | 168.2      | 5.3         | 168.2      | 5.3         |
| Weight (kg)           | 64.4       | 7.8         | 65.0       | 7.7         | 66.4       | 7.8         |
| BMI (kg/m²)           | 22.8       | 2.5         | 23.0       | 2.4         | 23.5       | 2.5         |
| VO₂max (mL/kg/min)    | 38.0       | 6.8         | 35.9       | 6.0         | 37.8       | 7.3         |
| 1st quartile (mL/kg/min) | <33.6     | <31.8       | <32.7       |             |             |             |
| 2nd quartile (mL/kg/min) | 33.6-37.2 | 31.8-35.4   | 32.7-37.2   |             |             |             |
| 3rd quartile (mL/kg/min) | 37.3-41.7 | 35.5-39.0   | 37.3-41.7   |             |             |             |
| 4th quartile (mL/kg/min) | >41.7     | >39.0       | >41.7       |             |             |             |

| **Aged 40-53 yrs (n=743)** |            |             |            |             |            |             |
| Age (years)           | 45.0       | 3.8         | 48.0       | 3.8         | 52.0       | 3.8         |
| Height (cm)           | 165.3      | 5.3         | 165.1      | 5.4         | 165.2      | 5.3         |
| Weight (kg)           | 62.5       | 7.8         | 62.8       | 7.7         | 63.9       | 7.9         |
| BMI (kg/m²)           | 22.9       | 2.5         | 23.0       | 2.4         | 23.4       | 2.4         |
| VO₂max (mL/kg/min)    | 34.6       | 6.3         | 33.8       | 5.6         | 35.7       | 6.7         |
| 1st quartile (mL/kg/min) | <30.0     | <30.0       | <30.9       |             |             |             |
| 2nd quartile (mL/kg/min) | 30.0-33.5 | 30.0-33.5   | 30.9-35.4   |             |             |             |
| 3rd quartile (mL/kg/min) | 33.6-38.1 | 33.6-37.2   | 35.5-39.0   |             |             |             |
| 4th quartile (mL/kg/min) | >38.1     | >37.2       | >39.0       |             |             |             |

BMI: body mass index, VO₂max: maximal oxygen uptake
Table 2. Spearman correlation coefficients for cardiorespiratory fitness assessed in the first, second and third tests.

|                | n   | First-second test | Second–third test | First–third test |
|----------------|-----|-------------------|-------------------|------------------|
| ALL            | 3718| 0.61 (0.59-0.63)  | 0.62 (0.60-0.64)  | 0.54 (0.51-0.56) |

Age (years)

|                | n   | First-second test | Second–third test | First–third test |
|----------------|-----|-------------------|-------------------|------------------|
| 18-29          | 1803| 0.50 (0.47-0.54)  | 0.58 (0.54-0.61)  | 0.46 (0.42-0.50) |
| 30-39          | 1172| 0.54 (0.50-0.58)  | 0.57 (0.53-0.60)  | 0.46 (0.44-0.53) |
| 40-53          | 743 | 0.54 (0.48-0.58)  | 0.60 (0.55-0.65)  | 0.47 (0.41-0.52) |

Spearman’s rank order coefficients (95% confidence interval)

Table 3. Number (percent) of participants cross-classified by quartiles of cardiorespiratory fitness in the first, second and third tests.

| Follow-up | 1st quartile | 2nd quartile | 3rd quartile | 4th quartile |
|-----------|--------------|--------------|--------------|--------------|
| Change from first to second test (weighted kappa: 0.47; 95% CI: 0.45-0.50) | | | | |
| Baseline (first) | | | | |
| 1st quartile | 530 (52.1) | 266 (26.1) | 148 (14.6) | 73 (07.2) |
| 2nd quartile | 277 (30.5) | 279 (30.8) | 236 (26.0) | 115 (12.7) |
| 3rd quartile | 149 (15.9) | 254 (27.2) | 297 (31.8) | 235 (25.1) |
| 4th quartile | 63 (07.3) | 130 (15.1) | 240 (31.8) | 426 (49.6) |
| Change from the second to third test (weighted kappa: 0.53; 95% CI: 0.51-0.56) | | | | |
| Baseline (second) | | | | |
| 1st quartile | 572 (56.1) | 294 (28.9) | 111 (10.9) | 42 (04.1) |
| 2nd quartile | 249 (26.8) | 294 (31.6) | 234 (25.2) | 152 (16.4) |
| 3rd quartile | 137 (14.9) | 249 (27.0) | 282 (30.6) | 253 (27.5) |
| 4th quartile | 48 (05.7) | 120 (14.1) | 212 (25.0) | 469 (55.2) |
| Change from the first to third test (weighted kappa: 0.43; 95% CI: 0.41-0.46) | | | | |
| Baseline (first) | | | | |
| 1st quartile | 504 (49.6) | 276 (27.1) | 147 (14.5) | 90 (08.8) |
| 2nd quartile | 248 (27.3) | 306 (33.7) | 201 (22.2) | 152 (16.8) |
| 3rd quartile | 189 (20.2) | 240 (25.7) | 256 (27.4) | 250 (26.7) |
| 4th quartile | 65 (07.6) | 135 (15.7) | 235 (27.4) | 424 (49.4) |

95% CI: 95% confidence interval
Note: Participants were divided into quartiles for each year depending on age group-specific (18-29, 30-39 and 40-53 years old in the first test) distributions of cardiorespiratory fitness.
ity levels measured via a questionnaire, reported a moderate degree of coincidence of 0.43 in males. Picavet et al.\textsuperscript{36}, who investigated changes in the 10-year stability of physical activity measured with a questionnaire using data from three time points - baseline, intermediate period and follow-up period - reported that changes in physical activity were observed in approximately 50% of participants during the follow-up period. Our investigation of changes in quartiles at the three time points indicated that approximately 70% of the participants were stable or moderately stable. The abovementioned results suggest that CRF during adulthood is more stable than the physical activity measured via questionnaires. Previous research investigating physical activity and CRF tracking in children, with a follow-up period roughly the same as that of the present study, also indicated that CRF leads to a higher tracking coefficient than physical activity\textsuperscript{14,17}. In some cohort studies\textsuperscript{37}, CRF has been reported to more strongly correlate with various outcomes than the physical activity measured via questionnaires. The results of these cohort

### Table 4. Change in cardiorespiratory fitness levels (quartiles) from the first to third test.

| First test | Second test | Third test | n  | %  | n  | %  |
|------------|-------------|------------|----|----|----|----|
| Stable     | Q1          | Q1         | Q1 | 346| 9.3|
|            | Q2          | Q2         | Q2 | 92 | 2.5|
|            | Q3          | Q3         | Q3 | 97 | 2.6|
|            | Q4          | Q4         | Q4 | 288| 7.7|
| Moderately stable | Q1  | Q1         | Q2 | 134| 3.6|
|            | Q2          | Q1/Q2      | 187|    | 5.0|
|            | Q2          | Q1/Q2/Q3   | 263|    | 7.1|
|            | Q3          | Q1/Q2/Q3   | 140|    | 3.8|
|            | Q3          | Q1/Q2/Q3   | 195|    | 5.2|
|            | Q3          | Q2/Q3/Q4   | 190|    | 5.1|
|            | Q3          | Q2/Q4      | 164|    | 4.4|
|            | Q4          | Q2/Q3/Q4   | 218|    | 5.9|
|            | Q4          | Q3/Q4      | 178|    | 4.8|
|            | Q4          | Q3         | 96 |    | 2.6|
| Moderately unstable | Q1  | Q1/Q2     | Q3 | 87 | 2.3|
|            | Q3          | Q1/Q2/Q3   | 122|    | 3.3|
|            | Q2          | Q1/Q2/Q3/Q4| 102|    | 2.7|
|            | Q4          | Q1/Q2/Q3/Q4| 115|    | 3.1|
|            | Q3          | Q1/Q2/Q3/Q4| 149|    | 4.0|
|            | Q2/Q3/Q4   | Q1          | 117|    | 3.1|
|            | Q4          | Q2/Q3/Q4   | 114|    | 3.1|
|            | Q3/Q4      | Q2          | 77 |    | 2.1|
| Unstable   | Q1          | Q4         | Q1/Q2/Q3/Q4| 73 | 2.0|
|            | Q1/Q2/Q3   | Q4          | 68 |    | 1.8|
|            | Q4          | Q1/Q2/Q3/Q4| 63 |    | 1.7|
|            | Q2/Q3/Q4   | Q1          | 43 |    | 1.2|

Note: Q1: 1st quartile, Q2: 2nd quartile, Q3: 3rd quartile, Q4: 4th quartile.
studies may be partly explained by the high CRF tracking shown above, in addition to the greater measurement error from self-report questionnaires.

There are various possible reasons for CRF having a higher tracking than the physical activity measured via questionnaires; one of them relates to the issue of measurement value reliability. Because of recall bias, physical activity measurements in questionnaire surveys may not be as reliable as CRF measurements. The second possible reason is differences in the period of physical activity. Physical activity measured via questionnaires examines activity levels within a relatively short period (1 day - 1 year), whereas CRF measurements may reflect not only physical activity levels within a short period of time, but also those within a relatively longer period. Thus, although CRF increases when physical activity is implemented, it must be continuously implemented over a certain period of time. Despite CRF decreasing when physical activity is stopped, the increase in CRF persists for a certain period of time. Accordingly, when using a questionnaire to measure physical activity, if a participant temporarily engages in a high level of physical activity at the time of the survey for some reason, the regular physical activity level of the participant may be overestimated. Furthermore, if a participant had temporarily stopped exercising, their physical activity level may be underestimated. In contrast, these factors seem to have less impact on CRF measurements. The third possible reason is the involvement of genetic factors in CRF levels. As it has been reported that CRF hereditability in sedentary people is 25%-65%, CRF may be maintained at a relatively high level in people with a hereditary background favorable to CRF, and at a relatively low level in those with an unfavorable hereditary background.

Lifestyle habits, especially the physical activity habit, affect the change in CRF in adulthood. Previous studies have reported that the stability of objectively-measured physical activity in adulthood is high. In addition to the abovementioned genetic factors in CRF, this may be a possible reason for moderately good tracking CRF in adulthood.

To the best of our knowledge, the present study is the first to investigate CRF tracking in a large-scale sample of male adults using data measured multiple times. However, this study has some limitations. First, the CRF measurement was indirect rather than direct. However, compared with an indirect method, similar to the one used in this study, and a direct method, Teräslinna et al. reported that the correlation coefficient between the two was 0.92. Thus, we believe that the maximum oxygen uptake estimates used in this study accurately reflect participant CRF. Second, with regards to the occupational field of the participants in the present study, health management staff recommended physical activity to individuals with low CRF. Because CRF was shown to be somewhat higher in the third test compared to the second test (Table 1), these recommendations may have affected their CRF. Thus, our results may over- or underestimate CRF tracking. Third, some cohort members were lost during follow-up due to the voluntary nature of the study. Thus, our results may be affected by selection bias. Fourth, as only male Japanese participants were included in this study, further investigation targeting female and/or other ethnic participants is required. Finally, as this study investigated 7-year CRF tracking, CRF tracking over a longer period remains unclear. Considering the fact that the results of analysis, according to the age range, indicated relatively high tracking for all age ranges, we expect that the results still indicate high tracking for a longer follow-up period than that reported in this study. However, as previous studies with long-term follow-up periods, such as those encompassing childhood and adulthood, did not result in high tracking coefficients, this needs to be studied further in the future. Furthermore, clarifying the factors (e.g. change in job category) and their influence, of the degree of tracking CRF in adulthood, are also challenges for the future.

In conclusion, this study indicates that the extent of tracking with regard to CRF is moderately good in Japanese male adults.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article. Takashi Okamoto and Koji Tsukamoto, co-authors in this study, are staff of Tokyo Gas Company.

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References

1) Archer E and Blair SN. 2011. Physical activity and the prevention of cardiovascular disease: from evolution to epidemiology. Prog Cardiovasc Dis 53: 387-396. doi: 10.1016/j.pcad.2011.02.006.
2) Kodama S, Saito K, Tanaka S, Maki M, Yachi Y, Asumi M, Sugawara A, Totsuka K, Shimano H, Ohashi Y, Yamada N and Sone H. 2009. Cardiorespiratory fitness as a quantitative predictor of all-cause mortality and cardiovascular events in healthy men and women: a meta-analysis. JAMA 301: 2024-2035. doi: 10.1001/jama.2009.681.
3) Ministry of Health, Labour and Welfare of Japan. 2006. Exercise and physical activity guide for health promotion 2006 ~ to prevent lifestyle-related diseases ~ (Tabata, I., Trans.). Available online at: http://www.mhlw.go.jp/eiken/programs/pdf/exercise_guide.pdf, accessed 11 July 2017.
4) Sawada SS, Lee IM, Naito H, Noguchi J, Tsukamoto K, Muto T, Higaki Y, Tanaka H and Blair SN. 2010. Long-term trends in cardiorespiratory fitness and the incidence of type 2 diabetes. Diabetes Care 33: 1353-1357. doi: 10.2337/dc09-1654.
10) Zhang P, Sui X, Hand GA, Hébert JR and Blair SN. 2014. Changes in physical fitness and all-cause mortality. A prospective study of healthy and unhealthy men. *JAMA* 273: 1093-1098.

9) Lee DC, Sui X, Church TS, Lavie CJ, Jackson AS and Blair SN. 2013. Changes in fitness and changes in mortality. *Lancet* 352: 759-762.

8) Lee DC, Sui X, Artero EG, Lee IM, Church TS, McAuley PA, Stanford FC, Kohl HW 3rd and Blair SN. 2011. Long-term effects of changes in cardiorespiratory fitness and body mass index on all-cause and cardiovascular disease mortality in men: the Aerobics Center Longitudinal Study. *Circulation* 124: 2483-2490. doi: 10.1161/CIRCULATIONAHA.111.038422.

7) Erikssen G, Liestøl K, Bjørnholt J, Thaulow E, Sandvik L and Erikssen J. 1998. Changes in physical fitness and changes in mortality. *Lancet* 352: 759-762.

6) Blair SN, Kohl HW 3rd, Barlow CE, Paffenbarger RS Jr, Gibbons LW and Macera CA. 1995. Changes in physical fitness and all-cause mortality. A prospective study of healthy and unhealthy men. *JAMA* 273: 1093-1098.

5) Sawada SS, Lee IM, Muto T, Matsuzaki K and Blair SN. 2012. Changes in fitness and fatness on the development of cardiovascular disease risk factors hypertension, metabolic syndrome, and hypercholesterolemia. *J Am Coll Cardiol* 59: 1691-1698.

4) Jackson AS, Sui X, Hébert JR, Church TS and Blair SN. 2010. Role of lifestyle and aging on the longitudinal change in cardiorespiratory fitness. *Arch Intern Med* 169: 1781-1787. doi: 10.1001/archinternmed.2009.312.

3) Jackson AS, Sui X, Hébert JR, Church TS and Blair SN. 2009. Role of lifestyle and aging on the longitudinal change in cardiorespiratory fitness. *Arch Intern Med* 169: 1781-1787. doi: 10.1001/archinternmed.2009.312.

2) Janz KF, Dawson JD and Mahoney LT. 2000. Tracking of physical activity and physical fitness from childhood to adulthood: the Young Hearts Project, Northern Ireland. *Int J Behav Nutr Phys Act* 7: 142-1429. doi: 10.1123/jpah.2014-0450.

1) TrTemplate: Yamamoto N, et al.}
among adults? The Doetinchem Cohort Study. *Med Sci Sports Exerc* 43: 74-79. doi: 10.1249/MSS.0b013e3181e57a6a.

37) Kaminsky LA, Arena R, Beckie TM, Brubaker PH, Church TS, Forman DE, Franklin BA, Gulati M, Lavie CJ, Myers J, Patel MJ, Piña IL, Weintraub WS and Williams MA; American Heart Association Advocacy Coordinating Committee, Council on Clinical Cardiology, and Council on Nutrition, Physical Activity and Metabolism. 2013. The importance of cardiorespiratory fitness in the United States: the need for a national registry: a policy statement from the American Heart Association. *Circulation* 127: 652-662. doi: 10.1161/CIR.0b013e31827ee100.

38) Kraus WE and Slents CA. 2005. Metabolic syndrome: recognition, etiology, and physical fitness as a component. In: *Nutrition and diabetes: pathophysiology and management* (Opara, ed.), 57-79, CRC Press, FL, USA.

39) Garber CE, Blissmer B, Deschenes MR, Franklin BA, Lamonte MJ, Lee IM, Nieman DC and Swain DP; American College of Sports Medicine. 2011. American College of Sports Medicine position stand. Quantity and quality of exercise for developing and maintaining cardiorespiratory, musculoskeletal, and neuromotor fitness in apparently healthy adults: guidance for prescribing exercise. *Med Sci Sports Exerc* 43: 1334-1359. doi: 10.1249/MSS.0b013e318213fefb.

40) Mujika I and Padilla S. 2001. Cardiorespiratory and metabolic characteristics of detraining in humans. *Med Sci Sports Exerc* 33: 413-421.

41) Teran-Garcia M, Rankinen T and Bouchard C. 2008. Genes, exercise, growth, and the sedentary, obese child. *J Appl Physiol* 105: 988-1001. doi: 10.1152/japplphysiol.00070.2008.

42) Teräslinna P, Ismail AH and Macleod DF. 1996. Nomogram by Astrand-Ryhming as a predictor of maximum oxygen intake. *J Appl Physiol* 21: 513-515.