Article

Relationships among Physical Activity, Physical Function, and Food Intake in Older Japanese Adults Living in Urban Areas: A Cross-sectional Study

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Abstract: Japan is experiencing a super-aging society faster than is anywhere else worldwide. Consequently, extending healthy life expectancy is an urgent social issue. To understand diet that supports the extension of healthy life expectancy, we studied the relationships among quality of life (QOL: SF-36 questionnaire), physical activity (number of steps and activity calculated using an accelerometer), physical function (muscle strength, movement function, agility, static balance, dynamic balance, and walking function) and dietary intake among 469 older adults living in the Tokyo metropolitan area (65–75 years old, men/women = 166/303) from February 23, 2017, to March 31, 2018. There was a significant positive association between physical QOL and steps, moderate-intensity activity, and high-intensity activity ($p < 0.05$), and a significant positive association ($p < 0.05$) between physical activity and movement, static balance, and walking functions, but no association with muscle strength. These three body functions were significantly positively correlated with intake of vegetables, seeds, fruits, and milk, and with magnesium, potassium, vitamin B6, and the dietary fibre/carbohydrate ratio and composition ratios ($p < 0.05$). Balancing food and nutrition may improve QOL in older adults through increased physical function and physical activity. Future verification of interventions is needed.

Keywords: quality of life; physical activity; physical function; food and nutrition; older Japanese adults

1. Introduction

Japan is experiencing a super-aging society at a faster rate than is anywhere else worldwide: approximately 28.4% of the total population is aged 65 years and over, and more than 18 million people are aged 75 years and over [1]. In such a social situation, there is a need to respond to the decrease in the working-age population (15–65 years old) and the increased burden of nursing care. In addition, from a medical perspective, reducing the burden of nursing care by extending healthy life expectancy is an urgent issue. Thus, a national health promotion program, Health Japan 21 (the second term), was formulated [2], given that metabolic syndrome and locomotive syndrome were observed as a response to cardiovascular diseases and decreased physical function due to aging.

Concerning abdominal fat, the accumulation of visceral fat is a higher risk factor for metabolic syndrome than is subcutaneous fat [3]. Thus, we have focused on visceral fat accumulation [4], which is key to the diagnostic criteria for metabolic syndrome, and we have examined the relationship between diet and lifestyle. In a previous study [5], we confirmed that dietary quality, quantity, time, night meals, fast eating, and inactivity are related to visceral fat accumulation. Among these factors, improving dietary quality might suppress visceral fat accumulation. Further examination revealed that the dietary composition of protein (kcal)/lipid (kcal) = 1.0, dietary fibre (g)/carbohydrate (g) > 0.063, and ω3 (mg)/lipid (g) > 0.054 may reduce the accumulation of visceral fat. In an additional clinical intervention study, these dietary compositions were shown to reduce visceral fat accumulation (the SMART WASYOKU® cuisine) [6].

The relationships among physical function, frailty, degree of care required, and lifestyle in older Japanese adults have been reported in several regions of Japan [7–9]. Cohort studies have reported the relationship between physical activity and dietary content based on qualitative measurement [10–14], where either diet or physical activity or function was evaluated using a qualitative assessment method. In particular, many dietary surveys adopted a food frequency questionnaire, the weakness of which is low quantitative accuracy [15]. Consequently, no research studies have performed quantitative assessments of dietary content, physical activity, and function. Therefore, we conducted a cross-sectional study among older Japanese adults to quantitatively evaluate the relationships among physical activity, physical function, and dietary content.

2. Materials and Methods

2.1. Participants

This study was conducted between February 23, 2017, and March 31, 2018. A cross-sectional study was conducted with 473 men and women aged between 65 and 75 years who were living in the suburban areas of west Tokyo. Based on multiple linear regression analysis of 36 items (characteristics, quality of life, physical activity, physical functions, and food intake), we aimed to include at least 360 subjects, namely 10 times the number of items [12]. We explained the examination to the participants at a briefing session and obtained their written informed consent to participate in the research. After excluding four people who did not participate in the measurements, 469 people who completed the study were included in the analysis (Figure 1).

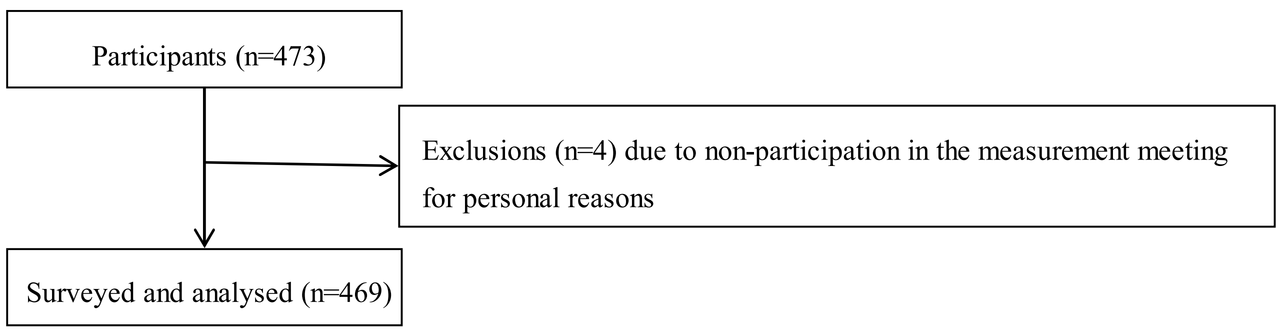

Fig. 1. Flow chart of participants

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This study procedure was approved by two ethics committees (Waseda University's Ethical Review Committee on Human Research and Kao Corporation's Institute of Biological Sciences Research Ethics Review Committee) and implemented in accordance with the Declaration of Helsinki (UMIN000026007).

2.2 Questionnaire survey

After agreeing to participate in the examination at the briefing session, the following questionnaire survey was administered and collected on the day of the measurement meeting: the Medical Outcomes Study 36-Item Short-Form Health Survey (SF-36), which assesses quality of life (QOL), and inquiries about physical conditions and medical history; the International Physical Activity Questionnaire (Japanese version), which confirms physical activity; and dietary and lifestyle questionnaires. For the SF-36, the following three dimensions were calculated from the scores of eight subscales, using

 doi:10.20944/preprints202301.0140.v1

specific standardized algorithms: physical component summary (PCS), mental component summary (MCS), and role–social component summary (RCS) [13].

2.3 Dietary survey

Photo recording was adopted as a quantitative assessment method. Participants took photographs of all meals, including snacks, for 3 days [5]. In addition, a description of all meals was prepared. Meal content was analysed by two independent dietitians skilled in meal photo analysis. Based on the results, the estimated intake of nutrients and foods was calculated based on the Standard Tables of Food Composition in Japan, using the residual method to adjust for total energy intake [16].

2.4 Physiological indicators

Height (cm), weight (kg), body mass index (BMI, kg/m^2), abdominal circumference (cm), visceral fat area (cm^2, EW-FA90; Panasonic Corporation, Osaka, Japan), body temperature (°C), and blood pressure (mmHg) were measured.

2.5 Physical activity

The amount of physical activity and the number of walking steps were measured while the individual performed their usual activities, using an accelerometer (Lifecorder EX; Suzuken Co. Ltd., Nagoya, Japan) placed on the participant's waist at all times while awake, except during swimming or bathing. The criteria for analysis were as follows: wearing of the accelerometer on their waist for a total duration of ≥4 days including weekdays and holidays, for ≥10 hours/day [17–19]. Exercise intensity was defined as follows: micro-exercise: <1.8, low intensity: 1.8–3.0, moderate intensity: 3.0–6.0, and high intensity: ≥6.0 (unit: metabolic equivalents) [20].

2.6 Physical functions

2.6.1. Muscle strength

For grip strength, the average value measured on each arm was determined. To determine knee extension muscle strength, one ankle was fixed with a belt, and a sensor detected the muscle strength when the participant extended the other side's knee while the experimenter supported the upper knee of the fixed side. The average value measured for each side was adopted, adjusted for body weight.

2.6.2. Movement function

The degree of locomotive syndrome was assessed using a locomotive functional scale questionnaire, two-step test, and standing movement test [21–23]. In the two-step test, the width which advanced two steps by the crotch and was corrected by height was adopted.

2.6.3. Agility function

The open–close stepping test was used. In the test, the inside and outside of the tape wire were opened and closed at the same time at intervals of 30 cm, and a step was taken. The number of times this could be stepped in 20 seconds was measured.

The participant sat in a chair with no armrests, with both feet placed in the centre of a simple measurement sheet (30 × 30 cm). The participants' hands were used to hold both sides of the chair. As soon as the experimenter signalled the participant to start, the participant opened their legs and spread their feet as quickly as possible, touching the floor beside the sheet with the forefoot or the entire sole of the foot, and then quickly returned their feet and legs to the original position. This series of actions constituted one repetition; the experimenter counted how many repetitions the subjects could perform in 20 seconds [24].

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2.6.4. Balance function

The one-leg standing test with eyes open (OLS test) was used to assess sedentary balance. The ability of the participant to stand on one leg with eyes open was measured for up to 120 seconds, in accordance with the procedures for physical tests for older adults designed by the Ministry of Education, Culture, Sports, Science and Technology [25].

The functional reach test was used to assess movement balance. The participant extended their arms as far forward as possible in the horizontal plane while keeping both their heels in contact with the ground. The score was obtained by measuring the distance between the start and end positions of the fingertips [26].

2.6.5. Walking function

The timed up and go test (TUG test) was used to assess walking function. The participant was instructed to move from a seated position in an armless chair to a standing position, walk 3 meters at their fastest safe pace, turn around, walk back to the chair, and sit down. They were allowed two attempts. The times taken to execute the motion series were averaged [27,28].

2.7 Blood analysis

Participants were asked to refrain from eating or drinking after 9:00 pm before the measurement day. Consequently, they fasted overnight for more than 12 hours, and blood samples were collected. The levels of the following variables were measured: items related to glucose and lipid metabolism (glucose, insulin, HbA1c, triglycerides, free fatty acids, total cholesterol, high-density, and low-density lipoprotein cholesterol), blood counts (white and red blood cell counts, platelet count, haemoglobin, haematocrit), minerals (sodium, potassium, chloride, calcium, magnesium, inorganic phosphorus, and iron), and liver and kidney function (aspartate aminotransferase, alanine aminotransferase, alkaline phosphatase, gamma-glutamyl transferase, creatine kinase, amylase, uric acid, urea nitrogen and creatinine).

2.8 Statistical analysis

All statistical analyses were performed using SPSS (version 24.0 for Windows; SPSS, Inc., Armonk, NY, USA). The relationships between QOL–physical activity and physical activity–physical function were analysed using multiple regression, adjusting for sex, age, and BMI. Foods and nutrients related to physical function were extracted using multiple regression analysis with a forward selection method by forced entry of sex, age, and BMI.

3. Results

The characteristics of the participants (n = 469) are shown in Table 1. Systolic blood pressure was more than 140 mmHg in both sexes, and the mean values of other characteristics were in the normal range, even though visceral fat accumulation was observed in men (Table 1).

 doi:10.20944/preprints202301.0140.v1

Table 1. Physiological characteristics of the older Japanese adults living in urban areas

	Total			Men			Women		
Number		469			166			303	
Age (years)	69.8	±	2.9	70.2	±	3.0	69.5	±	2.9
Body mass index (kg/m^2)	22.7	±	3.8	23.5	±	4.8	22.2	±	2.9
Visceral fat area (cm^2)	75.5	±	38.2	94.8	±	43.4	64.9	±	30.2
Systolic blood pressure (mmHg)	141	±	21	142	±	22	140	±	20
Diastolic blood pressure (mmHg)	81	±	12	83	±	12	80	±	11
Fasting blood glucose (mmol/L)	5.58	±	0.90	5.78	±	0.91	5.48	±	1.03
Triacylglycerol (mmol/L)	1.15	±	0.75	1.27	±	0.90	1.09	±	0.64
LDL-cholesterol (mmol/L)	1.76	±	0.43	1.61	±	0.41	1.85	±	0.47
HDL-cholesterol (mmol/L)	3.38	±	0.79	3.16	±	0.76	3.50	±	0.88

Values are presented as mean ± standard deviation.

The average number of steps per day was 7931 and 6962 in men and women, respectively (Table 2); there was no significant difference between the sexes. These values were higher than the average values among Japanese individuals of a similar age (6311 steps in men/5438 steps in women, at 65–74 years old) [29]. Grip strength and the OLS test in both sexes were lower than the Japanese averages for each age group.

Table 2. Comparison of physical functions between subjects with the national average

Physical function	Sex	Age (years)	n	Mean		SD	National average[†]
Number of steps	Men	65-75	166	9027	±	3422	6311
	Women	65-75	303	8484	±	2873	5438
Grip strength (kg)	Men	65-69	71	34.6	±	8.4	40.2
		70-75	93	33.4	±	6.9	38.1
	Women	65-69	161	24.0	±	5.5	25.3
		70-75	139	23.3	±	5.5	23.9
OLS test (sec)	Men	65-69	70	78.6	±	45.9	85.8
		70-75	94	62.7	±	45.9	74.6
	Women	65-69	164	76.1	±	43.2	89.0
		70-75	141	61.3	±	42.6	74.3

[†] National Health and Nutrition Survey 2017.

The PCS, MCS, and RCS were calculated based on the responses provided to the SF-36. The relationships between these component summaries and physical activity were examined using multiple regression analysis. The PCS was significantly positively associated with the number of steps and moderate- and high-intensity exercise. Similar associations were found between MCS and moderate-intensity exercise, RCS, and the number of steps (Table 3).

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Table 3. Results from multiple linear regression models adjusted for sex, age, and body mass index examining the association of QOLs with physical activities†

Physical activities / QOLs	PCS				MCS				RCS			
	B	SE	β	p-value	B	SE	β	p-value	B	SE	β	p-value
Number of steps	0.000	0.000	0.120	0.010	0.000	0.000	0.089	0.064	0.000	0.000	0.105	0.027
Micro exercise	-13.704	8.352	-0.080	0.102	-8.260	8.068	-0.051	0.306	-6.408	9.211	-0.034	0.487
Low intensity exercise	-1.938	11.844	-0.008	0.870	-10.175	11.411	-0.043	0.373	11.223	13.020	0.042	0.389
Medium intensity exercise	36.806	14.614	0.118	0.012	38.643	14.074	0.131	0.006	2.955	16.189	0.009	0.855
High intensity exercise	304.464	87.053	0.159	0.001	91.686	84.949	0.051	0.281	-18.089	97.045	-0.009	0.852

† Adjusted for sex, age, and body mass index.

B, partial regression coefficient; β, standardized partial regression coefficient; MCS, mental component summary score; PCS, physical component summary score; QOL, quality of life; RCS, role/social component summary score; SE, standard error

In addition, the relationship between physical activity and physical function was similarly analysed. The number of steps was significantly associated with the results of the two-step (locomotive function), OLS (sedentary balance function), and TUG tests (walking function) (Table 4). Similar associations were found between moderate-intensity exercise and the two-step test, high-intensity exercise, and the OLS test.

Table 4. Results from multiple linear regression models adjusted for sex, age, and body mass index examining the association of physical activities with physical functions†

Physical functions / Physical activities		Number of steps				Micro exercise				Low intensity exercise				Medium intensity exercise				High intensity exercise			
	Variable	B	SE	β	p-value	B	SE	β	p-value	B	SE	β	p-value	B	SE	β	p-value	B	SE	β	p-value
Muscle strength	Grip strength	1.68	22.4	0.004	0.940	0.000	0.000	0.004	0.942	0.000	0.000	0.032	0.578	0.000	0.000	-0.044	0.444	0.000	0.000	-0.019	0.746
	Knee extension muscle strength	10.2	1091	0.000	0.993	0.022	0.015	0.067	0.146	-0.011	0.011	-0.049	0.300	-0.010	0.009	-0.057	0.230	-0.001	0.001	-0.020	0.687
Movement function	Two step test	3789	892	0.195	0.000	-0.028	0.013	-0.098	0.031	0.010	0.009	0.051	0.267	0.016	0.007	0.105	0.024	0.001	0.001	0.045	0.342
Agility function	Open-close stepping test	18.3	27.2	0.031	0.502	0.000	0.000	0.051	0.255	0.000	0.000	-0.048	0.286	0.000	0.000	-0.031	0.507	0.000	0.000	-0.003	0.941
Balance function	OLS test (sedentary balance)	9.42	3.21	0.136	0.003	0.000	0.000	-0.050	0.271	0.000	0.000	0.043	0.355	0.000	0.000	0.017	0.709	0.000	0.000	0.120	0.012
	Functional reach test (movement balance)	10.1	20.8	0.022	0.627	0.000	0.000	0.011	0.812	0.000	0.000	-0.005	0.917	0.000	0.000	-0.024	0.597	0.000	0.000	0.067	0.147
Walking function	TUG test	-380	158	-0.110	0.017	0.000	0.002	0.000	0.992	0.000	0.002	-0.008	0.860	0.000	0.001	0.007	0.880	0.000	0.000	0.015	0.751

† Adjusted for sex, age, and body mass index

B, partial regression coefficient; β, standardized partial regression coefficient; OLS, one-leg standing test with eyes open; SE, standard error; TUG, Timed up and go

Further, the relationships among the results of the aforementioned physical function measurement tests (two-step, OLS, and TUG) and food intake were examined. Vegetable intake was associated with extension of the standing time (OLS test; p = 0.028), while cereal and meat intakes were related to shorter standing times (p = 0.012 and p = 0.009, respectively; Table 5). Vegetable and milk intakes were associated with faster movement (TUG test; p = 0.001 and p = 0.033, respectively); however, cereal intake was associated with a delay in movement (p = 0.031). Vegetable, seed, fruit, and beverage intakes were associated with longer strides (two-step test; p = 0.019, p = 0.004, p = 0.028, and p = 0.040, respectively), while egg intake was associated with shorter strides (p = 0.020). With respect to nutrients, magnesium (Mg) intake was positively related to the results of the OLS test, potassium (K) intake was positively related to the results of the TUG test, vitamin B6 (VB6) intake was positively related to the results of the two-step test, and the dietary fibre intake/carbohydrate intake ratio (Fib/C) was positively related to the results of all three tests.

Table 5. Results from multiple linear regression models adjusted for sex, age, and body mass index examining the association of physical functions with food intake†

Foods and nutrients / Physical functions		Two step test				OLS test				TUG test			
	Variable	B	SE	β	p-value	B	SE	β	p-value	B	SE	β	p-value
Foods	Vegetables	0.000	0.000	0.105	0.019	0.040	0.018	0.099	0.028	-0.001	0.000	-0.150	0.001
	Fruits	0.000	0.000	0.130	0.004	-	-	-	-	-	-	-	-
	Seeds	0.003	0.001	0.098	0.028	-	-	-	-	-	-	-	-
	Milk	-	-	-	-	-	-	-	-	-0.001	0.000	-0.101	0.033
	Beverages	0.000	0.000	0.092	0.040	-	-	-	-	-	-	-	-
	Cereals	-	-	-	-	-0.056	0.022	-0.114	0.012	0.001	0.000	0.101	0.031
	Egg	-0.001	0.000	-0.103	0.020	-	-	-	-	-	-	-	-
	Meat	-	-	-	-	-0.150	0.057	-0.117	0.009	-	-	-	-
Nutrients	K	-	-	-	-	-	-	-	-	0.000	0.000	-0.165	0.000
	Mg	-	-	-	-	0.113	0.032	0.161	0.000	-	-	-	-
	Vit B6	0.097	0.023	0.193	0.000	-	-	-	-	-	-	-	-
Nutritional composition	Fib/C	1.07	0.468	0.105	0.023	407	131	0.142	0.002	-8.17	2.63	-0.145	0.002

† Extracted using a forward selection method by forced entry of sex, age, and body mass index

B, partial regression coefficient; β, standardized partial regression coefficient; Fib/C, the ratio of fiber per carbohydrate; OLS, one-leg standing test with eyes open; SE, standard error; TUG, Timed up and go

4. Discussion

We conducted a study of the quantitative relationships among diet, physical functions, and physical activity in older Japanese adults. The intake of Mg, K, VB6, fibre, and foods that include these nutrients (i.e., vegetables, fruits, and seeds) was positively correlated with physical functions (i.e., movement, balance, and walking functions). Physical activity, positively related to these physical functions, might result in improved physical QOL.

The average values of items other than systolic blood pressure were within the diagnostic criteria for metabolic syndrome (Table 1) [30]. A higher average number of steps than those of Japanese individuals of similar age of both sexes suggested that the participants in this study lived active daily lives; however, their physical functions, such as muscle strength and balance, might not have been superior to those of other individuals of the same age (Table 2).

Physical activity, comprising steps, moderate-intensity exercise, and high-intensity exercise, was significantly positively associated with PCS. This finding is consistent with that of a previous report describing the relationship of PCS with the number of steps and exercise intensity [31]. Similar associations were found between MCS and moderate-intensity exercise and between RCS and number of steps. These results suggest that QOL is related to number of steps, moderate-intensity exercise, and high-intensity exercise.

The physical functions that were significantly associated with the number of steps were sedentary balance (OLS test), walking function (TUG test), and mobility (two-step test). Moderate- and high-intensity exercise was significantly related to mobility and sedentary balance, respectively. Thus, a significant association was found between physical activity (number of steps, moderate-intensity exercise and high-intensity exercise) and physical functions (sedentary balance, walking function, and mobility), while it appears that physical functions, such as muscle strength and agility, were not associated with physical activity. A high level of daily physical activity is reportedly related to high mobility function but not to muscle strength [32]. The results of the present study are generally consistent with those of the aforementioned report. Therefore, improvement of mobility function, not muscle strength, may be important to support physical activity in older adults.

Seed intake was positively associated with mobility (Table 5). Milk and fruit intakes were positively related to walking function and mobility, respectively. Vegetable intake was positively associated with all three physical functions; however, cereal intake was negatively related to sedentary balance and walking function. Egg intake was negatively associated with mobility. Mg intake was positively related to sedentary balance, K intake was positively related to walking function, VB6 intake was positively related to mobility, and Fib/C was positively related to all three physical functions.

Mg is found in vegetables and seeds; K is found in vegetables and fruits; VB6 is found in meat, fish, and seeds; and fibre is found in vegetables and fruits. Mg is involved in muscle relaxation and contraction [33], and its supplementation reportedly improves physical function [34]. K is reportedly involved in neurotransmission and muscle contraction, and it has been recently reported that VB6 intake is associated with agility and mobility [35]. In addition, Mg, K, and VB6 intakes were reported to be positively associated with physical activity [36]. Fibre intake, which has an unknown relationship with physical functions, was suggested to be associated with physical activity [37]. Fibre reportedly affects the absorption of various nutrients. The absorption of K and VB6 is primarily due to passive transport; therefore, the effect of fibre intake is unknown. Conversely, the enhancing effect of fibre on Mg absorption through active transportation has been reviewed at the level of animal experiments and clinical trials [38]. It was confirmed that Fib/C, not Mg intake, was significantly positively related to the blood Mg concentration based on multiple regression analysis (Table 6). Thus, fibre intake might indirectly affect physical function by increasing Mg absorption.

Table 6. Results from multiple linear regression models adjusted for sex, age, and body mass index examining the association of serum Mg concentration with Mg intake, total fiber intake and Fib/C ratio[†]

	serum Mg concentration			
	B	SE	β	p-value
Mg intake (mg/d)	0.000	0.000	0.089	0.055
Total fiber intake (g/d)	0.004	0.002	0.116	0.014
Fib/C	1.341	0.488	0.128	0.006

[†] Adjusted for sex, age, and body mass index.

B, partial regression coefficient; β, standardized partial regression coefficient;

Fib/C, the ratio of fibre per carbohydrate; Mg, magnesium; SE, standard error

Based on the results of this study, we elucidated the quantitative relationships among physical activity, physical function, and food intake in older Japanese adults living in urban areas. Several limitations of the present study should be considered. First, this study was conducted following a cross-sectional design. Long-term observational studies are needed to examine the diets that promote a high quality of life through improving physical function and activity. Second, the participants were living in urban areas. Third, from the comparison with the national average of steps in individuals of the same age, the participants seemed to be relatively active. Thus, it is necessary to study participants who live in rural areas and who participate in other activities.

In conclusion, we found significant relationships among intake of foods and nutrients, physical functions, physical activity, and physical QOL. The intake of certain foods and nutrients was positively correlated with physical functions. Physical activity, positively related to these physical functions, might result in improved physical QOL among older Japanese adults. In the future, we aim to conduct a clinical trial using nutrients and/or foods recognized from this study as possible intervention targets. Thus, we will propose a diet that supports movement and activities of the older adult population.

Author Contributions: The examination plan was prepared by all authors. T.F., K.F., and M.M. were in charge of the operation of the examination. T.F. analysed the data and drafted the paper. All authors considered the results and confirmed the contents of the paper.

Funding: This research was funded by Kao Corporation, registered number 818-20161118.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, approved by Waseda University's Ethical Review Committee on Human Research and Kao Corporation's Institute of Biological Sciences Research Ethics Review Committee (UMIN000026007 registered on 6 Feb 2017).

Informed Consent Statement: Informed consent was obtained from all participants involved in the study.

Data Availability Statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: T.F. and H.T. are employees of Kao Corporation.

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