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Original Research Article

Decreased Physical Activity Associated with Executive Dysfunction Correlates with Cognitive Impairment among Older Adults in the Community: A Retrospective Analysis from the Kurihara Project

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Key Words

Mild cognitive impairment · Dementia · Clinical Dementia Rating · Physical activity · Executive function · Retrospective study

Abstract

Background/Aims: No previous studies have explored the relationship between physical activity (PA) and executive dysfunction. ***Methods:*** We retrospectively evaluated the PA for 590 older participants in the Kurihara Project; 221 participants had a Clinical Dementia Rating (CDR) of 0 (healthy), 295 CDR 0.5 (very mild dementia), and 74 CDR 1+ (dementia). ***Results:*** In the complicated task, whether the motor intensity was high (e.g. farming) or low (e.g. shopping), PA exhibited an inverse relationship with the CDR level. By contrast, for simple tasks with high intensity (e.g. walking), no CDR group differences were noted. For PA with low intensity (e.g. cleaning), the CDR 1+ group exhibited decreased levels. ***Conclusion:*** PA was related to the burden of executive function in patients with mild cognitive impairment; however, in patients with dementia, PA was related to both the burden of executive function and motor intensity.

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Introduction

Dementia is characterized by memory loss that occurs in combination with impairment of other cognitive functions (e.g. behavior, personality changes, social functioning and/or the inability to perform activities of daily living) [1]. Physical activity (PA) has been consistently associated with decreased risk of cognitive decline and dementia, and its positive effects are evident for both Alzheimer's disease (AD) and vascular dementia [2, 3]. PA refers to any body movement that is produced as a result of contraction of skeletal muscles and that increases energy expenditure [4]. Exercise refers to planned, structured, and repetitive movement to improve or maintain one or more components of physical fitness [4]. Therefore, PA consists of exercise and all of the body movements involved in daily living, including housework and labor.

In the relationship between PA and dementia, the highest PA category is associated inversely with the risk of dementia and AD in the Cochrane Database of Systematic Reviews and in prospective epidemiological studies on the Web of Science databases [5]. PA has been reported to be a protective factor against incident dementia in a population-based cohort [6]. However, some systematic reviews have shown no evidence of benefit from exercise on cognition and neuropsychiatric symptoms [7], and a low statistical power of the effects of exercise on global cognition [8].

For the relationship between PA and mild cognitive impairment (MCI) including very mild dementia, some prospective cohort studies have revealed the following: (1) greater levels of PA were associated with a lower risk of incident MCI among the otherwise cognitively normal elderly [9]; (2) high levels of participation in PA were associated with reduced risk of dementia among the elderly with MCI [10], and (3) women who were engaged in aerobic exercise exhibited cognitive benefits, with improved performance on tasks of executive function [11]. However, while exercise in the elderly with MCI improved their cardiovascular fitness, no improvements in cognitive function were observed. It would appear that exercise may be beneficial prior to the onset of MCI but is less helpful after its onset [12]. Furthermore, low levels of light-intensity PA were not associated with any reduction in brain atrophy [13]. Meanwhile, the effects of light PA on memory among the elderly with MCI are not mediated by changes in the hippocampal volume [14].

With respect to the relationship between PA and executive function, some prospective cohort studies for elderly with AD have revealed that higher habitual PA levels were associated with reduced changes in executive function (map search task, digit symbol substitution task, controlled oral word association task, and verbal fluency task) [15]. Habitual PA status was associated with executive performance [16]. Furthermore, social participation was predictive of two domains of cognitive and executive function. The relative magnitude of this effect was comparable to PA level in a large cohort study [17]. However, those results also evaluated various levels/intensities of PA.

Considering these studies, there is promising evidence that PA can significantly improve cognitive function in people with dementia and their ability to perform daily activities, but there remains a lot of variation between trial results that were not explained, and the mechanisms implicated in this effect remain unclear [6]. There is little to no evidence supporting a relationship between PA (frequency, intensity, duration, type of activity, etc.) and cognitive decline (cognitively normal, MCI, and dementia) [11]. In particular, to date, no study has addressed the approach from the data of random sampling among the community-dwelling elderly.

The aim of this study was to clarify the relationship between executive dysfunction of PA in daily living and dementia. Using the database of the Kurihara Project, a community-based prevention program of stroke and dementia in Kurihara, the PA of healthy aging adults and adults with dementia was analyzed retrospectively.

Materials and Methods

Subjects

The Kurihara Project (2008–2010) was performed to focus on the old-old population (≥75 years old) for the prevention of stroke, dementia and bed confinement in Kurihara City, an agricultural town of 76,708 (Nov. 2015) in Miyagi Prefecture, northern Japan [18]. The study included 590 of the 1,252 subjects aged ≥75 years who underwent health examinations and provided informed consent for data analysis.

The study protocol was approved by the Institutional Review Board of the Tohoku University Graduate School of Medicine. The study conformed to the STROBE guidelines for cohort studies.

Clinical Dementia Rating Assessment

The clinical team, comprised of medical doctors and public health nurses who determined the Clinical Dementia Rating (CDR) for each participant, was blinded to the cognitive test results. Prior to the interviews with the doctors, public health nurses visited the participants' homes to evaluate their daily activities. Observations by family regarding the participants' lives were described using a semistructured questionnaire. Participants who lived alone were excluded from this investigation. The participants were then interviewed by doctors to assess episodic memory, orientation, etc. Finally, with reference to the information provided by the family, the participants' CDR stages were determined at a joint meeting. A reliable Japanese version of the CDR worksheet [19] was established, and dementia was diagnosed based on the DSM-IV criteria. One author (K.M.) was certified as a CDR rater at the Washington University School of Medicine Alzheimer's Disease Research Center Memory and Aging Project.

Assessment of Cognitive Impairment and Depression

Cognitive impairment was evaluated by the CDR [20] from the database of the Basic Information of Users (BIU) [21]. We categorized 590 subjects into 3 groups according to their CDR: the CDR 0 group (n = 221), which means they were healthy elderly; the CDR 0.5 group (n = 295), which means they had very mild dementia, and the CDR 1+ group (n = 74), which means they had dementia [22]. Also, we examined the impact of depression on cognitive decline. Depression was assessed by the short version of the Geriatric Depression Scale (GDS-15) cutoff score of 5/6 (low: <5, high: ≥6) indicating more severe depressive symptoms [23].

Assessment of Daily PA

PA in daily living was evaluated based on 23 items (table 1) in the BIU database. The public health nurses visited the subjects' homes to evaluate their daily activities. Observations by family members regarding the subjects' lives were recorded using a semistructured questionnaire. The 23 items were classified PA codes and metabolic equivalent (MET) values of the American College of Sports Medicine (ACSM) [24]. The classification of PA was evaluated using a double-blind trial, and the reliability testing was evaluated using the intraclass correlation coefficient (ICC) [25]. ICC assessment was 0.913 ($p < 0.0001$: almost perfect) when 33 randomly selected subjects out of the 590 subjects were tested.

PA was classified into 4 groups according to the intensity level of PA and executive function. PA intensity was the evaluated METs according to the criteria of the ACSM [24]. The amount of time spent on PA (h/day) was estimated using the data from the Multiple Indicator Cluster Surveys (MIC Survey) on the 2011 Survey on Time Use and Leisure Activities of Japan (see Appendix) [26], because it was not assessed in the Kurihara Project. The amount (intensi-

Table 1. METs and executive function level on PA items [24]

Item of specific activity	METs	Executive function
[Sedentary behavior (1.0–1.5 METs)]		
Participating in community activities (voluntary)	1.5	complicated task
Participating in a senior citizen's club	1.5	
Miscellaneous activities (e.g. reading, arts)	1.5	
Participating in community activities (involuntary)	1.5	simple task
Bathing (independent self-care)	1.5	
Child care or elderly care	1.5	
[Light intensity (1.6–2.9 METs)]		
Shopping (with/without a cart, standing/walking)	2.3	complicated task
Long-distance travel (by car or public transportation)	2.0	
Interaction with one's neighbors	2.0	
Cooking or food preparation	2.0	
Recreational activities (e.g. traveling, crafts, music)	2.0	
Walking (very slow paced walking inside/around the house)	2.0	simple task
Preparation of farming tools (e.g. sharpening tools)	2.0	
Cleaning or laundry (general household cleaning and laundry)	2.0	
[Moderate intensity (3–5.9 METs) and vigorous intensity (≥6 METs)]		
Farming (e.g. rice, planting, care of animals)	4.8	complicated task
Gardening (e.g. planting trees, crops, garden)	4.3	
Working or participating in volunteer activities (walk/stand combination)	3.0	
Gardening (e.g. weeding, removing snow or leaves)	3.8	simple task
Walking (e.g. for pleasure, dog, to work, moderate paced walking)	3.5	
Light intensity activities (e.g. calisthenics, petanque)	3.5	
Moderate intensity activities (e.g. ballroom dance, softball, golf)	4.0	
Vigorous intensity activities (e.g. jogging, swimming, tennis)	8.3	
Resistance training (e.g. muscular endurance, circuit/curves)	5.0	

Levels of executive function were categorized into dichotomous variables with a similar number of individuals according to whether the PA is a simple task or a complicated task.

ty × duration) of PA was calculated by METs × h/day. For example, the PA of 'shopping' is calculated using table 1 and the appendix as follows:

PA = [(68 min/60 min) × 3 days/week)] × (2.3 METs) = 1.1 METs × h/day

PA was then categorized into 2 groups (high: ≥3 METs, low: <3 METs) by intensity activity according to the criteria of the ACSM [27].

Assessment of Executive Function

Several long-term trials have shown that PA is associated with executive function [15, 28]. The PAs that showed effects towards executive function are as follows: aerobic walking [29], dual task-based exercise training [30], two sessions of exercise training [31], stepping activity [32], crossing a street at a pedestrian traffic light [33], and social participation [17]. Conversely, the PAs that did not show any positive effects on executive function include stretching and balance exercises [34], slow jogging [35], resistance exercise [36], moderate-intensity walking exercise [37], flexibility training [38], and single-task training [34]. These results suggested that dual task-based PA (which is complex PA) affected executive function, but single task-based PA (which is simple PA) whether PA is low or high exhibited no effect. We categorized the 23 items of PA in BIU data into 2 groups: complex tasks (e.g. shopping,

Table 2. Baseline demographics and clinical characteristics

	CDR 0	CDR 0.5	CDR 1+
Participants, n	221	295	74
Men, n†	92 (41.6%)	108 (36.6%)	25 (33.8%)
Age, years	79.0±3.6[b]	80.4±4.3[a]	82.3±4.4[a, b]
Educational level	9.3±2.1[b]	8.5±1.7[a]	7.8±1.5[a, b]
MMSE	25.4±2.6[b]	22.8±3.4[a]	16.2±5.4[a, b]
GDS	3.9±2.6[b]	4.8±3.1[a]	6.1±3.2[a, b]

Statistical analyses: ANOVA (post hoc test; Bonferroni test). † χ^2 test, $p < 0.05$. [a] Significant difference with CDR 0 ($p < 0.05$). [b] Significant difference with CDR 0.5 ($p < 0.05$). Values for age, educational level, MMSE and GDS are expressed as mean ± SD.

cooking, and farming) or simple tasks (e.g. walking, jogging, and removing snow) (table 1). In the cases exhibiting both tasks, the item of PA was categorized into the dichotomous groups of simple versus complicated tasks.

Statistical Analysis

In order to examine the interaction between the amount of daily PA and executive function, stratification analysis of the level of executive function was conducted. The analysis was performed to examine the contribution of CDR and PA intensity to PA amount. All statistical analyses were performed using SPSS version 20.0 (SPSS Japan Inc., Tokyo, Japan). Since the distribution of all continuous variables was not normal, the common logarithm was applied to normalize the data prior to analysis. Logarithmic transformation of the continuous covariates resulted in near-normalized distribution of the variables. The participants' characteristics at baseline were compared using analysis of variance. Dichotomous variables were expressed as percentages and continuous variables as the median (interquartile range). The analyses were performed after adjustment for age and sex. All statistical analyses were 2-tailed, and p values < 0.05 were considered significant.

Results

Prevalence of Dementia

Of the 590 subjects who agreed to take part in the study and underwent clinical examination, 221 (37.5%) were healthy, 295 (50.0%) had very mild dementia, and 74 (12.5%) had dementia. As we reported the prevalence of dementia in Japan, the ratio of prevalence exhibits both reliability and validity [39]. Table 2 presents the demographic data of the three CDR groups. There were no significant differences in sex among the three groups. The CDR 1+ group was the oldest with the lowest education level and Mini-Mental State Examination (MMSE) score, and the highest GDS score. The CDR 0.5 group was older with a lower education level and MMSE score, and a higher GDS score compared with the CDR 0 group.

The Total Amount of PA and CDR Level

Table 3 presents the results of analysis of covariance (ANCOVA) of the relationship between the total amount of PA (PA amount) and the CDR level. The CDR 0.5 group exhibited a lower PA amount than the CDR 0 group ($p < 0.001$). The CDR 1+ group exhibited a lower PA

Table 3. Total PA (95% CI) by CDR categories

	Total PA by CDR			p for trend
	CDR 0	CDR 0.5	CDR 1+	
Total PA	9.74 (9.40–10.08)	8.70 (8.41–9.00)[a]	4.90 (4.31–5.50)[a, b]	0.000
Total PA by intensity				
Light PA (<3 METs)	6.82 (6.62–7.03)	6.39 (6.22–6.57)[a]	3.60 (3.25–3.96)[a, b]	0.000
High PA (≥3 METs)	2.92 (2.66–3.18)	2.31 (2.09–2.53)[a]	1.30 (0.85–1.75)[a, b]	0.000

PA was calculated by METs × h/day. Statistical analyses: ANOVA (Bonferroni test) adjusted for sex and age. [a] Significant difference with CDR 0 ($p < 0.05$). [b] Significant difference with CDR 0.5 ($p < 0.05$).

amount than both the CDR 0 and 0.5 groups ($p < 0.001$). Next, the PA amount was classified into two groups based on PA intensity (light PA: <3 METs, high PA: ≥3 METs) and ANCOVA was conducted. The PA amount of the light-intensity group decreased progressively from the CDR 0 group to the CDR 1+ group ($p < 0.001$). Similarly, the PA amount of the high-intensity group also decreased progressively according to the CDR group ($p < 0.001$).

PA Amount and CDR Level Stratified by the Level of Executive Function

In order to further examine the interaction between PA amount and executive function, stratification analysis of the level of executive function was performed. The analysis was performed by two groups classified as GDS score because there is interaction between depression and PA intensity. Table 4 presents the ANCOVA for the relationships between the PA amount and the CDR categories after performing the stratification analysis of the executive function level and GDS.

In the complicated task of executive function, the light-intensity (e.g. shopping) and high-intensity (e.g. farming) PA groups showed that the PA amount of the CDR 0.5 group was lower than the PA amount of the CDR 0 group ($p < 0.0001$) and that the PA amount of the CDR 1+ group was lower than that of the CDR 0.5 group ($p < 0.001$) (p for trend < 0.0001). In the simple task, the high-intensity PA group (e.g. walking) showed similar PA amounts for all 3 CDR groups. In the light-intensity PA group (e.g. cleaning), there was no statistical difference in the PA amount between the CDR 0 and CDR 0.5 groups. However, the PA amount of the CDR 1+ group was lower than those of the CDR 0 and 0.5 groups (each $p < 0.0001$). Those results were significant relationships independent of GDS and education level.

Discussion

This retrospective study investigated the relationships between PA and executive function and dementia. In particular, the diagnosis of dementia was determined using evidence-based medicine with the CDR and was classified into 3 categories (healthy, very mild dementia, and dementia). Our results suggest that cognitive decline is related to the burden of executive function of PA in daily living.

Prevalence of Dementia

The prevalence of dementia and very mild dementia among all of the participants was 12.5 and 50.0%, respectively. The prevalence of dementia in Japan has been reported to vary from 3.8 to 11.0% among those aged 65 years and older [39]. However, though there have

Table 4. Total PA (95% CI) stratified by the level of executive function with GDS and intensity for CDR categories

	Total PA by CDR			p for trend	Effect of education	
	CDR 0	CDR 0.5	CDR 1+		F	p
Total PA in simple executive function						
Light PA with low GDS	2.19 (2.10–2.27)	2.21 (2.13–2.29)	1.50 (1.30–1.69)[a, b]	0.000	1.25	0.264
Light PA with high GDS	2.36 (2.18–2.53)	2.26 (2.14–2.39)	1.54 (1.33–1.75)[a, b]	0.000	3.04	0.083
High PA with low GDS	0.90 (0.69–1.11)	1.01 (0.82–1.21)	0.83 (0.34–1.32)	0.806	0.29	0.589
High PA with high GDS	0.67 (0.35–0.99)	0.73 (0.50–0.96)	0.29 (0.10–0.68)	0.151	0.00	0.953
Total PA in complicated executive function						
Light PA with low GDS	4.68 (4.50–4.87)	4.30 (4.13–4.46)[a]	2.35 (1.92–2.78)[a, b]	0.000	0.17	0.678
Light PA with high GDS	4.44 (4.08–4.81)	3.88 (3.62–4.15)[a]	2.00 (1.56–2.45)[a, b]	0.000	0.42	0.518
High PA with low GDS	2.07 (1.83–2.31)	1.55 (1.33–1.76)[a]	0.74 (0.19–1.30)[a, b]	0.000	2.08	0.151
High PA with high GDS	2.19 (1.78–2.61)	1.13 (0.83–1.42)[a]	0.65 (0.14–1.15)[a]	0.000	0.04	0.838

Low GDS: <5, high GDS: ≥6; PA was calculated by METs × h/day. Statistical analysis: ANOVA (Bonferroni test) adjusted for sex, age, education, and GDS. [a] Significant difference with CDR 0 ($p < 0.05$). [b] Significant difference with CDR 0.5 ($p < 0.05$).

been no previous reports of the prevalence among the old-old population, aged 75 years and older, we reported the prevalence with reliability and validity [39].

PA Amount and CDR Level

We initially examined the relationships between the PA amount and CDR level, and showed that the PA amount decreased in a step-wise manner in the CDR 0, 0.5, and 1+ groups. The inverse correlation between PA and CDR level supported these findings even when the PA amount was classified by PA intensity.

The majority of published evidence from the observational and controlled studies conducted to date clearly underscores the positive association between PA and cognitive function [40]. One prospective study investigated the long-term influence of PA on the risk of dementia among the elderly Japanese population [41], and showed that the active group showed significantly lower crude incidence of AD compared with the inactive group. Furthermore, several studies have shown that regular PA could represent an important and potent protective factor for cognitive decline and dementia in elderly persons [7, 42]. The current results confirm the previous findings of a positive effect of PA on cognitive function among elderly adults.

PA Amount and Executive Function among the CDR Groups

We performed a stratified analysis of the relationships between CDR level and PA amount according to the burden of executive function. The results of the stratification analysis of CDR level and PA amount suggest the following: for the complicated task, whether PA intensity was high (e.g. farming) or low (e.g. shopping), PA amount exhibited an inverse relationship with the CDR level. By contrast, simple tasks exhibited different results. Specifically, for the high-intensity PA group (e.g. walking), there were no differences based on the CDR grouping. However, for the low-intensity PA group (e.g. cleaning), the CDR 1+ group exhibited a lower PA amount compared with the CDR 0 and 0.5 groups. The association between PA and CDR was an independent relationship; thus, it is not influenced by educational level, GDS, and age.

Our study indicated a significant relationship between PA and executive function. Higher-level executive function was reported to be necessary for the regulation of PA in a cohort study [32]. Improvements in executive function correlated with increases in gait speed and PA in a

prospective cohort study of community-dwelling older adults with falls [43]. In an observational study, the prevalence and severity of executive dysfunction were demonstrated in AD patients [44]. Furthermore, several prospective studies have reported that social participation is positively associated with executive function [17, 45]. The results also revealed that the PA amount in the daily living of the CDR 0 group is higher than in the CDR 1+ group in both the simple and complicated task groups of executive function. In a 1-year cohort study of executive function changes in elderly with AD, higher habitual PA levels were associated with reduced change in executive function [15], and in longitudinal multilevel models, low levels of PA led to subsequent declines in executive function among older adults [46]. However, our study indicated that whether the PA level was high or low, the PA with the complicated task exhibited an inverse relationship with CDR level. Considering these findings, our results indicated that long-term PA with the complicated task in daily living might decrease according to the dementia severity.

Interestingly, we reported various findings of PA amount among the CDR categories depending on PA intensity and the levels of executive function. The higher PA levels in participants with/without cognitive impairment were associated with significantly higher whole-brain and parietal lobe volume, and reduced ventricular dilation. Furthermore, AD and very mild dementia correlated significantly with lower brain volume across the whole brain, with pervasive associations revealing frontal lobe atrophy and ventricular dilation [47]. PA was associated independently with greater whole brain and regional brain volumes and reduced ventricular dilation. Our findings suggest that the effect of PA on the elderly with cognitive impairment may be related not only to PA intensity, but also the type/levels of executive function.

Limitations and Conclusion

The present study has several limitations. Firstly, this was a retrospective analysis that used the database of the Kurihara Project; unfortunately, the database did not investigate the actual time of PA. We estimated the duration and the frequency of PA using data from the Statistics Bureau of Japan. This may be a major limitation because all statistical work is based on estimated data. It is impossible to draw the direction of the relationship. The association may be just a consequence of progression of cognitive decline (more difficult activities were drawn earlier). In addition, PA was based on a recording by recall method, in which no information was obtained regarding the actual activities for each PA session.

Moreover, because this was an observational study, we could not conclude whether PA with the complicated task reduced the risk for dementia and functional decline. Therefore, an intervention trial should be undertaken to confirm the existence of a relationship between PA and the complicated task and dementia and functional decline.

In conclusion, our study found that PA was related to the burden of executive function for MCI; however, PA for dementia was related to both the burden of executive function and level of motor intensity. Since previous reports on ‘exercise’ interventions for dementia prevention have not considered the burden of executive function, we should be cautious in our interpretation of such results.

Appendix

The Amount of Time Spent on PA Using the Data from MIC Survey in Japan, 2011

Item of specific activity	Time spent per day, min		Frequency per week, days	
	men	women	men	women
Participating in community activities (voluntary)	93	97	1.3	1.1
Participating in a senior citizen's club	96	97	1.3	1.3
Miscellaneous activities (e.g. reading, arts)	93	81	1.3	1.2
Participating in community activities (involuntary)	93	97	1.3	1.1
Bathing (independent self-care)	39	42	7.0	7.0
Child care or elderly care	15	64	0.8	0.7
Shopping (with/without a cart, standing/walking)	68	64	3.0	3.0
Long distance travel (by car or public transportation)	73	60	5.0	5.0
Interaction with one's neighbors	73	60	5.0	5.0
Cooking or food preparation	88	131	2.7	2.8
Recreational activities (e.g. traveling, crafts, music)	73	60	0.9	1.2
Walking (very slow paced walking inside/around the house)	38	25	3.2	2.9
Preparation of farming tools (e.g. sharpening tools)	64	75	1.9	1.9
Cleaning or laundry (general household cleaning and laundry)	64	75	2.7	2.8
Farming (e.g. rice, planting, care of animals)	142	123	1.9	1.9
Gardening (e.g. planting trees, crops, garden)	121	47	1.9	1.9
Working or participating in volunteer activities (walk/stand combination)	169	147	0.8	0.6
Gardening (e.g. weeding, removing snow or leaves)	142	123	1.9	1.9
Walking (e.g. for pleasure, dog, to work, moderate paced walking)	81	66	3.2	2.9
Light intensity activities (e.g. calisthenics, petanque)	81	66	1.6	1.7
Moderate intensity activities (e.g. ballroom dance, softball, golf)	81	66	1.5	1.5
Vigorous intensity activities (e.g. jogging, swimming, tennis)	81	66	2.3	2.1
Resistance training (e.g. muscular endurance, circuit/curves)	81	66	2.5	2.4

MIC = The Multiple Indicator Cluster Surveys (MIC survey) on The 2011 Survey on Time Use and Leisure Activities of Japan. Survey subjects: age, ≥75 years; area: the countryside of the Miyagi Prefecture.

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Disclosure Statement

None of the authors have any conflicts of interest to declare.

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