Neural correlates of older adults' self-overestimation of stepping-over ability

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Abstract A growing body of literature indicates that cognitively intact older adults tend to overestimate their physical functioning (e.g., step-over ability), which may lead to fall risk. However, the neural correlates underlying this phenomenon are still unclear. We therefore investigated the neural basis of older adults' self-overestimation of stepping-over ability. A total of 108 well-functioning community dwelling older adults (mean age = 73.9 years) performed step-over tests (SOT) in two ways: self-estimation of step-over ability and an actual step-over task. During the self-estimation

task, participants observed a horizontal bar at a distance of 7 m and estimated the maximum height (EH) of successful SOT trials. The actual SOT was then performed to determine the actual maximum height (AH) of successful trials. Participants also underwent positron emission tomography with ^{18}F -fluorodeoxyglucose at rest to assess cerebral neural activity. The SOT showed that 22.2 % of participants overestimated their step-over ability. A regression analysis adjusted for potential covariates showed that increased self-estimation error (difference between EH and AH) was correlated with lower glucose metabolism in the bilateral orbitofrontal cortex (OFC) and left frontal pole. Only the significant correlation between self-estimation error and OFC activity persisted after correcting for multiple comparisons. For well-functioning healthy older adults, overlooking one's own functional decline may be influenced by reduced metabolic activity in the anterior prefrontal cortex, particularly in the OFC. Our findings also suggest that functional decline in the OFC prevents older adults from updating the qualitative/quantitative values of their impaired physical abilities.

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Introduction

Accurate self-estimation (or self-awareness) of our own physical abilities is essential for healthy cognition, providing us the ability to choose adequate daily activities.

Any discrepancy between an actual action and its estimation, particularly overestimation, may place individuals at risk for goal-directed behavioral failures (e.g., tripping and stumbling while walking). The inability in recognizing behavioral or functional impairments resulting from a neurological disease (e.g., Alzheimer's or stroke) has been termed in several words, such as "anosognosia," "lack of insight," and "reduced awareness of deficits" (Ecklund-Johnson and Torres 2005; Zamboni and Wilcock 2011). However, this cognitive deficit is not always derived from neurological diseases alone.

Recent studies indicate that even healthy older adults are unaware of age-related physical declines and thus tend to overestimate their physical abilities, compared to young adults (Butler et al. 2011; Gabbard et al. 2011; Lafargue et al. 2013; Robinovitch and Cronin 1999; Sakurai et al. 2013). Furthermore, cross-sectional and longitudinal studies have revealed that older adults' tendencies to overestimate their physical abilities are associated with accidental falls (Fujimoto et al. 2015; Sakurai et al. 2013). Therefore, self-overestimation of physical abilities may well be reflective of age-related cognitive deficits and is most likely to result in hazardous behaviors in response to environmental challenges. However, most findings are of behavioral evidence and the neural basis of this form of self-overestimation remains unclear.

Using patients with Alzheimer's disease (AD) and other forms of dementia, recent research has investigated the anatomical correlates of one's declines in self-awareness of cognitive deficits. The anatomical evidence generally suggests that several brain regions, such as cortical midline structures comprising the prefrontal cortex (PFC), temporo-parietal region, insula, and anterior/posterior cingulate, mediate functions relevant to self-appraisals (Northoff et al. 2006; Schmitz and Johnson 2007; Zamboni and Wilcock 2011). For instance, Shibata et al. (2008), using single photon emission computed tomography (SPECT), showed that an unawareness of memory impairment among AD patients correlated with decreased perfusion in the orbitofrontal cortex (OFC). Rosen et al. (2010) further showed that accuracy of self-appraisals for cognitive performance negatively correlated with gray matter atrophy in the right ventromedial PFC. More recently, Shany-Ur et al. (2014) showed that atrophy in a number of regions, such as the right frontal regions, anterior insula, putamen, thalamus, and medial and lateral temporal lobe regions, correlated with overestimation of

one's ability to perform activities of daily living (ADLs). These aforementioned findings raise the possibility that unawareness of one's own physical limitations/declines even in cognitively healthy older adults may probably be caused by functional declines in the frontal, medial parietal, and parieto-temporal regions (Zamboni and Wilcock 2011).

Accuracy of self-estimated physical abilities has been examined with various study tasks, such as gait (Beauchet et al. 2010), reaching (Butler et al. 2011; Robinovitch and Cronin 1999), and step-over (Sakurai et al. 2013; Sakurai et al. 2014a) tasks. Recent studies using these tasks consistently showed that older adults tend to overestimate their physical abilities in comparison with young adults (Beauchet et al. 2010; Gabbard et al. 2011; Lafargue et al. 2013; Robinovitch and Cronin 1999; Sakurai et al. 2013), and the overestimation is more evident among older adults who show some declines in the abilities as such (Butler et al. 2011; Robinovitch and Cronin 1999; Sakurai et al. 2013).

In the present study, accuracy of self-estimated physical abilities was assessed using a step-over action: the step-over test (SOT; Sakurai et al. 2013; Sakurai et al. 2014a). We assumed that during daily activities, if older adults overestimate their step-over ability (i.e., their leg elevation is lower than they expect), this may increase a risk for tripping during a step-over action, which could lead to falls. Therefore, the ability to correctly estimate one's step-over ability is essential for the safe performance of daily activities.

Our main purpose of this study was to investigate the neural correlates underlying the age-related self-overestimation of stepping-over ability in a sample of cognitively and physically healthy, community-dwelling older adults. To this end, the present study used PET with ^{18}F -fluorodeoxyglucose (FDG-PET), which can detect early-stage neural changes by measuring cerebral glucose metabolism that faithfully reflects neural activity (Sakurai et al. 2014b; Sperling et al. 2011). Considering that accuracy of self-estimation of physical ability deteriorates with age (Robinovitch and Cronin 1999; Sakurai et al. 2013), age-related reduction in cerebral glucose metabolism may generally overlap with neural correlates of self-overestimation of stepping-over ability. We thus also examined aging effects among our participants on cerebral glucose metabolism to elucidate the underlying mechanisms of age-related self-overestimation. Based on previous research findings, we hypothesized that overestimation of step-over ability

should correlate with lower glucose metabolism (i.e., reduced neural activities) at the regions, such as the frontal, medial parietal, and parieto-temporal regions, which are thought of as regions underpinning self-knowledge and self-evaluation (Amodio and Frith 2006; Zamboni and Wilcock 2011).

Materials and methods

Participants

This cross-sectional study included 108 community dwelling older adults (mean age = 73.9 years, SD = 5.4; 73.1 % were women) who were recruited from a database of individuals available from Tokyo Metropolitan Institute of Gerontology. Participants were included if they were as follows: (i) aged 65 years or older, (ii) absent unstable medical conditions, and (iii) fully functional in terms of their instrumental ADLs (IADLs), which was assessed using the Tokyo Metropolitan Institute of Gerontology Index of Competence (TMIG-IC) (Koyano et al. 1991). For the TMIG-IC, rating scores for the three subscales (IADL, intellectual activity, and social roles) ranged from 0 to 13, with higher scores indicating greater functional capacity. Exclusion criteria included (i) presence of any neuromuscular and/or mental disorder, (ii) uncorrected visual defects leading to inability to visually identify the experimental device (corrected binocular visual acuity <1.0 identified by a visual acuity examination using the Landolt ring chart), (iii) history of a cerebrovascular disorder or a head injury, (iv) gait disturbances (e.g., Parkinsonism or need of a walking aid), (v) use of psychoactive medications or tranquilizers, and (vi) anatomical abnormalities on MRI (e.g., high cortical atrophy or white matter hyperintensities, defined as grade 3 on the Fazekas scale), as diagnosed by an experienced neuroradiologists (KI).

The study was conducted in accordance with the ethical standards of the Declaration of Helsinki. The research protocol was approved by the Tokyo Metropolitan Institute of Gerontology, and all participants provided written, informed consent.

Measurements

Participants traveled to ambulatory tertiary health center and participated in health-checkup including SOT, medical/psychological interviews, and physical/

cognitive assessments. Within 3 months before/after the SOT, each participant underwent MRI and FDG-PET examinations at the Tokyo Metropolitan Institute of Gerontology in a fasting state of at least 5 h.

Step-over test (SOT)

Step-over performance and self-estimation accuracy were measured using the step-over test (SOT), which has been validated in a previous study with older adults and has shown high test-retest reliability (Sakurai et al. 2013). The SOT was conducted in a sound-isolated, smooth, and flat passageway, illuminated with homogeneous white light. A black wooden bar (25 × 25 × 900 mm) attached to a sliding aluminum pole, with a plate-shaped base, was used for measuring self-estimation of step-over ability. A measuring tape was attached to the aluminum pole to measure the bar height. The black wooden bar was designed to be quickly releasable from the aluminum pole, using a pinch-like stopper in order to prevent participants from falling whenever they touched the bar with their feet. Adjustments to the bar height were in the range of 10 to 80 cm. This SOT device was placed 2 m in front of a white wall.

Participants first performed the self-estimation test and then the actual step-over task. Participants were asked to observe the bar from a distance of 7 m. The experimenter manually and slowly adjusted the height of the bar vertically, between 10 and 80 cm, in either direction. As the bar was moved, participants were asked to say “stop” at the point where they believed the bar had reached the maximum height that they could step over (i.e., estimated height, EH). They were instructed to imagine stepping over the bar with their bodies facing straight ahead, with no restrictions to posture, except for jumping. Participants were allowed to amend their EH after the experimenter manually adjusted the bar height. At this point, no time restriction was imposed on their estimation. Four self-estimation trials were conducted, with two ascending and two descending series of manipulations. Participants received no feedback at any point while performing the SOT.

Subsequently, the bar was set at the participants' mean EH (over the four trials), and they were asked to approach the bar and step over it. If they failed to step over the bar (i.e., touched/kicked the bar with their foot/lower limb) at the EH, the bar was lowered by 3 cm. Alternatively, if they succeeded at the EH, the bar was raised by 3 cm. Participants were then asked to

step over the bar, again, at the new height. This was repeated until participants either succeeded or failed to step over, and the final height at which they were successful across two consecutive trials was recorded as the individual AH (i.e., the actual maximum height).

The ability to step over an obstacle generally correlates with lower limb length. For this reason, the EH and AH were divided by the length of the lower limb (the distance from the greater trochanter to the ground through the lateral malleolus). This ratio was used as an individual mean of EH and AH for subsequent analyses. The difference between the EH and AH (Δ height) was then calculated to determine individual accuracy, or bias error (i.e., underestimation or overestimation), of the self-estimation of step-over ability. The Δ height was then standardized with the AH using the following formula, $[(EH - AH)/AH] \times 100$. The percentage of participants who failed to step over the bar at the EH was calculated.

MRI/PET scanning protocol and image processing

Three-dimensional MRI (3D-MRI) images for detecting abnormal brain structure, and FDG-PET analyses, comprised gadolinium-enhanced T1-weighted and T2-weighted scans (1.5-T Sigma Excite scanner, GE, Milwaukee, WI, USA). 3D-FDG-PET imaging was subsequently performed to evaluate regional cerebral glucose metabolic values (PET scanner SET 2400W; Shimadzu, Kyoto, Japan). Forty-five minutes after the intravenous injection of FDG (approximately 150 MBq), a 6-min emission scan was used to create images with a 128×128 (transverse section) $\times$ 63 (slices) matrix size and $2.0 \times 2.0 \times 3.125$ mm voxel size. Attenuation was corrected with a transmission scan using a $^{68}\text{Ga}/^{68}\text{Ge}$ source. During the tracer-accumulation phase, participants remained supine, quiet, and motionless in a dimly lit and quiet room with their eyes open and their ears unplugged. A total of 1–2 mL of venous blood was drawn twice, immediately before the intravenous FDG injection and 30 min after the injection. Plasma glucose concentration was measured thereafter.

Basic image processing was carried out using Dr. View software (AJS, Tokyo, Japan) and statistical parametric mapping SPM8 (Wellcome Trust Centre for Neuroimaging, London, UK) implemented in MATLAB (MathWorks, Sherborn, MA). All 3D-FDG-PET images were anatomically normalized and resampled (XYZ matrix $79 \times 95 \times 80$ mm and voxel size $2 \times 2 \times 2$ mm) with the FDG template created from FDG images of 15

physically, neurologically, and psychiatrically healthy subjects. Images were smoothed using a 12-mm full-width half-maximum (FWHM) isotropic kernel.

Interview and questionnaire items

Demographic characteristics (i.e., age and gender), depressive mood, cognitive functioning, and blood glucose level were recorded and assessed as covariates of the relationship between cerebral glucose metabolism and self-estimation of stepping-over ability. Depressive mood was assessed using a 15-item version of the Geriatric Depression Scale (GDS), where higher GDS scores indicate greater depression (Yesavage 1988). Cognitive function was assessed by the mini-mental status examination (MMSE) (Fujiiwara et al. 2010), which is a widely used tool for investigating overall cognitive functioning and has a maximum score of 30 points, with higher scores indicating higher overall cognitive functioning. For blood glucose level, participants had their blood drawn before performing PET scanning. Blood analysis was carried out using a sequential autoanalyzer. Participants were also asked about a fall experience within a year. Falls were defined as any unintentional drops/falls to the ground or floor, excluding bicycle accidents, accidental contact with furniture, walls, or other environmental structures and sudden cardiovascular or central nervous system events.

Statistical analyses

Descriptive statistics of the differences between the older adults who overestimated their step-over ability (i.e., overestimation group) and those who succeeded on the SOT trials at their EH (i.e., non-overestimation group) was analyzed using Chi-square tests and multivariate analysis of variance (MANOVA).

For the SOT variables, two-way analysis of variance (ANOVA) adjusted by gender and age was performed for both SOT height type (i.e., EH and AH) and group (i.e., overestimation group vs. non-overestimation group) factors. The relationship between self-estimation (i.e., EH) and actual step-over ability (i.e., AH) was examined with Pearson correlation analyses, as well as the relationship between the self-estimation error (Δ height) and age, EH, and AH. These statistical analyses were performed with a PC-compatible version of IBM SPSS version 20.0 (SPSS Inc., Chicago, IL), and a p value less than .05 was considered statistically significant.

A voxel-wise correlation analysis was performed between FDG-PET images and age, EH, AH, and Δ height (i.e., SOT variables) across participants, implementing a multiple regression procedure in SPM8 (adjusting for covariates) run in MATLAB. Set cluster size was greater than 50 voxels, and the initial cluster threshold for statistical significance was set to $p < .001$, uncorrected. Clusters were considered significant when falling below a cluster-corrected $p(\text{FWE}) = .05$. The locations of brain region were transformed from MNI coordinates into Talairach standard brain coordinates. If significant correlation was found in the white matter, the result was excluded from description in the result section.

Results

Table 1 shows participant characteristics. Half of our participants (51.9 %) were young-older adults (<75 years old). Overall, our participants had good global cognitive function (mean MMSE = 29.2, ranging from 27 to 30), without any IADL disability (mean TMIG-IC = 12.4),

and with more than 13 years of education, on average (i.e., 43 participants experienced education higher than high school).

The SOT showed that 22.2 % of participants overestimated their step-over ability and failed to step over the bar at their EH. For 14 participants in non-overestimation group (16.7 %), EH matched their AH (i.e., Δ height was zero). MANOVA analyses on all the variables of participant characteristics (Table 1) showed that the age variable alone was significant for non-overestimation and overestimation groups. Furthermore, 9 out of 84 (10.7 %) participants in non-overestimation and 9 out of 24 (37.5 %) in overestimation groups reported a fall experience within a year, with these percentage data significantly differing between non-overestimation and overestimation groups ($p = .002$).

Figure 1 shows EH and AH among non-overestimation and overestimation groups. A two-way ANOVA adjusted by gender and age showed a significant interaction ($F_{1, 104} = 122.3$, $p < .001$) between the group (i.e., non-overestimation and overestimation) and SOT height type (i.e., EH and AH) factors, with significant

Table 1 Participants characteristics

Variables, mean (SD)	All participants (<i>n</i> = 108)	Non-overestimation (<i>n</i> = 84)	Overestimation (<i>n</i> = 24)	<i>p</i> value
Female, <i>n</i> (%)	79 (73.1)	60 (71.4)	19 (79.2)	.451
Age	73.9 (5.4)	73.3 (5.5)	76.3 (4.6)	.017
Years of education	13.2 (2.2)	13.3 (2.3)	12.9 (1.9)	.396
Height	155.0 (7.2)	155.7 (7.4)	152.5 (5.8)	.058
Weight	54.0 (9.6)	54.5 (9.5)	52.0 (9.8)	.254
Lower leg length	75.4 (5.1)	75.5 (5.5)	74.9 (3.1)	.625
Systolic blood pressure, mmHg	125.2 (33.1)	124.1 (33.1)	129.0 (15.8)	.487
Diastolic blood pressure, mmHg	71.3 (18.4)	70.6 (19.9)	73.7 (11.4)	.465
Blood glucose level, mg/dl	95.4 (11.4)	95.9 (11.0)	93.9 (12.9)	.448
Hypertension, <i>n</i> (%)	37 (34.3)	25 (29.8)	12 (50.0)	.065
Cardiac disease, <i>n</i> (%)	9 (8.3)	6 (7.1)	3 (12.5)	.402
Diabetes mellitus, <i>n</i> (%)	7 (6.5)	6 (7.1)	1 (4.2)	.601
Arthritis, <i>n</i> (%)	12 (11.1)	10 (11.9)	2 (8.3)	.623
Fall experience within a year, <i>n</i> (%)	18 (16.7)	9 (10.7)	9 (37.5)	.002
TMIG-IC	12.4 (0.9)	12.4 (0.9)	12.3 (1.0)	.693
GDS	2.5 (2.3)	2.4 (2.2)	2.7 (2.7)	.604
MMSE	29.2 (1.1)	29.3 (1.0)	28.9 (1.4)	.087

Overestimation group participants: participants who failed to step over the bar at the EH

TMIG-IC Tokyo Metropolitan Institute of Gerontology Index of Competent, *GDS* Geriatric Depression Scale, *MMSE* mini-mental state examination, *EH* estimated height, *AH* actual height, Δ height the difference between the EH and AH with the following formula, $[(EH - AH)/AH] \times 100$

Fig. 1 Comparisons between EH and AH among non-overestimation and overestimation groups. Error bars represent standard deviations. $*p < .001$

main effects neither for SOT height type ($F_{1, 104} = 2.6$, $p = .110$) nor group ($F_{1, 104} = 1.4$, $p = .241$). Subsequent post-hoc tests showed a significant simple main effect of group at both EH ($p < .001$) and AH ($p < .001$). Figure 2 shows scatter plots depicting respective relationships between the four variables, namely, EH, AH, Δ height (i.e., self-estimation error), and age. A relatively high correlation coefficient appeared for EH and AH ($r = 0.586$, $p < .001$). The variable Δ height showed significant positive correlation coefficients with EH ($r = 0.432$, $p < .001$) and age ($r = 0.246$, $p = .018$), while resulting in a negative correlation with AH ($r = -0.420$, $p < .001$).

For the FDG-PET data, a voxel-wise correlation analysis adjusting for gender and blood glucose level showed that the right/left thalamus, the left caudate, the left cingulate gyrus, the right superior temporal gyrus

Fig. 2 Scatter diagrams of the step-over test (SOT) variables and age. **a** The scatter diagram of EH and AH. **b** The scatter diagram of Δ height and EH. **c** The scatter diagram of Δ height and AH. **d** The scatter diagram of Δ height and age. Above the diagonal indicates

overestimation of actual step-over ability (**a**). Positive Δ height values (vertical axis) represent overestimation, that is, situations in which the participants were unable to step over the bar positioned at the estimated height. EH estimated height, AH actual height

(BA 38) and right/left insula showed a decrease in glucose metabolism in association with age. These relationships were remained significant after correcting multiple comparisons.

Figures 3 shows statistical parametric maps and scatter diagrams of the significant correlations between Δ height and brain metabolism. By adjusting for age, gender, GDS score, MMSE score, and blood glucose level, Δ height was negatively correlated with glucose metabolism in the right/left inferior frontal gyrus (OFC: $p = 0.012$ and $p = 0.011$, respectively: BA11) and left medial frontal gyrus activities (frontal pole: $p = 0.029$; BA 10) (Table 2); a positive correlation between Δ height and brain metabolism did not appeared. After a correction for multiple comparisons, the significant relationship at the left frontal pole was attenuated ($p = 0.063$), whereas the right/left OFC and Δ height relationship remained significant ($p = 0.040$ and $p = 0.036$, respectively). There were no positive/negative correlations between EH/AH and brain metabolism.

Discussion

The present study demonstrated a robust linear relationship between lower glucose metabolism in the OFC and

overestimated step-over ability, which is independent of age. This finding is in line with the concept that the OFC is involved in adequate self-appraisals (Rosen et al. 2010; Salmon et al. 2006; Shany-Ur et al. 2014). Furthermore, the percentage of participants who reported a fall experience within a year in overestimation group was almost threefold higher than that of the participants in non-overestimation group. Our results showed that older adults with hypermetabolism in the OFC tended to underestimate their step-over ability, suggesting that the OFC may contribute to avoiding known and unknown risks of an accident. This report provides the first evidence of neural correlates among cognitively intact older adults regarding age-related self-overestimation of physical ability, which might lead to a risk of tripping and possible falls.

Characteristics of self-estimated step-over ability among older adults

In accordance with previous studies that demonstrated a tendency for older adults to overestimate their physical abilities (Butler et al. 2011; Gabbard et al. 2011; Lafargue et al. 2013; Robinovitch and Cronin 1999; Sakurai et al. 2013), 22.2 % of older adults in the present

Fig. 3 Significant relationship between brain metabolism and overestimation of step-over ability. **a** Statistical parametric maps (voxel-level significance of $p < 0.001$, uncorrected). **b** Scatter

diagrams of Δ height and glucose metabolism (normalized value) in the right orbitofrontal cortex (OFC), left OFC, and left frontal pole

Table 2 Negative correlation between regional cerebral metabolism and estimation error

Region	Side	BA	K	Talairach coordinates			T value
				X	Y	Z	
Inferior frontal gyrus (orbitofrontal cortex)	R	11	574	25	28	−19	5.40
	L	11	592	−25	30	−20	5.15
Medial frontal gyrus (frontal pole)	L	10	411	−2	52	2	4.03 ^a

Significance level for correlated clusters was set at voxel-level significance of $p < .001$, uncorrected, combined with cluster-level information of $p < .05$ (FWE). Corrected covariates include age, gender, GDS score, MMSE score, and blood glucose level

^aCorrelation is marginally significant

study overestimated their step-over ability and failed to step over the bar at their EH. In the present study, overestimation group showed significant higher self-estimation (EH) and lower actual ability (AH) than those of non-overestimation group. These results indicate that some older adults have no clear awareness of their age-related decrease in step-over ability. For the accuracy of self-estimation, although EH and AH were moderately correlated among our participants ($r = 0.586$), stronger correlations ($r = 0.624$ – 0.709) were observed among young adults who succeeded on the SOT trials at their EH (i.e., no participants were “overestimators”) in previous studies (Sakurai et al. 2013). The smaller EH-AH correlation coefficient for older adults indicated that they inconsistently and incorrectly estimated their SOT ability with less relying on their current SOT ability. Our older participants therefore seemed not to have accurately estimated their actual SOT ability.

Furthermore, Δ height (self-estimation error) appeared to be moderately correlated with EH ($r = 0.432$) and AH ($r = -0.420$). These relationships suggest that the older adults who showed relatively low SOT ability (AH) tended to overestimate (or underestimate to a lesser extent) their SOT ability, resulting from an increased EH. A similar finding has been evident for reaching (Butler et al. 2011; Robinovitch and Cronin 1999) and gait (Beauchet et al. 2010) abilities. Although the present and previous findings suggest that there is a close relationship between the level of physical ability and self-estimation accuracy, our results revealed no significant correlations between regional cerebral metabolism and EH or AH. It has been suggested that poor executive functioning (e.g., working memory) significantly correlates with the overestimation of physical abilities among fallers (Liu-Ambrose et al. 2008), but not among non-fallers (Sakurai et al. 2014a). On the basis of this finding, a likely explanation for the present

findings is that a specific cognitive domain, such as working memory, may affect the interaction between physical functioning level and self-estimation accuracy.

The present study also demonstrated that the results were consistent with previous findings (Fujimoto et al. 2015; Sakurai et al. 2013), such that the percentage of older participants who reported a fall experience within a year in overestimation group was almost threefold higher than that of the participants in non-overestimation group (37.5 % vs. 10.7 %, respectively). This result suggests that, in accordance with previous findings, the concept that overestimation of physical capabilities can explain the high risk of falls and, potentially, be a new target for interventions.

Neural basis of the self-estimation of step-over ability

Overestimation of step-over ability, or less of an underestimation, in healthy older adults was significantly correlated to decreased glucose metabolism in the OFC. Since our participants had normal binocular sight, and self-overestimation of step-over ability may not be caused by issues with visual height perception (Sakurai et al. 2016), this relationship seems to be independent of visual functioning. While our analyses on the behavioral data showed a significant difference in age between the non-overestimation and overestimation groups and a weak positive correlation coefficient between Δ height and age ($r = 0.246$), we could not observe an overlap between the neural correlates of the self-overestimation and age-related reduction in cerebral glucose metabolism in the FDG-PET analysis. Considering that adjustment for age did not alter the right/left OFC and Δ height relationship in the regression analyses, the impact of aging given to reduced neural activity in the OFC, resulting in the overestimation, is seemingly small among older adults aged over 65.

The orbitofrontal involvement is in line with an abundant literature pointing to the frontal areas' role in awareness or metacognitive processes (McGlynn and Schacter 1989; Zamboni and Wilcock 2011), and is well supported by previous studies revealing the neural correlates of an inability to recognize functional impairment among patients with neurological disorders (e.g., anosognosia) measured with volumetric MRI (Rosen et al. 2010; Shany-Ur et al. 2014), SPECT (Hanyu et al. 2008; Shibata et al. 2008) and PET (Perrotin et al. 2015; Salmon et al. 2006). Moreover, poor awareness of one's own abnormal movements has been observed in Huntington's disease but not in Parkinson's disease, which may be predominantly associated with the orbitofrontal–limbic pathology in Huntington's disease (Sitek et al. 2011).

The OFC is involved in processing information concerning reward and punishment, in evaluating valences, and in representing and updating the subjective reward value placed on objects, information, and goals (Rolls 2000); therefore, the OFC is important for updating the value of possible future outcomes (Amodio and Frith 2006; Ridderinkhof et al. 2004). One anosognosia model in a patient with AD proposed that either generally diminished consciousness, failure, or disconnected attention—responsible for comparing recently registered self-related information with previous knowledge—may reflect inaccurate self-estimations, particularly overestimations (Agnew and Morris 1998). Our results suggest that reduced neural activity in the OFC prevents older adults from updating the qualitative/quantitative values of their impaired physical abilities (Salmon et al. 2006; Shany-Ur et al. 2014). More specifically, older adults who likely overestimated their physical abilities may have not assigned a reward value to self-related processing and maintained accurate self-knowledge based either on previous failure (e.g., perception of decline in physical functioning due to tripping over obstacles) or on successful motor actions. Our speculation may be underpinned by previous findings suggesting that an inactive lifestyle, such as spending little time outdoors, is independently associated with increased overestimation of step-over abilities, probably resulting from less opportunities to recognize their current physical ability (Sakurai et al., 2014a).

Although our significant correlations diminished after correcting for multiple comparisons, glucose metabolism in the left frontal pole was negatively correlated with increased self-estimation errors (i.e.,

overestimation). The anterior PFC has been implicated in high-level cognitive control (Burgess et al. 2007; Fletcher and Henson 2001) that involves perceptual decision-making (Heekeren et al. 2008) and sensory metacognition (Rounis et al. 2010), indicating processes thought to be key for metacognitive sensitivity. Furthermore, individuals with greater metacognitive sensitivity on a perceptual task had a greater gray matter density in the neighboring frontal polar region (BA10) (Fleming et al. 2010). Thus, by extension, we can speculate that the OFC may play an important role in correctly perceiving one's own physical abilities in cooperation with the frontal pole; this is in line with results showing that the OFC is functionally and anatomically connected with the frontal pole (Catani et al. 2012).

Although our study has several strengths, including being the first to assess the neural correlates of age-related self-overestimation and included a large sample for using FDG-PET, some limitations need to be considered. First, this study used a cross-sectional design, which precludes any determination of causal relationships between cerebral metabolism and self-estimation accuracy. To help alleviate this issue, our regression analyses did adjust for potential covariates, including age, cognitive functioning, depressive mood, and blood glucose level. Second, our sample was composed of older adults; therefore, we did not examine the differences between older and other ages in terms of the relationship between accuracy of self-estimation of physical ability and glucose metabolism in the OFC. Future longitudinal studies are needed to examine causal relationships and mediators for these associations using diverse samples (e.g., young adults).

Conclusion

The present study demonstrated that correct self-estimation may rely on adequate neural activity in the OFC, perhaps in cooperation with the frontal pole. This is in line with the concept that the OFC is involved in adequate self-appraisals. Considering that overestimation caused by unawareness of reduced physical ability was associated with fall experience, our findings suggest that functional decline in this region may prevent older adults from updating the qualitative/quantitative values of their impaired physical abilities, and this in turn may lead to fall risk.

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Conflict of interest The authors declare that they have no conflicts of interest.

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