International Journal of EXERCISE SCIENCE

Original Research

Rate of Perceived Exertion and Cardiorespiratory Fitness in Older Adults with and without Alzheimer's Disease

ANDREA BEVAN†2, ERIC VIDONI‡2, and AMBER WATTS‡1,2

[1]Department of Psychology, University of Kansas, Lawrence, KS, USA; [2]University of Kansas Alzheimer's Disease Center, Fairway, KS, USA

†Denotes graduate student author, ‡Denotes professional author

ABSTRACT

International Journal of Exercise Science 13(3): 18-35, 2020. Exercise has many benefits for physical and cognitive health in older adults, yet there are many barriers to exercise adherence in this population. Subjective perception of exercise difficulty, or rate of perceived exertion (RPE), may especially be a barrier to exercise in individuals with Alzheimer's disease (AD), due to changes in initiation and motivation that accompany changes in cognition and brain function. RPE is the most commonly used measure of subjective effort in exercise research, yet the relationship between RPE and objective fitness is not fully understood in older adults. A better understanding is needed to support initiation, engagement, and maintenance of exercise and determine the appropriateness for use of RPE as a measure in this population. Our study aimed to 1) evaluate the degree to which objective measures of cardiorespiratory fitness correlates with the most commonly used subjective measure of effort, RPE and 2) examine any difference in the relationship between objective cardiorespiratory fitness and RPE between individuals with and without AD. We explored these relationships during a graded exercise test. Objective fitness and subjective effort were negatively associated. Independent of cardiorespiratory fitness, older age, female gender, cognitive impairment, and use of heart medications predicted greater self-reported effort during exercise. Results are discussed in terms of social psychological phenomena and potential neuropsychological deficits leading to increased subjective feelings of effort. These findings establish that the RPE measure may not be appropriate and may even detract from effort during graded exercise testing among older adults with AD.

KEY WORDS: Exercise, subjective effort, workload, graded exercise test

INTRODUCTION

Older adults are the most sedentary of all age groups (20, 52), and those with cognitive impairment are even more sedentary (74, 73). This pattern of behavior leads to many deleterious health and cognitive effects (49). It is estimated that at least one third of Alzheimer's disease (AD) cases worldwide are attributable to modifiable risk factors, including physical inactivity (69). Therefore, increasing physical activity, including structured exercise, is a promising strategy to improve health and cognitive functioning in older adults with AD (24, 48). The present study will focus on barriers related to perceived difficulty of physical exertion and evaluate the appropriateness of the most commonly used measure of perceived exertion in older adults with and without AD.

The most common measure for assessing subjective difficulty of exercise is Borg's scale, Rating of Perceived Exertion (RPE). RPE uses a numerical and verbal expression scale of how hard a participant feels their body is working. Self-evaluation of physical effort is thought to rely on the interpretation of the current exercise experience where the participant is asked to estimate the perceived exertion at intervals dictated by the researcher. This draws on perceptual, psychological, physiological, and performance or situational gestalt factors (27). The bodily sensations and feedback, and the actual performance of a specific physical activity all inform the expression of RPE. The assessment of RPE integrates information from various bodily sensations and processes (34, 55), yet exactly how these factors impact RPE is not fully understood. Accurate memory of a previous exercise experience, verbal memory ability, and recognition and matching of numerical and verbal anchors on the scale are cognitive skills required for the expression of RPE. Notably however, there are assumptions made for the use of RPE in those with cognitive impairment that may not be valid compared to those who are cognitively intact.

RPE is commonly used in research along with complimentary objective measures of strain such as heart rate, blood pressure, and oxygen consumption. Psychological factors may contribute uniquely to this self-report measure in older adults, especially those with cognitive impairment. In the estimation of RPE, participants are asked to evaluate their perceived level of exertion. When focusing on the internal state of exertion during exercise, RPE has been shown to increase in adults, but contrary to expectation, when being distracted from pain and muscle fatigue, RPE has also been shown to increase (47).

Similar mixed results are also seen with older adults. In one study, active older adults' heart rate did not correlate with RPE while snow skiing (64), but other studies reported a correlation between heart rate and RPE during an underwater treadmill test (59). In some studies, RPE was found to increase with HR and VO_2 among older adults (23, 65), leading to the assumption that RPE is an effective monitoring index of physical exertion, yet coronary artery disease (CAD), common in older adults, has been found to reduce the correlation between objective and subjective evaluations of effort (31, 45). The mixed results of traditional objective exercise markers highlight the need to explore whether it is appropriate to use RPE as a measure of perceived effort for all older adults including those with AD, which is the primary focus of the current study.

Researchers have reported found that exercise is associated with a negative affective state or a decline in positive affect in older adults (67). This pattern of affect and perceived effort during exercise likely informs motivation and perceived strain to start and continue an exercise session.

It stands to reason that reliance on cognitive processes, memory of past exercise experiences, as well as felt experiences in the body relating to RPE may be negatively impacted in individuals with cognitive impairment. Some evidence suggests RPE can be interrupted by cognitive impairment or injury (15, 22). Given the cognitive demands of generating subjective ratings of exertion, using RPE to assess perceived exertion in individuals with cognitive impairment may be unwarranted. Deficits in executive function, (53), memory, attention, abstract reasoning, and language (33), may impact self-assessment and expression of perceived strain related to RPE.

People with AD may not be able to make necessary adjustments to physical effort, unlike people who are cognitively intact. Impaired judgment due to semantic impairment, awareness, insight, and communication difficulties likely impact exercise behavior and the ability to subjectively rate the experience (18, 41, 50). Thus, people with AD may not be able to make necessary adjustments to physical effort, compared to people who are cognitively intact. Due to a lack of studies regarding the relationship of RPE and cognitive impairment, it is hard to draw clear conclusions. Though there is initial support that RPE measures may not correlate as strongly with objective measures of physical exertion in older adults with AD (77, 78), firmly establishing this relationship in older adults with and without AD is a necessary first step. The current study is one of very few to evaluate RPE in older adults, and if the first to include both male and female participants, and to explore what the relationship between appropriate objective and subjective measures of exercise effort looks like at the early stages of AD (24, 48). The first aim of the present study is to evaluate the degree to which exercise testing correlates with the most commonly used subjective measure of effort. We hypothesize that the objective and subjective measures will be correlated, though more weakly than younger adults (12, 14). The second study aim is to examine differences in the relationship between objective cardiorespiratory fitness and subjective ratings of exertion between individuals with and without AD. We hypothesize that the correlation between objective and subjective measures will be weaker in individuals with AD. That is, we expect participants without AD to show a stronger stepwise match between VO_2 peak and subjective ratings with increased workload on the graded exercise test; whereas we expect participants with AD to show more discrepancy between these two measures on the graded exercise test.

METHODS

Participants

The sample was drawn from a large registry of well-characterized AD patients and older adult controls without cognitive impairment. Participants in the sample had previously undergone a full physical exam, neurological testing, and a review of medical history before being recruited into any studies. This research was carried out fully in accordance to the ethical standards of the International Journal of Exercise Science (60). Our study was approved by the Institutional Review Board and all participants or their designated representatives provided consent for participation in the research. All participants completed a treadmill GXT using the Modified Bruce Protocol (37) providing objective (VO_2 peak, heart rate) and subjective (RPE) measures.
Participants (n = 237; AD = 96; non-AD = 141) attended a baseline clinical and exercise evaluation. We included participants with no cognitive impairment, mild cognitive impairment,

or dementia with etiology diagnosis of probable AD based on clinical and cognitive test results using standard criteria (2, 54): Clinical Dementia Rating (CDR) of 0.5, or 1 (very mild to mild dementia); (57), at least 55 years of age, community dwelling, adequate visual and auditory ability to perform cognitive testing, stable medication dose, and ability to participate in a scheduled exercise evaluation. Exclusion criteria included clinically significant psychiatric disorder, systemic illness or infection likely to affect safety, clinically-evident stroke, or significant musculoskeletal symptoms that prohibit exercise testing. Individuals with active (< 2 years) ischemic heart disease (myocardial infarction or symptoms of coronary artery disease) or uncontrolled diabetes mellitus were also excluded.

Protocol

Whole body mass was determined using a digital scale accurate to ± 0.1kg (Seca Platform Scale, Seca Corp., Columbia, MD), and height (in cm) was measured by stadiometer with shoes off, from which body mass index (BMI; weight (kg)/height (m^2)) was calculated.

Cardiorespiratory capacity (VO_2 peak) was measured by a graded treadmill exercise test (GXT) using a modified Bruce protocol (37) designed for older adults, in which participants began walking at a pace of 1.7 miles per hour at 0% incline, and the grade and/or speed was increased at each subsequent 2-minute interval. Participants were attached to a 12-lead electrocardiograph (ECG) to continuously monitor heart rate rhythm. Distal leads were placed on the torso. A 2-way, on-rebreathing valve, headgear, mouthpiece, and nose clip were worn and blood pressure and RPE were acquired during the last 30 seconds of each stage. Expired gases were collected continuously, and oxygen uptake and carbon dioxide production were averaged at 15-second intervals. (TrueOne 2400, Parvomedics, Sandy, UT). Peak oxygen consumption during the GXT (VO_2 peak) was used as an index of cardiorespiratory fitness.

An exercise physiologist familiarized each participant with the exercise equipment and testing protocol and explained the Borg Rating of Perceived Exertion (RPE) Scale. The exercise test was terminated if the participant reached volitional exhaustion by expressing the need to stop or if three ACSM criteria for maximal oxygen consumption were reached (4); plateau in oxygen consumption despite increase in workload, Borg scale rating of > = 17, heart rate within 10% rate of age predicted maximum, and RER > = 1.1. Only participants reaching or exceeding an RER of 1.1 were included for analysis in this study.

Cognitive measures for immediate and delayed recall were assessed with The Craft Story 21-Item Recall (immediate and delayed; 25) or Logical Memory I and II (immediate and delayed recall; Wechsler Memory Scale 3rd edition, 75). Verbatim words recalled are scored with a point and summed separately for both time points. Equivalent scores for both tasks were normed and validated by the Alzheimer's Disease Centers (ADC) in 2015 opting for a newer non-proprietary version of the test battery and allowing for comparison of both tasks together (56, 44). All immediate and delayed recall scores regardless of test were adjusted accordingly for a single score for comparison.

Covariates included age, sex, years of education, and use of heart and lung medication as covariates in the models. Some medications can affect this ratio such as medications that increase or decrease the output of the heart and lungs (e.g., beta agonists such as albuterol, beta blockers such as propranolol (61, 72, 76)).

Statistical Analysis

Analyses were performed with a total of 237 participants. Multilevel modeling (MLM) was used to establish the relationship between the objective measure VO_2 peak, and the subjective (RPE) measures for each person at each stage during the 10-stage GXT. In estimation of statistical power for MLM, it is generally accepted that with over 50 participants, sufficient power can be assumed (38). Random effects for the intercept and slope of VO_2 peak were tested for model fit using restricted estimated maximum likelihood (REML; 11, 62), guarding against type I error. Fixed factors age, gender, heart medication use, and CDR were tested for model fit using maximum likelihood (ML). Our measure of effect size, R^2, was calculated with REML. Both a marginal R^2 and conditional version of R^2 are reported. The marginal R^2 denotes the variance explained in RPE by only fixed effects and the conditional R^2 denotes the entire model, including fixed and random effects (58).

Within-person variables are objective (VO_2 peak) and subjective (RPE) measures of fitness nested within people. VO_2 peak, a continuous variable, was mean centered for interpretation. AD status of CDR (0, 0.5, and 1) and immediate and delayed story recall scores are between-person variables that were tested separately as moderators. Age, gender, and heart medication use were included in the model as between-person covariates. Immediate and delayed recall were included as between-person covariates. Race and education were not included in the analyses due to lack of variation in the sample to account for model fit. Statistical significance of fixed and random effects were determined by deviance of residuals using chi-square-versus-degrees-of-freedom analyses to test model differences. Descriptive statistics and group differences for all variables of interest were calculated (see Table 1). P-values were obtained by *t*-tests using Satterhwaite approximations to degree-of-freedom. Chi-square tests were used for each fixed and random effect for model fit.

Table 1. Participant Characteristics.

Descriptives	Total Sample (*n* = 237)		CDR = 0 (*n* = 141)		CDR = 0.5		CDR = 1		CDR = 0.5 or 1 (*n* = 96)
	M (*SD*)	%	*M* (*SD*)	%	*M* (*SD*)	%	*M* (*SD*)	%	*M* (*SD*)
Age	71.47 (6.85)		72.12 (6.45)		69.34 (6.68)		73.49 (7.56)		70.67 (7.23)
Gender (Female)		48.1		58.0		42.4		21.9	
Reached VO_2 max		82.8		94.7		68.3		67.2	
On Heart Medication		25.3		30.6		19.7		16.8	
CDR = 0		55.5							
CDR = 0.5		30.0							
CDR = 1		14.5							

	Sample that Reached RER ≥ 1.1 (*n* = 167)			
	CDR = 0 (*n* = 91)	CDR = 0.5 (*n* = 49)	CDR = 1 (*n* = 27)	CDR = 0.5 or 1 (*n* = 76)
	M (*SD*)	*M* (*SD*)	*M* (*SD*)	*M* (*SD*)
VO_2 max	23.22* (5.37)			21.35* (4.93)
VO_2 peak	17.30* (5.28)	16.85* (5.16)	15.98* (5.24)	

Note: * $p < .01$

RESULTS

For all analyses, we used R (R Core Team, 2012) and *lme4* (7) to perform linear mixed effects analyses. Visual inspection of residual Q-Q plots indicated a normal distribution of residuals for all analyses. An intraclass correlation (ICC = 0.0) indicated no variation within the sample on RPE across the GXT stages. The ICC value indicated even with the non-independence of these data, it would be possible to treat these data as independent measures. However, there are still benefits to using MLM, especially given the nested structure of these data (36).

For all analyses, the difference in the -2 log likelihood of the random intercepts model and random slopes model were significantly different, thus the VO_2 peak was allowed to vary for individuals and across stages of the GXT. We explored the relationship between objective and subjective measures of fitness and whether cognitive status had a moderating effect on the relationship between VO_2 peak and RPE (see Table 2).

Table 2. Predictors of Subjective Fitness (RPE).

Fixed Components[a]		Model 1	Model 2	Model 3[d]	Model 4	Model 5	Model 6	**Model 7**	Model 8
Intercept	$\hat{\gamma}_{00}$	12.534 (0.114)***	12.88 (0.173)***	13.161 (0.184)***	6.929 (1.842)***	5.059 (1.853)**	3.921 (1.738)*	**4.213 (1.693)***	4.260 (1.686)*
VO_2 peak	$\hat{\gamma}_{10}$		0.693 (0.693)***	0.794 (0.022)***	0.792 (0.022)***	0.786 (0.022)***	0.783 (0.021)***	**0.783 (0.021)*****	0.798 (0.026)***
Age	$\hat{\gamma}_{01}$				0.086 (0.025)***	0.102 (0.025)***	0.103 (0.023)***	**0.094 (0.023)*****	0.093 (0.093)***
Gender	$\hat{\gamma}_{02}$					1.176 (0.336)***	1.765 (0.324)***	**1.709 (0.315)*****	1.711 (0.314)***
CDR = 0.5	$\hat{\gamma}_{03}$						1.542 (0.361)***	**1.616 (0.351)*****	1.588 (0.361)***
CDR = 1.0	$\hat{\gamma}_{04}$						2.812 (0.474)***	**2.920 (0.463)*****	2.609 (0.497)***
On Medication	$\hat{\gamma}_{05}$							**1.140 (0.322)*****	1.134 (0.321)***
VO_2 peak X CDR = 0.5	$\hat{\gamma}_{11}$								-0.019 (0.048)
VO_2 peak X CDR = 1.0	$\hat{\gamma}_{12}$								-0.119 (0.072)
Variance of Random Components[b]									
Random Intercept	$\hat{\tau}_{00}$	0.00	5.978	6.818	6.375	5.700	4.816	**4.491**	4.266
Random Slope (VO_2 peak)	$\hat{\tau}_{10}$			0.046	0.046	0.046	0.044	**0.043**	0.042
$Cor(\hat{\tau}_{00}, \hat{\tau}_{10})$				0.41	0.38	0.28	0.33	**0.32**	0.31
Sigma (e)	$\hat{\sigma}^2$	16.44	5.439	4.332	4.338	4.354	4.372	**4.380**	4.395
Deviance (-2LL)		7153.0	6195.9	6112.1	6093.5	6082.6	6043.4	**6031.3**	6028.5
Δ^2 (df)			957.12*** (1)	92.003*** (2)	11.129*** (1)	10.843*** (1)	39.191*** (2)	**12.17*** (1)**	2.733 (2)
R^2 marginal[c] (conditional)			0.529 (0.775)	0.576 (0.852)	0.579 (0.847)	0.581 (0.838)	0.599 (0.831)	**0.602 (0.826)**	0.602 (0.825)

Note: * $p < 0.05$, ** $p \leq 0.01$, *** $p < 0.001$, [a]Fixed effects estimated using maximum likelihood, gamma, standard error, and significance reported; [b]Random components estimated using restricted estimation maximum likelihood [c] pseudo R^2 was estimated using REML, [d] Deviance and corresponding χ^2 difference test calculated using REML; CDR = Clinical Dementia Rating, **Bolded** model = final model

VO_2 peak random intercept and random slope were each supported for better model fit. Models 3-7 indicated VO_2 peak, age, gender, medication usage, and CDR status affected RPE, each with unique contributions to variance explained. There was not a statistically significant interaction effect of VO_2 peak x CDR. Thus, the relationship between VO_2 peak and RPE did not differ by dementia status (see Figure 1).

The full model including a random intercept and random slope accounted for 82.6% of the variance, such that increasing VO_2 peak led to greater reported RPE values. Older age, female gender, use of heart medication, and cognitive impairment (CDR 0.5 or 1), all led to greater reported RPE. The interaction term was not significant, suggesting cognitive status did not moderate the relationship between objective and subjective measures of fitness in our sample.

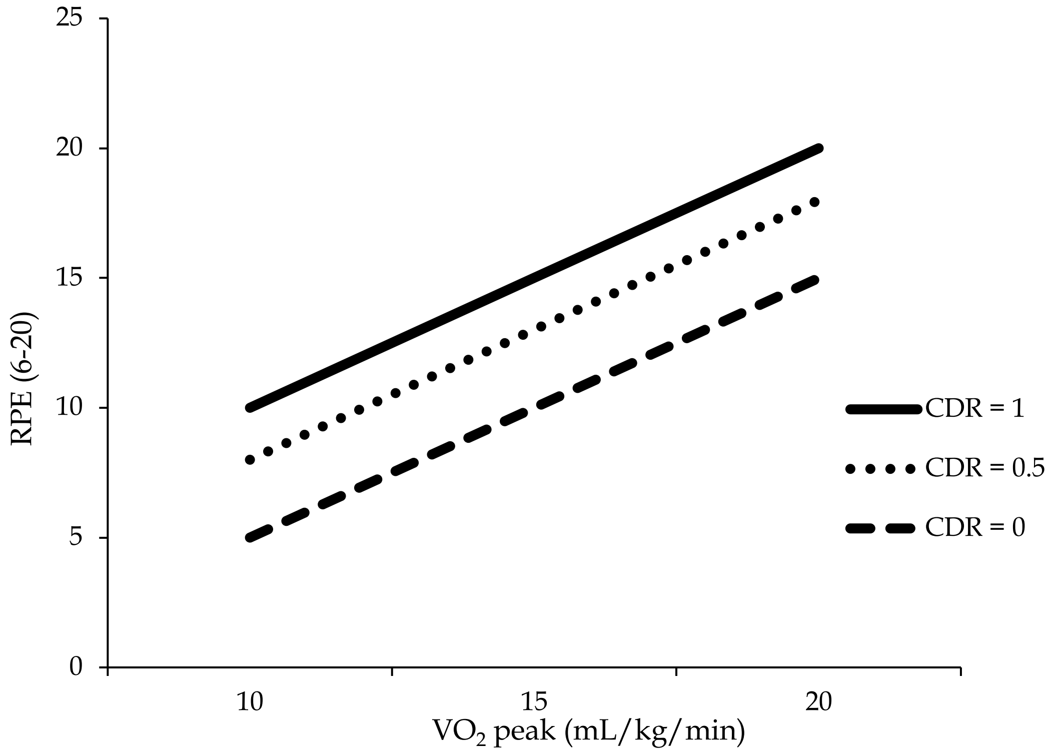

Figure 1. Main Effect for Alzheimer's Disease Status on RPE. No interaction on the relationship between VO_2 peak and RPE. The use of random intercept and random slope in the model allowed for the illustration of greater RPE starting points with greater cognitive impairment despite controlling for objective fitness level.

We evaluated whether memory performance moderated the relationship between objective and subjective measures of fitness. Immediate Story Recall (ISR) and Delayed Story Recall (DSR) scores were centered and analyses were performed on all cognitively healthy participants (CDR = 0) (see Table 3). Models 7 and 8 indicated ISR and the interaction term, VO_2 peak x ISR were not significant predictors in the model. The same process was performed in models 7 and 8, with DSR, and the interaction term VO_2 peak x DSR yielding non-significant results. The full model including a random intercept and random slope of relationship between VO_2 peak and RPE, such that increasing VO_2 peak, older age, female gender, and use of heart medication, all led to greater reported RPE. However, memory, including immediate or delayed recall, was not a predictor of RPE and the relationship between VO_2 peak and RPE was not dependent on memory.

Table 3. Predictors and Memory Recall of Subjective Fitness (RPE) for Cognitively Healthy Participants (CDR = 0).

Fixed components[a]		Model 1	Model 2	Model 3[d]	Model 4	Model 5	**Model 6**	Model 7	Model 8
Intercept	$\hat{\gamma}_{00}$	12.270 (0.146)***	12.347 (0.215)***	12.639 (0.230)***	6.802 (2.422)**	3.963 (2.433)	**4.276 (2.348)**	4.083 (2.684)	5.319 (2.531)*
VO_2 peak	$\hat{\gamma}_{10}$		0.720 (0.019)***	0.804 (0.025)***	0.802 (0.025)***	0.794 (0.025)***	**0.794 (0.025)*** **	0.642 (0.120)***	0.668 (0.094)***
Age	$\hat{\gamma}_{01}$				0.080 (0.033)*	0.105 (0.032)**	**0.096 (0.031)** **	0.094 (0.032)**	0.088 (0.032)**
Gender	$\hat{\gamma}_{02}$					1.539 (0.427)***	**1.411 (0.414)*** **	1.422 (0.419)***	1.489 (0.417)***
On Medication	$\hat{\gamma}_{03}$						**1.259 (0.401)** **	1.254 (0.400)**	1.312 (0.400)**
ISR	$\hat{\gamma}_{04}$							.017 (0.066)	
DSR	$\hat{\gamma}_{05}$								-0.042 (0.053)
VO_2 peak X ISR	$\hat{\gamma}_{11}$							.010 (0.008)	
VO_2 peak X DSR	$\hat{\gamma}_{12}$								0.009 (0.006)
Variance of random components[b]									
Random intercept	$\hat{\tau}_{00}$	0.00	5.582	6.477	6.153	5.158	**4.757**	4.734	4.725
Random slope (VO_2 peak)	$\hat{\tau}_{10}$			0.034	0.033	0.032	**0.032**	0.032	0.032
$Cor(\hat{\tau}_{00}, \hat{\tau}_{10})$				0.60	0.59	0.46	**0.46**	0.44	0.46
Sigma (e)	$\hat{\sigma}^2$	17.01	5.202	4.382	4.389	4.419	**4.432**	4.430	4.422
Deviance (-2LL)		4496.5	3828.0	3789.2	3776.7	3765.6	**3756.1**	3754.4	3752.3
Δ^2 (df)			668.49*** (1)	46.204*** (2)	5.691* (1)	11.159*** (1)	**9.503** (1)**	1.650 (2)	3.721 (2)
R^2 marginal[c] (conditional)			0.561 (0.788)	0.591 (0.849)	0.592 (0.845)	0.599 (0.831)	**0.604 (0.826)**	0.604 (0.826)	0.603 (0.826)

Note: * $p < 0.05$, ** $p \leq 0.01$, *** $p < 0.001$, [a]Fixed effects estimated using maximum likelihood, gamma, standard error, and significance reported; [b]Random components estimated using restricted estimation maximum likelihood [c] pseudo R^2 was estimated using REML, [d] Deviance and corresponding χ^2 difference test calculated using REML; CDR = Clinical Dementia Rating; ISR = Immediate Story Recall; DSR = Delayed Story Recall, **Bolded** model = final model

We repeated the analyses for those with a CDR equaling 0.5 (very mild dementia) and CDR = 1 (mild dementia) to explore whether memory explained or moderated the relationship between objective and subjective measure of fitness and a similar pattern of results were seen (see Table 4 for ISR and DSR). VO_2 peak random intercept and random slope were each supported for better model fit. Models 3-5 indicated VO_2 peak, age, and female gender affected RPE each with unique variance. Models 6-8 indicated medication, ISR, and the interaction term VO_2 peak x ISR, were not significant predictors of the change in RPE, not supporting our exploratory Aim 3.

The same process was performed in models 6-8 where medication, DSR, and the interaction term VO_2 peak x DSR were not significant factors in the model. The full model including a random intercept and random slope explained 83.1% of the variance, such that increasing VO_2 peak, older age, and female gender, all led to greater reported RPE. However, memory, including immediate or delayed recall, did not explain change in RPE in participants with very mild and mild dementia, not supporting this hypothesis.

Table 4. Predictors and Memory Recall of Subjective Fitness (RPE) for Participants (CDR 0.5 and 1).

Fixed components[a]		Model 1	Model 2	Model 3[d]	Model 4	**Model 5**	Model 6	Model 7	Model 8
Intercept	$\hat{\gamma}_{00}$	12.973 (0.179)***	13.639 (0.367)***	13.927 (0.235)***	6.945 (2.597)**	**4.408 (2.453)**	4.725 (2.417)	5.676 (2.514)*	5.601 (2.509)*
VO_2 peak	$\hat{\gamma}_{10}$		0.641 (0.025)***	0.765 (0.039)***	0.762 (0.039)***	**0.752 (0.039)*** **	0.753 (0.039)***	0.670 (0.075)***	0.692 (0.056)***
Age	$\hat{\gamma}_{01}$				0.096 (0.036)**	**0.120 (0.033)** **	0.112 (0.033)**	0.109 (0.033)**	0.107 (0.033)**
Gender	$\hat{\gamma}_{02}$					**2.063 (0.508)*** **	2.067 (0.499)***	2.020 (0.500)***	2.043 (0.500)***
On Medication	$\hat{\gamma}_{03}$						0.982 (0.556)		
ISR	$\hat{\gamma}_{04}$							-0.071 (0.053)	
DSR	$\hat{\gamma}_{05}$								-0.053 (0.050)
VO_2 peak X ISR	$\hat{\gamma}_{11}$							0.011 (0.009)	
VO_2 peak X DSR	$\hat{\gamma}_{12}$								0.012 (0.008)
Variance of random components[b]									
Random intercept	$\hat{\tau}_{00}$	0.00	5.514	6.366	5.795	**4.509**	4.338	4.453	4.468
Random slope (VO_2 peak)	$\hat{\tau}_{10}$			0.069	0.068	**0.071**	0.072	0.073	0.072
$Cor(\hat{\tau}_{00}, \hat{\tau}_{10})$				0.26	0.20	**0.05**	0.03	0.08	0.09
Sigma (e)	$\hat{\sigma}^2$	15.21	5.786	4.209	4.209	**4.216**	4.207	4.195	4.201
Deviance (-2LL)		2645.6	2345.9	2303.0	2290.7	**2276.4**	2273.4	2272.8	2272.8
Δ^2 (df)			299.69*** (1)	49.197*** (2)	6.898** (1)	**14.286*** (1)**	3.033 (1)	3.643 (2)	3.615 (2)
R^2 marginal[c] (conditional)			0.494 (0.741)	0.562 (0.850)	0.566 (0.844)	**0.574 (0.831)**	0.573 (0.829)	0.578 (0.833)	0.577 (0.832)

Note: * $p < 0.05$, ** $p \leq 0.01$, *** $p < 0.001$, [a]Fixed effects estimated using maximum likelihood, gamma, standard error, and significance reported; [b]Random components estimated using restricted estimation maximum likelihood [c] pseudo R^2 was estimated using REML, [d] Deviance and corresponding χ^2 difference test calculated using REML, **Bolded** model = final model

DISCUSSION

Few studies have evaluated the relationship between RPE and VO_2 (23,65); however, no studies to our knowledge have evaluated the relationship between VO_2 peak and RPE measures of fitness to determine whether cognitive status moderates this relationship in older adults. The relationship between objective and subjective measures of fitness is important to determine whether the felt experience during exercise in this population matches physiological ability and whether RPE is an appropriate measure in older adults with and without AD. Given the benefits of exercise, specifically in this population, it is important to identify physiological and psychological barriers to regular exercise engagement.

In the full sample, lower cardiorespiratory fitness (VO_2 peak), older age, female gender, impaired cognitive status, and use of heart or lung medication predicted higher levels of perceived effort. The objective physiological measure of fitness (VO_2 peak) accounted for the largest proportion of the variance (57.6%) in RPE suggesting that self-perceptions are highly dependent on physiological ability levels. All of the other predictors accounted for substantially lower proportions of variance, with dementia status accounting for 1.8% unique variance in reported RPE, such that greater impairment led to increased reported effortful feeling. Older age, female gender, and use of heart or lung medication each accounted for less than 1% of the variance. The relationship between VO_2 peak and RPE was not dependent on cognitive status or scores on a test of verbal memory. This suggests that the nature of the relationship between objective and subjective measures of effort are the same for individuals with and without AD or varying levels of memory performance. The physiological response to aerobic exercise undergoes important changes with aging, even in the absence of cardiovascular disease (28). The linear pattern of increasing VO_2 peak and increasing RPE seems intuitive -- the harder the exercise test, the more demand on the cardiorespiratory system. However, when objective fitness is accounted for, certain demographics predicted a greater effortful feeling. It is therefore important to evaluate the utility and appropriateness of RPE use as a measure of subjective effort in older adults with and without AD. Though RPE may be an appropriate measure in adults it may present undue burden on older adults or at the very least not effectively monitor the intended outcome.

Despite evidence that aerobic capacity decreases starting at age 30 (5), with even greater rates observed over the age of 50 (63), our data suggest when controlling for fitness level, older age still predicted a reported increased effortful feeling. Although physiological fitness decreases with older age, many factors influence attitudes and prejudices about aging (30), such as expectations and stereotypes. Indeed, positive expectations regarding aging have been found to be associated with more engagement in physical activity and better physical function among older adults (10). Negative beliefs about aging are pervasive in Western society. Diminished social roles have led to negative biases of aging and low expectations can be internalized by older adults. Furthermore, others then project these biases and expectations about decreased physical ability and function with older age on this population (for a full review, see 51). The internalized negative beliefs about function among older adults are associated with a variety of negative outcomes for physical and psychological health (43, 46). Aging self-stereotypes have been shown to influence walking behavior, such that participants exposed to positive aging stereotypes showed a significant increase in swing time (i.e., time spent with one foot off the ground while walking) and gait speed compared to participants with negative aging stereotypes (35). The average increase in speed was comparable to the gain observed when older adults participated in rigorous exercise programs for several weeks (e.g., 3, 16). In the current study, it is possible that negative internalized beliefs about physical function primed the expectation that greater subjective feelings of effort should occur when engaging in exercise. It is not a common social expectation for individuals between 60 and 80 years of age to be exercising. Furthermore, these negative internalized beliefs may lead individuals to be less active, in turn making the exertion feel more effortful.

Internalized beliefs of decreased physical ability with older age may also trigger stereotype threat. Stereotype threat occurs when cues in the environment make negative stereotypes associated with an individual's group status salient, triggering physiological and psychological processes that have detrimental consequences for behavior (68). Negative stereotype threat has been associated with older adults including physiological arousal (26, 9) decreased effort (70), and reduction in performance expectations (19, 21). The current findings that older age, women, and people taking heart or lung medication reported the treadmill test as more effortful despite controlling for actual fitness level might be attributed to negative expectations or stereotype threat. RPE highlights the exertion one feels during exercise, which in itself may make salient negative expectations and stereotypes about older adults and fitness level. Perhaps performing in a medical setting prompted a psychological process that led to self-report greater effortful feelings when engaging in exercise. Another stereotype threat may have included participating in an exercise test similar to that of a stress test for diagnosis of heart disease commonly prescribed for older adults. It is possible that concern about heart disease may also prompt internalized negative beliefs about increased age and decreased function leading to self-report greater effort while exercising. Given these results, we therefore conclude that Borg's RPE may not adequately or accurately measure or monitor changes during exercise in older adults with and without AD.

A future study can specifically address RPE usage during a GXT for this population that may provide support for or against using this measure. Although we did not measure them here, future studies may benefit from explicit evaluation of the role of expectations regarding aging and stereotype threat in this process. Aligned with stereotype threat literature among older adults (43), testing whether social expectations and beliefs are contributing to greater self-reported effortful feelings are warranted. Such studies can include inoculation via positive aging stereotypes, lowering anxiety, psychoeducation about stereotype threat, or by attributing difficulty to external circumstances rather than ability (1, 6, 17, 32, 42), which may ameliorate negative consequences if stereotype threat is contributing to a greater effortful feeling, as actual fitness level is not the explanation.

These data contribute an important view of understanding that limited physiological ability is not the only potential barriers to exercise in older adults with and without cognitive impairment. The finding that AD cognitive status explained a significant proportion of variance in reported RPE, even when actual fitness level was controlled for, suggests a pathological brain process related to AD is an important possible explanation.

Heart medication usage physiologically lowers cardiac output during increased demand on the body. This may contribute to a more effortful feeling during exercise. However, not all medications in the same class of drugs result in the same cardiac responses. Thus, the literature is moving toward testing specific heart and respiratory medications' effect on metabolic and respiratory exchange rate. For example, a common medication prescribed to treat high blood pressure, bisoprolol, was found to have no effect on heart rate, VO_2 max, and RPE with the RER threshold exceeding 1.10 in men compared to a placebo (76). It is reasonable that someone on cardiac mediation may be physiologically limited in their cardiac output and could explain the experience of greater subjective effort during the GXT. Conversely, someone on respiratory medication may increase oxygen consumption and could explain some differences in subjective effort. For some, negative expectations about being on heart or lung medication and exercise may play a role in increased subjective feeling, which can be specifically evaluated again via inoculation or psychoeducation of heart and lung medication's effect on exercise.

One limitation of the current study is a homogeneous sample made up of mostly White, highly educated older adults in the Midwest. Thus, these findings are not generalizable to a more diverse population. The present study did not directly measure several possible explanatory mechanisms that may contribute to differences in RPE. These include interoception work load tests (29), stereotype threat innoculation (6, 35, 43), and exercise self-efficacy (39). Interoception is the ability to consciously perceive internal bodily states that inform felt experiences, which has a regulatory function of homeostatis (71). Normal aging brain changes may affect interoception as it relates to RPE, but specifically with pathological aging, brain areas most commonly affected overlap with interoception (e.g., insula), and warrant further study.

On the basis of these data, physiological ability does not explain the increased subjective feeling of exercise in people with AD compared to healthy older adults, nor does verbal memory. The verbal memory measure we used captures the recall of a story and may not be appropriate for evaluating memory of physical events that require body awareness. We are not aware of any memory measure for recall of physical sensations. Perhaps a measure of executive function such as task switching performance would better tap into the cognitive demand of an exercise test and simultaneous RPE rating for older adults (8, 40).

An area that has not been studied in older adults with and without AD is stereotype threat innoculation. During a GXT, reading, watching or listening to a short snipet about the ease of the test and how older adults did much better than anticipated may prime older adults with a postive valance as opposed to a potentially negative prime to begin with (6, 35, 42). Examining this frame may lend insight into stereotype threat and expectations related to the subjective RPE scale. The felt expereience is an important factor in the engagement of exercise for anyone, especially older adults, and even more so for those with cognitive impairment.

If the felt experience acts as a barrier for exercise engagment for people with cognitive impairment, this is a promising platform for interventions. Extra support and encouragment during an exercise session for this popuIuation may prove helpful for exercise adherence. Psychoeducation and prediction of subjective difficulty about exercise may reduce the effortful feeling. Greater exercsie self-efficacy has been shown to influence RPE (39). Exposure and positive experiences of exercise may improve exercise self-efficacy through progressive mastery of exercise behavior in older adults. Thus, exposure and support may help initiate and sustain exercise behavior.

These data are the first to indicate that the relationship between physiological fitness and social constructs contribute to perceived difficulty of exercise in male and femaile older adults with and without early stages of AD. These data have implications for understanding how AD may impact how exercise feels and related exercise behavior and adherence. These findings can guide future research to explore factors related to beliefs, expectations, and interoceptive abilites, because physiological fitness may not be the only limiting factor in exercise behavior. The field of psychology has a unique opportunity to intervene on exercise change among older adults with and without AD known to increase overall health and brain health.

REFERENCES

1. Abrams D, Crisp RJ, Marques S, Fagg E, Bedford L, & Provias D. Threat inoculation: Experienced and imagined intergenerational contact prevents stereotype threat effects on older people's math performance. Psychol Aging 23: 934-939, 2008.

2. Albert M S, DeKosky ST, Dickson D, Dubois B, Feldman HH, Fox N C… Phelps CH. The diagnosis of mild cognitive impairment due to alzheimer's disease: Recommendations from the national institute on aging-alzheimer's association workgroups on diagnostic guidelines for alzheimer's disease. Alzheimer's & Dementia 7: 270-279, 2011.

3. Alexander NB. Gait disorders in older adults. J AM Geriatr Soc 44: 434-451, 1996.

4. ACSM ACoSM. ACSM's guidelines for exercise testing and prescription. 8th ed. Philladelphia: Lippincott Williams & Wilkins; 2010.

5. Astrand I. Aerobic work capacity in men and women with special reference to age. Acta Physiologica Scandinavian Supplemental 169: 1-92, 1960.

6. Barber SJ, Selliger J, Yeh N, & Tan SC. Stereotype threat reduces the positivity of older adults' recall. J Gerontol B Psychol Sci Soc Sci April: 2018.

7. Bates DM, Maechler M, & Bolker B. lme4: Linear mixed-effects models using S4 classes. R package version 0.999999-0: 2012.

8. Belleville S, Bherer L, Lepage E, Chertkow H, & Gauthier S. Task switching capacities in persons with alzheimer's disease and mild cognitive impairment. Neuropsychologia 46: 2225-2233, 2008.

9. Blascovich J, Spencer SJ, Quinn D, & Steele C. African Americans and high blood pressure: the role of stereotype threat. Psychol Sci 12: 225-229, 2001.

10. Breda AI & Watts AS. Expectations regarding aging, physical activity, and physical function in older adults. Gerontol Geriatr Med: 3: 1-8, 2017.

11. Bolker BM, Brooks ME, Clark CJ, Geange SW, Poulsen JR, Stevens MHH, & White JSS. Generalized linear mixed models: a practical guide for ecology and evolution. Trends Ecol Evol 24: 127-135, 2009.

12. Borg G. Perceived exertion: A note on "history" and methods. Med Sci Sports 5: 90-93, 1973.

13. Borg G. Psychophysical bases of perceived exertion. Med Sci Sports Exerc 14: 377-381, 1982.

14. Borg G, Ljunggren G, & Ceci R. The increase of perceived exertion, aches and pain in the legs, heart rate and blood lactate during exercise on a bicycle ergometer. Eur J Appl Physiol 54: 343-349, 1985.

15. Boutcher SH. *Cognitive Performance, Fitness, and Aging*. In: Biddle SJH, Fox KR, Coutcher SH editors. Physical activity and psychological well-being. London: Routledge 118-130, 2000.

16. Buchner DM, Beresford SA, Larson EB, LaCroix AZ, & Wagner EH. Effects of physical activity on health status in older adults II: Intervention studies. Annu Rev Public Health 13: 469-488, 1992.

17. Burgess DJ, Warren J, Phelan S, Dovidio J, & Van Ryn M. Stereotype threat and health disparities: What medical educators and future physicians need to know. J Gen Intern Med 25: 169-177, 2010.

18. Burgio L, Allen-Burge R, Stevens A, Davis L, Marson D. Caring for Alzheimer's disease patients: Issues of verbal communication and social interaction. In J. M. Clair & R. M. Allman (Eds.), The gerontological prism: Developing interdisciplinary bridges. Baywood Pub Co; 2000

19. Cadinu M, Maass A, Frigerio S, Impagliazzo L, & Latinotti S. Stereo-type threat: The effect of expectancy on performance. Eur J Soc Psychol 33: 2003.

20. Caspersen CJ, Pereira MA, & Curran KM. Changes in physical activity patterns in the United States, by sex and cross-sectional age. Med Sci Sports Exerc 32: 1601-1609, 2000.

21. Chasteen AL, Bhattacharyya S, Horhota M, Tam R, & Hasher L. How feelings of stereotype threat influence older adults' memory performance. Exp Aging Res 31: 235-260, 2007.

22. Chodzko-Zazko WJ & Moore KA. Physical fitness and cognitive functioning in aging. Exerc Sports Sci Review 22: 195-222, 1994.

23. Chung P-K, Zaho Y, Liu JD, & Quach B. A brief note on the validity and reliability of the rate of perceived exertion scale in monitoring exercise intensity among Chinese older adults in Hong Kong. Perceptual & Motor Skills: Motor Skills and Ergonomics 121: 805-809, 2015.

24. Colcombe S, & Kramer AF. Fitness effects on the cognitive function of older adults: A meta-analytic study. Psychol Sci 14: 125-130, 2003.

25. Craft S, Newcomer J, Kanne S, Dagogo-Jack A, & Alderson A. Memory improvement following induced hyperinsulinemia in Alzheimer's disease. Neurobiol Aging 17: 123-130, 1996.

26. Croizet JC, Despres G, Gauzins ME, Huguet P, Leyens JP, Meot A. Stereotype threat undermines intellectual performance by triggering a disruptive mental load. Pers Soc Psychol Bull 30: 721-731, 2004.

27. Eston RG & Parfitt CG. Perceived exertion. Paediatric Exerc Physiol Elsevier, London: 275-297, 2006

28. Fletcher GF, Balady GJ, Amsterdam EA, Chaitman B, Eckel R, Fleg J, Froellcher VF…Bazzarre, T. Exercise standards for testing and training: A statement for healthcare professional from the American Heart Association. Circ 104: 1694-1740, 2001.

29. Garcia-Cordero I, Sedeño L, de la Fuente L, Slachevsky A, Forno G, Klein F, Lillo P, Ferrari J.,…Ibañez, A. Feeling, learning from and being aware of inner states: Interoceptive dimensions in neurodegeneration and stroke. Philos Trans, R Soc, B: 371, 2016.

30. Gilbert CN, & Ricketts KG. Children's attitudes toward older adults and aging: A synthesis of research. Educ Gerontol 34: 570-586, 2008.

31. Go AS, Mozaffarian D, Roger VL, Benjamin EJ, Berry JD, Borden WB…Turner MB. Heart disease and stroke statistics-2013 update: A report from the American Heart Association. Circ 127: e6-e245, 2013.

32. Good C, Aronson J, & Inzlicht M. Improving adolescents' standardized test performance: An intervention to reduce the effects of stereotype threat. J Appl Dev Psychol 24: 645-662, 2003.

33. Grady CL, Haxby JV, Horwitz B, Sundaram M, Berg G, Schapiro M… Rapoport SI. Longitudinal study of the early neuropsychoglical and cerebral metabolic changes in dementia of the Alzheimer type. J Clin Exp Neuropsychol 10: 576-596, 1998.

34. Hampson DB, Gibson A, Lambert MI, & Noakes TD. The influence of sensory cues on the perception of exertion during exercise and central regulation of exercise performance. Sports Med 31: 935-952, 2001.

35. Hausdorff JM, Levy BR, & Wei JY. The power of ageism on physical function of older persons: Reversibility of age-related gait changes. J Am Geriatr Soc 47: 1346–1349, 1999.

36. Hayes AF. A primer on multilevel modeling. Hum Commun Res 32: 385-410, 2006.

37. Hollenberg M, Ngo LH, Turner D, & Tager IB. Treadmill exercise testing in an epidemiological study of elderly subjects. J Gerontol Bio Sci 53A: 259-267, 1998.

38. Hox J. Multilevel analysis: Techniques and applications, second edition. New York: Routledge: 2010.

39. Hu L, McAuley E, Motl RW, & Konopack JF. Influence of self-efficacy on the functional relationship between ratings of perceived exertion and exercise intensity. J Cardiopulm Rehabil Prev 27: 303–308, 2007.

40. Hutchison KA, Balota DA, & Duchek JM. The utility of stroop task switching as a marker for early-stage alzheimer's disease. Psychol Aging 25: 545-559, 2010.

41. Jacus JP, Dupont MP, Herades Y, Pelix C, Large H, & Baud M. Awareness disorders in alzheimer's disease and in mild cognitive impairment. Encephale 40: 180-187, 2014.

42. Johns M, Schmader T, & Martens A. Knowing is half the battle: Teaching stereotype threat as a means of improving women's math performance. Psychol Sci 16: 175-179, 2005.

43. Kim SH. Older people's expectations regarding ageing, health-promoting behaviour, and health status. J Adv Nurs 65: 84-91, 2009.

44. Kolen MJ & Brennan RL. Test Equating. New York, NY: Springer; 1995.

45. Kollenbaum VE. Interoception of cardiovascular stress in myocardial infarction patients. Frankfurt/Main: Peter Lang-Verlag 1990.

46. Levy BR. Stereotype embodiment: A psychosocial approach to aging. Curr Dir Psychol Sci 18: 332-336, 2009.

47. Lohse KR & Sherwood DE. Defining the focus of attention: Effects of attention on perceived exertion and fatigue. Front Psychol November 332: 1-10, 2011.

48. Maliszewska-Cyna E, Lynch M, Oore JJ, Nagy PM, & Aubert I. The benefits of exercise and metabolic interventions for the prevention and early treatment of alzheimer's disease. Curr Alzheimer's Res 14: 47-60, 2017.

49. Mañas A, Del Pozo-Cruz B, Garcia-Garcia FJ, Guadalupe-Grau A, & Ara I. Role of objectively measured sedentary behavior in physical performance, frailty and mortality among older adults: A short systematic review. Eur J Sports Sci 17: 940-953, 2017.

50. Mârdh S, Nägga K, & Samueisson S. A longitudinal study of semantic memory impairment in patients with alzheimer's disease. Cortex 49: 528-533, 2013.

51. Maxfield M & Bevan A. Aging and Coping with Mortality: Understanding Attitudes about Aging and Age-Related Differences in Coping with Death. Handbook of Terror Management (Eds) Clay Routledge and Matthew Vess; 2018.

52. McAuley E, Hall KS, Motl RW, White SM, Wojcicki TR, Hu L, & Doerksen SE. Trajectory of declines in physical activity in community-dwelling older women: Social cognitive influences. J Gerontol: Series B 64: 543-550, 2009.

53. McDade E, Kim A, James J, Sheu LK, Kuan DC, Minhas D, Gianaros PJ…Klunk W. Cerebral perfusion alterations and cerebral amyloid in autosomal dominant alzheimer's disease. Neurol 19: 710-707, 2014.

54. McKhann G, Drachman D, Folstein M, Katzman R, Price D, & Stadlan EM. Clinical diagnosis of alzheimer's disease: Report of the NINCDS-ADRDA work group under the auspices of department of health and human services task force on alzheimer's disease. Neurol 34: 939-944, 1984.

55. Mihevic PM. Sensory cues for perceived exertion: A review. Med Sci Sports Exerc 13: 150-163, 1981.

56. Monsell SE, Dodge HH, Zhou XH, Bu Y, Besser LM, Mock C, Hawes SE…Weintraub S. Neuropsychology work group advisory to the clinical task force. Results from the NACC uniform data set neuropsychological battery crosswalk study, 2017.

57. Morris JC. The clinical dementia rating (CDR): Current version and scoring rules. Neurol 43: 2412-2414, 1993.

58. Nakagawa S & Schielzeth H. A general and simple method for obtaining R^2 from generalized linear mixed-effects models. Methods Ecol Evol 4: 133-142, 2013.

59. Nakanishi Y, Kimura T, & Yokoo Y. Physiological responses to maximal treadmill and deep water running in the young and middle aged males. Appl Human Sci 18: 81-86, 1999.

60. Navalta JW, Stone WJ, Lyons TS. Ethical Issues Relating to Scientific Discovery in Exercise Science. Int J Exerc Sci 12(1): 1-8, 2019.

61. Pearson SB, Banks DC & Patrick JM. The effect of 3-adrenoceptor blockade on factors affecting exercise tolerance in normal man. Brit J Clin Pharm 8: 143-148, 1979.

62. Pinheiro JC, & Bates DM. Mixed-Effects Models in S and S-PLUS. New York, NY: Springer; 2000.

63. Rogers MA, Hagberg JM, Martin WH, Ehsani AA, & Holloszy JO. Decline in VO2max with aging in master athletes and sedentary men. J Appl Physiol 68: 2195-2199, 1990.

64. Scheiber P, Seifert JG, & Müller E. Instructor-paced vs. self-paced skiing modes in older recreational applier skiers. J Strength Cond Res 25: 988-996, 2011.

65. Shigematsu R, Ueno LM, Nakagaichi M, Nho H, & Tanaka K. Rate of perceived exertion as a tool to monitor cycling exercise intensity in older adults. J Aging Phys Acti 12: 3-9, 2004.

66. Shono T, Fujishima K, Hotta N, Ogaki T, Ueda T, Otoki K…Shimizu T. Physiological responses and RPE during underwater treadmill walking in women of middle and advanced age. J Physiol Anthropol Appl Human Sci 19: 195-200, 2000.

67. Smith AE, Eston R, Tempest GD, Norton B, & Parfitt G. Patterning of physiological and affective responses in older active adults during a maximal graded exercise test and self-selected exercise. Eur J Appl Physiol 115: 1855-1866, 2015.

68. Steele CM, & Aronson J. Stereotype threat and the intellectual test performance of African Americans. Journal of Personality and Social Psychology 69: 797-811, 1995.

69. Stephen R, Hongisto K, Solomon A, & Lönnroos E. Physical activity and alzheimer's disease: A systematic review. J Gerontol: Bio Sci 22: 733-739, 2017.

70. Stone J. Battling doubt by avoiding practice: the effects of stereotype threat on self-handicapping in white athletes. Pers Soc Psychol Bull 28: 2002.

71. Vaitl D. Interoception. Biological Psychology 42: 1-27, 1996.

72. Van Baak MA. Beta-adrencoceptor blockade and exercise. Sports Med 5: 209-225, 1998.

73. Varma VR & Watts A. Daily physical activity patterns during the early stage of alzheimer's disease. J Alzheimer's Dis 55: 659-667, 2016.

74. Watts AS, Vidoni ED, Loskutova N, Johnson DK, & Burns JM. Measuring physical activity in older adults with and without early stage alzheimer's disease. Clin Gerontol 36: 356-374, 2013.

75. Wechsler D. Wechsler Memory Scale- Third Edition San Antonio, TX: The Psychological Corporation, 1997.

76. Wonish M, Hofmann FM, Hoedl R, Schwaberger G, Pokan R, von Duvillard SP... Klein W. Effect of beta(1)-selective adrenergic blockade on maximal blood lactate steady state in healthy men. Eur J Appl Physiol 87: 66-71, 2002.

77. Yu,F & Bill K. Correlating heart rate and perceived exertion during aerobic exercise in alzheimer's disease. Nurs Health Sci 12: 375-380, 2010.

78. Yu F, Demorest SL, & Vock DM. Testing a modified perceived exertion scale for alzheimer's disease. PsyCh Journal, 4, 38-46, 2015. doi: 10.1002/pchj.82. Epub Jan 30: 2015.