PLAGIARISM DECLARATION

PLAGIARISM

This means that you present substantial portions or elements of another's work, ideas or data as your own, even if the original author is cited occasionally. A signed photocopy or other copy of the Declaration below must accompany every piece of work that you hand in.

DECLARATION

1. I know that Plagiarism is wrong. Plagiarism is to use another's work and pretend that it is one's own.

2. I have used the American Psychological Association formatting for citation and referencing. Each significant contribution to, and quotation in, this essay/report/project from the work or works, of other people has been attributed, cited and referenced.

3. This essay/report/project is my own work.

4. I have not allowed, and will not allow anyone to copy my work with the intention of passing it off as his or her own work.

SIGNATURE:

NAME: Katherine Tredinnick

STUDENT NUMBER: TRDKAT001

Physical Fitness and Age Interact to Predict Intra-Individual Variability in Cognitive Performance of University Students

Katherine Tredinnick

ACSENT Laboratory
Department of Psychology
University of Cape Town

Supervisors: Dr Kevin Thomas
Co-supervisor: Björn Christ
Abstract: 264
Main text: 7692

Abstract

A growing literature emphasizes the importance of studying factors that promote brain health and protect against cognitive decline. Circumstantial evidence, documented in previously published research reports, suggests that higher levels of physical activity are associated with better cognitive performance, as indexed by traditional group-average measures. However, few published studies use reaction time (RT) measures of intra-individual variability (IIV_{RT}; within-person performance variability over successive measurements of RT at different occasions) to show that, in healthy young adults, physical activity is positively correlated with cognitive performance. This cross-sectional exploratory study aimed to contribute to the literature on the neuroprotective role of physical activity. Specifically, I investigated the relationship between physical fitness (as measured by a self-report questionnaire and an aerobic task) and IIV in cognitive performance (as measured by two blocks of simple reaction time (SRT) tasks and two blocks of choice reaction time (CRT) tasks, all administered within one test session) among healthy university students (N = 55; age range = 18-23 years). Analyses suggested that fitness interacts with age to significantly predict IIV_{RT} across (a) the first block of SRT trials, (b) the first block of CRT trials, and (c) both blocks of CRT trials, taken together. In fitter individuals, those who are younger had higher IIV_{RT} scores (i.e., performed more poorly) during those blocks than those who were older, suggesting that fitness may play a neuroprotective role. Such research into the neuroprotective role of physical fitness is important as it can be used as evidence in the promotion of healthy lifestyle choices.

Keywords: physical activity, fitness, intra-individual variability, cognitive performance, neuroprotective factor

Physical Fitness and Age Interact to Predict Intra-Individual Variability in Cognitive Performance of University Students

A growing literature emphasizes the importance of research into factors that promote brain health, improve cognitive performance, and protect against cognitive decline. Empirical evidence suggests that specific elements of a healthy lifestyle, such as physical fitness, may play such a neuroprotective role (see, e.g., Benedict et al., 2013; Cipriani, Lucetti, Danti, & Nuti, 2015). Improved physical fitness benefits both physical health (e.g., reduces the risk of developing certain chronic diseases; Lambert, Bohlmann, & Kolbe-Alexander, 2001) and cognitive performance (e.g., Benedict et al., 2013; Kimura, Yasunaga, & Wang, 2013; Ruscheweyh et al., 2011). Despite the implications of this body of research, epidemiological data suggest that approximately 30% of the world's population might be considered inactive (Hallal et al., 2012). In South Africa, public health studies indicate that the large majority of citizens are not meeting the minimum physical activity recommendations (Shisana et al., 2014).

Fitness and Cognitive Performance

Cardiovascular (or aerobic) fitness is often described as the primary mediator explaining the positive relationship between physical activity and cognitive performance (Åberg et al., 2009). Many studies of elderly individuals support this 'cardiovascular fitness hypothesis' (e.g., Benedict et al., 2013; Colcombe et al., 2003; Erickson & Kramer, 2009). Additionally, higher levels of physical activity at midlife are associated with better cognitive performance, especially on memory tasks, and have been shown to protect against dementia (e.g., Andel et al., 2008; Lautenschlager et al., 2008). At the opposite end of the lifespan, studies of young children suggest that increased physical activity is linked to improved school achievement (e.g., Kim et al., 2003; Sibley & Etnier, 2003).

However, there is relatively little research on associations between cardiovascular fitness and cognition in adolescents and young adults. Moreover, the data that does exist is often conflicting (Åberg et al., 2009). Although most extant studies in the field offer support for the cardiovascular fitness hypothesis in young adulthood (e.g., Åberg et al., 2009; Wu et al., 2011), some report negative associations between frequent or strenuous physical activity and cognitive performance (e.g., Etnier, Nowell, Landers, & Sibley, 2006; Tomporowski, 2003).

Cognitive Performance as Indexed by Intra-Individual Variability

Most neuropsychological research on cognitive performance uses statistics grounded in between- and within-group mean differences, most often within cross-sectional research designs. This approach assumes that cognitive performance within individuals and groups (and particularly in healthy individuals and groups) is relatively stable from one test occasion to the next (Jackson, Balota, Duchek, & Head, 2012; MacDonald, Karlsson, Rieckmann, Nyberg, & Bäckman, 2012). In contrast, the observation of intra-individual variability (IIV), or within-person performance variability, in cognitive performance suggests there are transient and systematic changes in an individual’s cognitive performance from one test occasion to the next (Gorus, De Raedt, Lambert, Lemper, & Mets, 2008; MacDonald, Nyberg, & Bäckman, 2006). Over the past two decades, a rapidly-growing literature has begun to assert that IIV is a more sensitive and accurate measure of cognition than traditional mean-based measures and, hence, the use of IIV in cognitive research is increasing (Dykiert, Der, Starr, & Deary, 2012; Hultsch, MacDonald, & Dixon, 2002; MacDonald, Li, & Bäckman, 2009).

IIV scores are highest in individuals with some form of neuropathology (e.g., patients with attention-deficit/hyperactivity disorder (ADHD), schizophrenia, traumatic brain injury, or age-related neurodegenerative disorders; MacDonald, Nyberg, Sandblom, Fischer, & Bäckman, 2008; Sugarman et al., 2014). Hence, a developing field of research suggests that IIV in cognitive performance may be used as a tool to detect changes in brain health, and may be a predictor of cognitive decline associated with neurodegeneration (Dykiert et al., 2012; Gorus et al., 2008; Hultsch et al., 2002; Sugarman et al., 2014; Tales et al., 2012).

Often, IIV studies in psychology measure fluctuating scores on reaction time (RT) tasks (e.g., Jackson et al., 2012; MacDonald et al., 2012). RT, a latency-based measure, refers to the time that passes between the appearance of a stimulus and the participant’s response to that stimulus (Bielak, Hultsch, Strauss, Macdonald, & Hunter, 2010). RT-based measures are generally regarded as superior to accuracy-based measures (i.e., tasks without a timed component, and in which participants can respond correctly or incorrectly) as associations between potential predictors (e.g. age, fitness) and IIV_{RT} are unaffected by controlling for mean performance (Murphy, West, Armilio, Craik, & Stuss, 2007).

Fitness and Intra-Individual Variability

Although, as noted above, many studies report a positive association between physical fitness and cognitive performance (see, e.g., Dik, Deeg, Visser, & Jonker, 2003; Lautenschlager et al., 2008), relatively fewer studies have demonstrated this positive association when cognitive performance is indexed by IIV. Furthermore, within the group of studies that have demonstrated this association, most focus on samples older adults or on clinical groups (e.g., Cruise et al., 2011; Kimura et al., 2013). Wu et al. (2011) conducted one of the few studies investigating this relationship in a sample of healthy, young participants. Those researchers grouped 48 pre-adolescent children (age range 8-11 years) according to their scores on an aerobic fitness test. They measured IIV in cognitive performance using an RT task, and found that fitter participants delivered less variable performance.

Summary, Rationale and Research Hypothesis

Understanding the neuroprotective role of cardiovascular fitness is important as it can inform policy changes and can be used as evidence in the promotion of physical activity among a largely inactive local and global population. Although there is evidence suggesting that increased physical activity improves cognitive performance, most of it is derived from studies of older adult samples and clinical groups, and most of those studies used traditional group average measures (e.g., Kimura et al., 2013; Kramer et al., 1999). To my knowledge, no studies use IIV_{RT} to show that, in young, healthy adults, physical activity is associated with increased cognitive performance. Indeed, even in studies using group average measures, there is some equivocation as to whether there is a positive association between physical fitness and cognitive performance in young, healthy adults (Tomporowski, 2003).

My study aimed to address this gap in the literature by investigating the relationship between physical fitness (as measured by a self-report questionnaire and an aerobic task) and IIV in cognitive performance (as measured by RT tasks) in healthy, young adults. Specifically, I investigated the hypothesis that fitness is a significant predictor of IIV_{RT}, with increased levels of fitness being negatively associated with IIV_{RT} scores.

Methods

Design and Setting

The study was of an exploratory and relational cross-sectional design. The outcome variable was IIV_{RT}, and the predictors were cardiovascular fitness (as measured by a Multi-Stage Run Test), physical activity (as measured by the International Physical Activity Questionnaire), body mass index, and the key sociodemographic variables of age and sex. The design comprised three phases: (1) a screening phase, to check participant eligibility; (2) a cognitive testing phase, in which participants completed RT tasks (and also answered the above-mentioned questionnaires and had their BMI calculated); and (3) a fitness testing phase, in which participants completed the Multi-Stage Run Test. Screening took place online, cognitive testing took place in the University of Cape Town (UCT) Department of Psychology, and fitness testing took place at the UCT Sports Centre.

Participants

Recruitment. Using G*Power software (Faul, Erdfelder, Lang, & Buchner, 2007), I ran an a priori power analysis using parameters of a moderate effect size (Cohen's f = 0.35), α set at the conventional .05, and a desired statistical power of .80. This analysis suggested that a sample size of 50 would adequately power the study.

Using convenience sampling, I recruited 55 young adults (age range = 18-23 years, inclusive) from the UCT community. All participants were recruited using university email advertisements (see Appendix A) and the UCT Department of Psychology's Student Research Participation Programme (SRPP; see Appendix B).

Eligibility criteria. All participants had to be between 18 and 25 years of age, inclusive. This criterion was put in place because the study focused on the relationship between physical fitness and IIV in young adults. Individuals were excluded from the study if they had (a) experienced a head injury with loss of consciousness for more than 30 minutes, (b) a current or past psychiatric disorder, (c) a current or past neurological disorder, (d) current substance abuse or dependence, (e) any infectious disease that affects the central nervous system (CNS), (f) a physical injury that might have impacted performance on the Multi-Stage Run Test, (g) a Beck Depression Inventory-Second Edition (BDI-II) score ≥ 29, and (h) a STAI-Trait score ≥ 59. These exclusion criteria have been described as potential confounding variables in tests of cognition, and are consistent with the criteria used in previous studies of IIV in cognitive performance (Kimura et al., 2013; Sugarman et al., 2014; Wu et al., 2011).

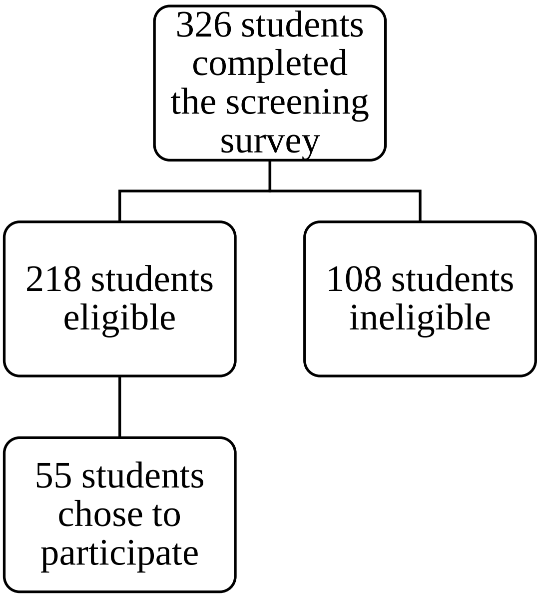

Figure 1. Participant attrition through the study protocol (*N* = 326 to *N* = 55).

Of the 327 participants who completed the surveys, 218 were eligible for further participation. Of that number, 55 (27 women, 28 men, all UCT undergraduate students) chose to participate (see Figure 1).

Measures

Screening measures. These measures were used in the online screening survey to ascertain which individuals were eligible to participate.

Health Index. This study-specific instrument (see Appendix C) gathered details regarding the participant's medical history and current medical status. I used it as a screening measure for neurological, psychiatric, and CNS disorders, as well as alcohol and substance abuse/dependence.

General Health Questionnaire 28 (GHQ-28). This 28-item self-report measure screens for minor psychiatric disorders (see Appendix D, Goldberg & Hillier, 1979). It consists of four subscales, each featuring seven items: somatic symptoms, anxiety/depression, social dysfunction, and severe depression. Individuals with a total score above 23 may be classified as having a minor psychiatric disorder (Goldberg et al., 1997). Hence, any individuals who scored above 23 were excluded from participating further.

Psychometric studies suggest the GHQ-28 has high test-retest reliability (α = .78- .90) and high internal consistency reliability and validity (e.g., Goldberg et al., 1997; Sterling, 2011). Moreover, it has been shown to be valid for use with South African samples (Moch, Panz, Joffe, Havlik, & Moch, 2003).

Beck Depression Inventory-Second Edition (BDI-II). This 21-item self-report measure screened for depressive symptoms (see Appendix E; Beck, Steer, & Brown, 1996). Respondents chose one of four statements (each scored on 4-point Likert-type scale) that best described how they had been feeling over the previous 2 weeks. The total score was obtained by summing all of the item responses, with higher scores indicating higher levels of depressive symptomatology. Individuals who score above 29 are conventionally classed as ‘severely depressed’ (Beck et al., 1996). Hence, anyone scoring at or above that level was excluded from further participation.

The test-retest reliability of the BDI-II is good (α = .93), and it has high internal consistency (α = .91) and adequate content validity (Beck et al., 1996; Dozois, Dobson, & Ahnberg, 1998). Numerous published studies suggest the instrument is valid for use with South African samples (see, e.g., Henry, Wolf, Ross, & Thomas, 2015; Ward, Flisher, Zissis, Muller, & Lombard, 2003).

State-Trait Anxiety Inventory-Trait Form (STAI-Trait). This 20-item instrument measures general anxiety levels (see Appendix F; Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). Each item is a statement that requires response using a 4-point Likert-type scale, with higher scores indicating higher levels of anxiety.

The STAI-Trait has high internal consistency (α = .86 to .95), high test-retest reliability (r = .69 to .89), and good construct validity (Spielberger & Vagg, 1984). Several published studies suggest the instrument is a reliable and valid measure of trait anxiety in South African samples (see, e.g., Basson et al., 2010; Pretorius & Norman, 1992).

Laboratory measures. The questionnaires described below gathered information regarding potential predictors of IIV_{RT} (e.g., age, sex, and physical activity).

Sociodemographic questionnaire. This study-specific instrument (see Appendix G) gathered information about potentially relevant biographical or demographic variables. For instance, information about age and sex is important to collect because those variables influence the relationship between fitness and IIV in cognitive performance (Anstey, Dear, Christensen, & Jorm, 2005; Dik et al., 2003; Dykiert et al., 2012).

The International Physical Activity Questionnaire Short Form (IPAQ-S). This 7-item self-report measure was used to gauge participants’ physical activity, including leisure-, domestic-, work-, and travel-related activities (see Appendix H; Hagströmer, Oja, & Sjöström, 2006). The scores for walking, moderate-intensity, and vigorous-intensity activity are weighted differently according to their energy requirements in multiples of the resting metabolic rate (METs), which are 3.3, 4, and 8 METs respectively. These MET scores are multiplied by minutes performed of that activity and are combined for a total score of overall physical activity (in MET minutes).

The IPAQ-S has adequate validity and reliability (Hagströmer et al., 2006). In South African samples, it appears to have adequate test-retest reliability (*r* = .58 to .77) but poor criterion validity (*r* = .40; Wetherbee et al., 2001).

Deary-Liewald reaction time tasks. I used two computerized tests of RT, a simple reaction time (SRT) task and a choice reaction time (CRT) task (Deary, Liewald, & Nissan, 2011; downloaded from (www.ccace.ed.ac.uk/research/software-resources/software). These tasks were presented on standard 15-inch computer screens with Windows 10 operating systems to ensure refresh rates were standardised across the computers (Demirci, 1996). On the SRT task, participants are required to provide one set response upon the appearance of one set stimulus. Specifically, they are instructed to press the space bar when they see a black cross appear in a white box on the computer monitor. On the CRT task, there are four stimuli, each requiring a unique response. Specifically, participants are instructed to watch for a black cross flashing in one of four white squares, and to then press the key corresponding to the square in which the cross flashed (i.e., there are four stimuli-response associations). Both tasks have good internal consistency (SRT α = .94, CRT α = .97) and good validity (Deary et al., 2011).

Physiological measures. These measures gathered physiological information about the participants.

Body mass index (BMI). Measures of BMI are commonly used to indicate whether one's weight is healthy or not. It is calculated by measuring the height and the weight of the participant and dividing body weight (in kilograms) by height (in metres squared). A score of below 18.5 indicates that an individual is 'underweight', a score of 18.5-24.9 indicates 'normal weight', a score of 25-29.9 indicates 'overweight', and a score above 30 indicates 'obesity' (World Health Organization, 1998).

Multi-Stage Run Test (MSRT). The multi-stage 20m shuttle run test (Leger & Lambert, 1982) is one of the most commonly used methods to obtain an estimate of maximal oxygen uptake (VO_{2max}). VO_{2max} is an indicator of aerobic capacity in that it refers to the amount of oxygen one's body uses in 1 minute (Kavcic, Milic, Jourkesh, Ostojic, & Ozkol, 2012). The MSRT is simple to administer and allows groups of participants to be tested simultaneously (St Clair Gibson, Broomhead, Lambert, & Hawley, 1998). The correlation between MSRT-predicted and objectively-measured VO_{2max} is moderate (*r* = .68; Kavcic et al., 2012).

In the MSRT, the participant has to run back and forth between two lines that are 20 metres apart, reaching each line before a pre-recorded beep sounds. At the outset, the beeps are spaced relatively far apart, so that the participant is encouraged to run at a speed of about 8.5 km/h. The frequency of beeps increases steadily, however, so that the participant has to increase speed incrementally (by at least 0.5 km/h) at each new level. The test is complete when the participant can no longer keep up with the pace of the beeps.

The maximal speed for each participant is then recorded as the speed of the last completed round. Thereafter, the VO_{2max} of each participant is predicted using the following equation: $y = 6.0\,x - 24.4$, where y is their predicted VO_{2max} (ml/kg/min) and x is their maximal speed (km/h; St Clair Gibson et al., 1998).

Procedure

Screening phase. After receiving full ethical clearance, I began recruiting participants (see Appendix H). I distributed advertisements via email and the SRPP website. These advertisements provided details about the study, and also outlined the eligibility criteria. Those who met the criteria participated in further online screening (i.e., the Health Index, GHQ-28, BDI-II, and STAI-Trait), administered via the SurveyMonkey platform (www.surveymonkey.com). At the end of the survey, there was a section with psychotherapy/counselling referrals for participants to use if they felt distressed in any way after completing the questionnaires.

Cognitive testing phase. Those found to be eligible to participate were notified via email and were provided with online links to book a testing session (one time slot that included both the cognitive and fitness testing sessions). Although each session allowed slots for six participants, not every session was fully booked, and certain participants did not arrive at their scheduled time, and therefore the average group size was four participants.

The cognitive testing sessions took place in UCT Department of Psychology research laboratories. After arriving at the laboratory, participants read and signed the informed consent document (see Appendix J), and then completed the sociodemographic questionnaire and the IPAQ. I then measured their weight and height so that I could calculate their BMI. Thereafter, each participant was seated in front of a computer so that the RT tasks could be administered. I delivered standardised instructions and explained that both speed and accuracy were of equal importance in completing the tasks. They were then given the chance to practice, with the software administering 10 SRT trials and 10 CRT trials. There followed Block 1 of SRT tasks (25 trials), Block 1 of CRT tasks (50 trials), Block 2 of SRT tasks (25 trials), and Block 2 of CRT tasks (50 trials). This testing phase lasted approximately 45 minutes.

Fitness testing phase. Immediately after the cognitive testing was complete, the participants and I moved to the UCT Sports Centre, where they completed the MSRT. I explained the procedure of the test to the participants, and they then completed the shuttle run. Each of these test sessions lasted approximately 30 minutes.

Debriefing and compensation. After the fitness testing was complete, participants were given a verbal and written debriefing (see Appendix K) and the opportunity to ask study-related questions. I awarded 3 SRPP points to Psychology students after they had completed all phases of my study. Students from outside the Department of Psychology were entered into a prize-giving draw for R1000, R500, and R250 shopping vouchers.

Statistical Analyses

Cleaning the data. After collecting data, I scored and logged them into an MSExcel spreadsheet. Participants had to record at least 75% accuracy (as measured by a correct response to the presented stimuli) on both SRT and CRT tasks for their datasets to be included in the final sample. All 55 participants met this condition. I then scoured the data for outliers, and removed all RTs shorter than 150 ms or 3 *SD* above the mean for that particular block, as per convention (Bielak et al., 2010; Christ, Thomas, & Combrinck, 2017; Garrett, MacDonald, & Craik, 2012). I then replaced missing scores with new values, using a statistically robust regression-based multiple imputation method (Lachaud & Renaud, 2011).

Extracting IIV. I then analysed the data using SPSS (version 24). First, I used random intercept and random slope models to control for the systematic effects that predict mean RT scores. I then captured the residuals, and converted them to *t*-scores. By computing the standard deviations of these *t*-scores, I obtained i*SD*s, the primary IIV outcome variable (Hultsch, Strauss, Hunter, & MacDonald, 2008).

Inferential analyses. I then compiled a complete set of descriptive statistics for the dataset, examining measures of central tendency and variation (e.g., mean, standard deviation, range) to check that the distributional assumptions underlying subsequent inferential statistical analyses were met. Finally, I performed exploratory univariate general linear model (GLM) analyses to test the hypothesised predictors of IIV_{RT} (most notably to assess whether fitness (as measured by MSRT-predicted VO_{2max} scores) made a unique and strong contribution to the variance in the outcome variable (IIV_{RT})). I checked all assumptions underlying GLM as well as potential influential cases that might have affected the validity of the models.

Results

Sample Characteristics

Table 1 shows that sample-mean BMI and VO_{2max} scores were in the range conventionally defined as "average" (World Health Organization, 1998). However, although the sample's age range was relatively small (due, of course, to the age-related inclusion criterion), BMI, IPAQ, and VO_{2max} ranges showed more variability.

Table 1

Sample Characteristics (N = 55)

Variable	Minimum	Maximum	*M*	*SD*
Age (years)	18	23	20.78	1.37
BMI (kg/m^2)	18.66	39.89	24.51	3.63
VO_{2max}	23.01	57.45	35.89	9.66
IPAQ-S (MET mins)	594	14100	3807.85	2964.53

Note. BMI = body mass index; IPAQ-S = International Physical Activity Questionnaire Short Form. VO_{2max} scores are predicted from performance on the Multi-Stage Run Test; higher scores indicate higher fitness levels. Similarly, higher IPAQ scores indicate higher levels of physical activity.

Table 2 shows the results of a series of independent-samples *t*-tests assessing between-sex differences in terms of age, BMI, VO_{2max}, and IPAQ scores. The data suggest that men were significantly fitter (i.e., had significantly higher VO_{2max} values) and had significantly higher BMIs.

Table 2

Between-sex Comparisons: Sample Characteristics (N = 55)

	Sex				
Variable	Men (*n* = 28)	Women (*n* = 27)	*t*	*p*	ESE
Age (years)	21.00 (1.49)	20.56 (1.22)	1.21	.233	0.33
BMI (kg/m^2)	25.90 (3.80)	23.06 (2.85)	3.13	< .001***	0.94
VO_{2max}	41.82 (9.00)	29.74 (5.69)	5.92	.003**	0.84
IPAQ-S (MET mins)	4457.34 (2607.12)	3134.30 (3204.52)	1.68	.098	0.45

Note. Values presented are means, with standard deviations in parentheses. BMI = body mass index; IPAQ-S = International Physical Activity Questionnaire Short Form; ESE = effect size estimate (in this case, Cohen's *d*). VO_{2max} scores are predicted from performance on the Multi-Stage Run Test; higher scores are indicative of higher fitness levels. Similarly, higher IPAQ scores are indicative of higher levels of physical activity.

**p* < .05. ***p* < .01. ****p* <. 001.

Table 3 shows the results of correlational analyses of the sample characteristic variables. This series of analyses detected only one significant association, that between age and fitness (V_{O2max}).

Table 3

Correlation Matrix: Sample characteristics (N = 55)

Variable	Age	BMI	VO_{2max}	IPAQ
Age	1.00			
BMI	-.064 (.641)	1.00		
VO_{2max}	**.267 (.048)**	.001 (.991)	1.00	
IPAQ-S	-.222 (.103)	.104 (.449)	.250 (.066)	1.00

Note. Data presented are Pearson's *r* correlation coefficients and associated *p* values. BMI = body mass index; IPAQ-S = International Physical Activity Questionnaire Short Form. All *p*-values are two-tailed. Statistically significant *p*-values are indicated in boldface font.

Figure 2 shows the correlation between age and fitness in the current sample (*N* = 55). On average, older participants had higher Multi-Stage Run Test-predicted VO_{2max} scores (indicating better aerobic capacity) than younger participants.

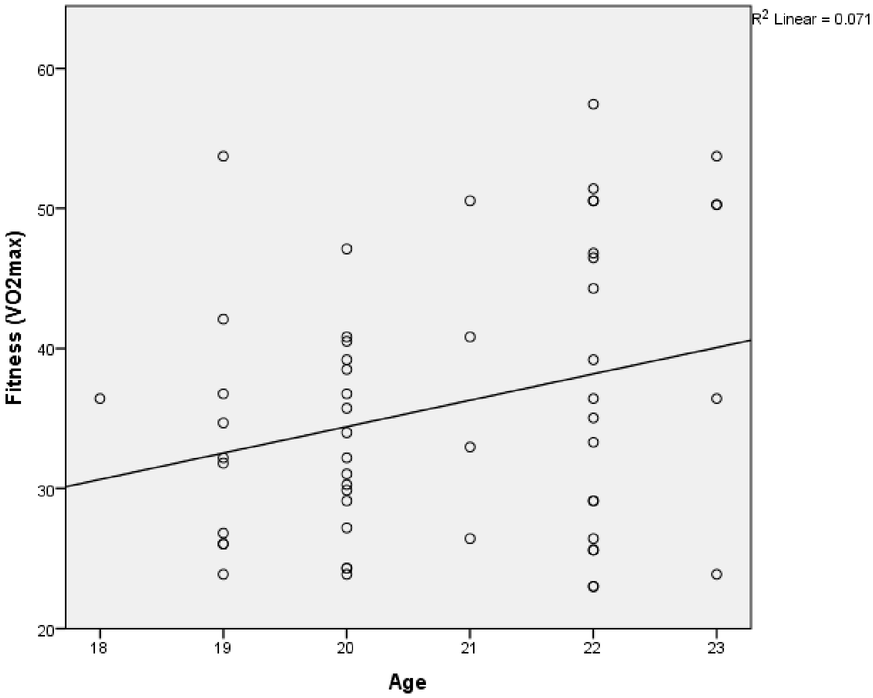

Figure 2. Correlation between age and fitness in the current sample (*N* = 55).

Extracting iSDs

A random intercept model (RIM) sought to determine which factors significantly predicted performance on Blocks 1 and 2 of the SRT task (see Table 4). The model detected three significant main fixed effects: Block, BMI, and VO_{2max}. Mean SRT scores were slower in Block 2 than in Block 1, and faster in those with higher BMI scores and in those with higher MSRT-predicted VO_{2max} scores.

I then added the variables identified as significant (Block, BMI, and VO_{2max}) and their higher-order interactions to a more complex RIM to partial out systematic effects from the data. After running this model, I captured the residuals of the SRT data.

Table 4

Random Intercept Model: Fixed effects for SRT Blocks 1 and 2 (N = 55)

Source	*F*	*df*	*p*
Sex	3.48	1, 48	.068
Block	82.45	1, 2693	< .001***
BMI (kg/m^2)	5.26	1, 48	.026*
Age (years)	3.99	1, 48	.051
VO_{2max}	9.97	1, 48	.003**
IPAQ-S	< .001	1, 48	.983
Trials	.39	1, 2693	.533
SES	.32	1, 48	.577

Note. SRT = Simple Reaction Time task; BMI = body mass index; IPAQ-S = International Physical Activity Questionnaire Short Form.
$*p < .05$; $**p < .01$. $***p < .001$.

A second RIM sought to determine which factors significantly predicted performance on Blocks 1 and 2 of the CRT task (see Table 5). The model detected two significant main fixed effects: Block and Trials. Regarding the main effect of Block, mean CRT scores were slower in Block 2 than in Block 1. Regarding the main effect of Trials, reaction times became slower as the number of trials increased.

I added the variables identified as significant (Block and Trials) and their higher-order interactions to a more complex RIM, and I added a random slope model (RSM) for Trials, to partial out systematic effects from the data. After running this model, I captured the residuals of the CRT data.

Table 5

Random Intercept Model: Fixed effects for CRT Blocks 1 and 2 (N = 55)

Source	*F*	*df*	*p*
Sex	1.16	1, 48	.287
Block	12.86	1, 5443	< .001***
BMI (kg/m^2)	0.73	1, 48	.398
Age (years)	1.43	1, 48	.238
VO_{2max}	0.66	1, 48	.420
IPAQ-S	0.73	1, 48	.396
Trials	30.99	1, 5443	< .001***
SES	.92	1, 48	.342

Note. CRT = Choice Reaction Time task; BMI = body mass index; IPAQ-S = International Physical Activity Questionnaire Short Form.
***$p < .001$.

Extracting Intra-individual Variability

I used the extraction approach described by Hultsch et al. (2008) to capture the residuals (*z*-scores) from the RIMs and RSM, and then converted those values to *t*-scores. Then, I calculated the *SD*s for each block of *t*-scores for each participant to ascertain the participants' *iSD*s (i.e., the primary measure of IIV).

Table 6 presents mean RT and IIV_{RT} scores for the sample across the SRT and CRT tasks. The data depicted there suggest that Mean CRT scores were more variable than Mean SRT scores, but that *iSD* for SRT was more variable than that for CRT.

Table 6

Descriptive Statistics for Reaction Time Tasks: Mean Scores and iSD Scores (N = 55)

Variable	Minimum	Maximum	*M*	*SD*
Mean RT				
SRT				
Block 1	251.72	388.94	296.70	23.76
Block 2	262.64	400.80	310.07	26.49
Session	257.18	394.87	303.39	23.85
CRT				
Block 1	349.66	590.36	457.26	51.07
Block 2	335.82	567.62	464.92	50.07
Session	363.50	613.11	461.09	249.61
iSD				
SRT				
Block 1	4.91	16.88	9.23	3.00
Block 2	16.88	17.94	9.87	2.99
Session	4.97	17.41	9.56	2.54
CRT				
Block 1	4.63	13.48	9.4	1.95
Block 2	5.57	15.83	10.04	2.28
Session	5.80	14.66	9.72	1.91

Note. SRT = simple reaction time; CRT = choice reaction time; *iSD* = intraindividual standard deviation. SRT Session is the average of SRT Block 1 and Block 2. CRT Session is the average of CRT Block 1 and Block 2.

Predictors of Intra-individual Variability on the SRT Task

I conducted three exploratory univariate GLMs, one for each of the IIV_{RT} on SRT Block 1, SRT Block 2, and SRT Session (i.e., the average of Block 1 and 2 scores). Predictor variables were sex, age, and MSRT-predicted VO_{2max}, and all of the interactions among them. The only significant model here was that predicting IIV_{RT} on SRT Block 1 (see Table 7). That model contained significant interactions between sex and age, and between age and VO_{2max}. Although the main effects of age and VO_{2max} were also significant predictors of the outcome, these effects are not meaningful given the significant interactions observed.

Table 7

Univariate General Linear Model: Predicting IIV_{RT} on SRT Block 1 (N = 55)

Predictor	SS	*df*	MS	*F*	*p*	η_p^2
Corrected model	57.50	5	11.50	1.31	.275	.118
Age	45.07	1	45.07	5.14	.028*	.095
Sex	35.29	1	35.29	4.02	.050	.076
VO_{2max}	46.35	1	46.35	5.28	.026*	.097
Sex x Age	35.77	1	35.77	4.08	.049*	.077
Age x VO_{2max}	48.47	1	48.47	5.52	.023*	.101

Note. SS = sums of squares; MS = mean square. For the overall model, $R^2 = .12$.
*$p < .05$.

Figure 3 is a graphic depiction of the Age x VO_{2max} interaction in predicting IIV_{RT} on SRT Block 1. In the ‘poor fitness’ group of participants, those who are younger have, on average, lower IIV_{RT} scores than those who are older. In contrast, in the ‘good fitness’ group those who are younger have, on average, higher IIV_{RT} scores than those who are older. The ‘average fitness’ group is somewhat similar to the ‘poor fitness’ group in that, on average, younger people have lower IIV_{RT} scores than those who are older, although the line is flatter (indicating less of a relationship between age and fitness) than that of the ‘poor fitness’ group.

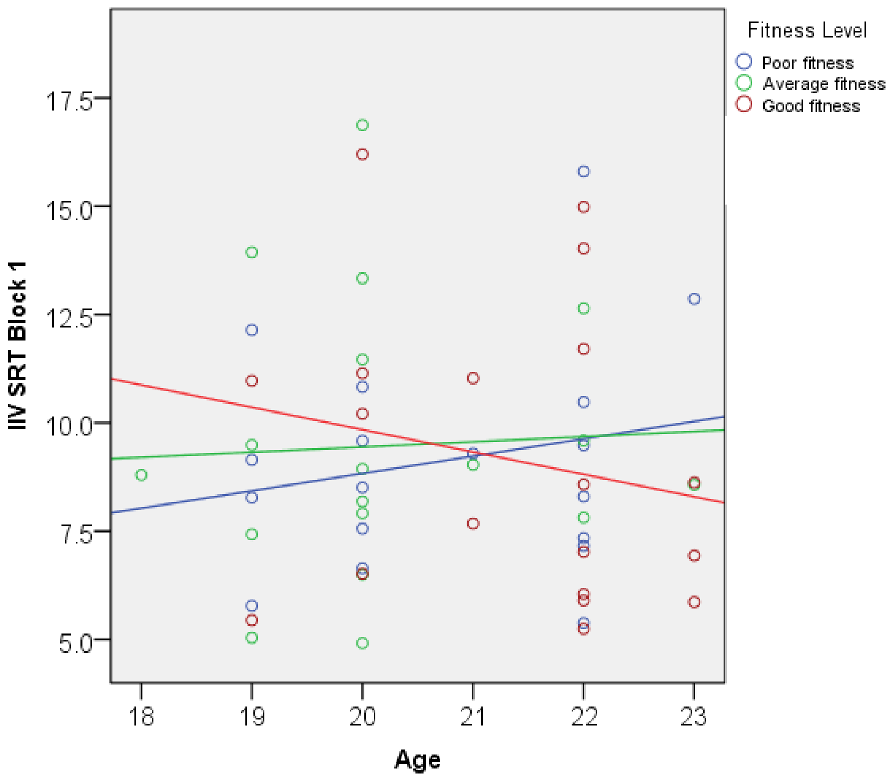

Figure 3. The significant interaction effect between age and MSRT-predicted VO_{2max} (as an indicator of physical fitness) in predicting IIV_{RT} for Simple Reaction Time Block 1 performance (*N* = 55). Fitness level is classified as follows: ‘poor fitness’ = VO_{2max} range of 23-34; ‘average fitness’ = VO_{2max} range of 35-46; ‘good fitness’ = VO_{2max} range of 47-58.

Figure 4 is a graphic depiction of the Age x Sex interaction in predicting IIV_{RT} on SRT Block 1. Women who are younger have, on average, higher IIV_{RT} scores than those who are older. In contrast, men who are younger have, on average, lower IIV_{RT} scores than those who are older.

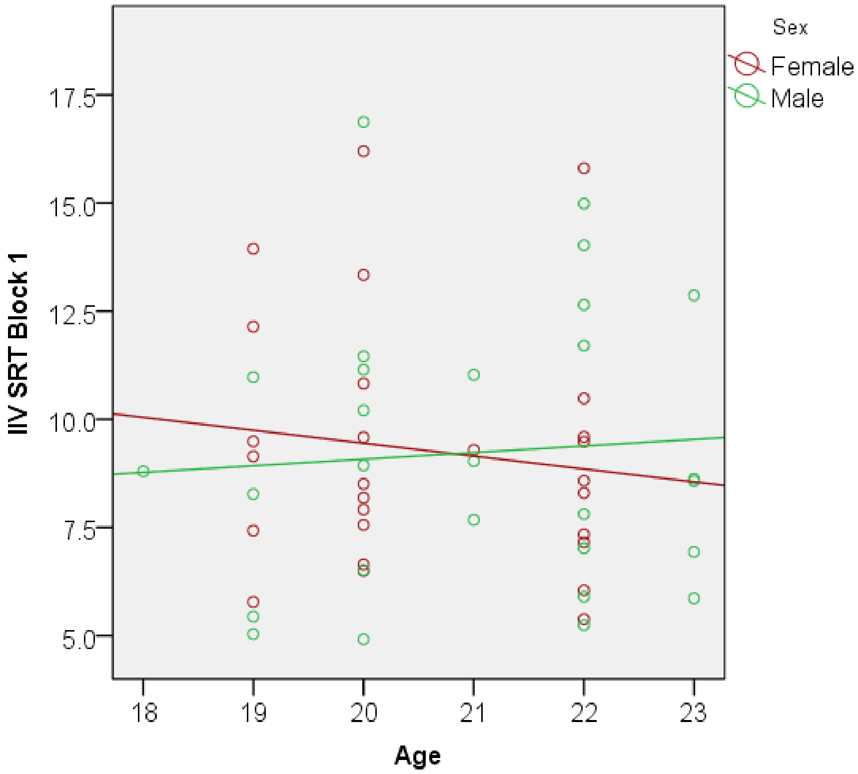

Figure 4. The significant Sex x Age interaction effect in predicting IIV_{RT} for Simple Reaction Time Block 1 performance (N = 55).

Predictors of Intraindividual Variability on the CRT Task

I conducted three exploratory univariate GLMs, one for each of the IIV_{RT} on CRT Block 1, CRT Block 2, and CRT Session (i.e., the average of Block 1 and 2 scores). Predictor variables were sex, age, and MSRT-predicted VO_{2max}, and all of the interactions among them. The significant models here were those predicting IIV_{RT} on CRT Block 1 (see Table 8) and on CRT Session (see Table 9). Both models contained significant interactions between age and VO_{2max}. Although, in both cases, the main effects of age and VO_{2max} were also significant predictors of the outcome, these effects are not meaningful given the significant interaction observed.

Table 8

Univariate General Linear Model: Predicting IIV_{RT} on CRT Block 1 (N = 55)

Predictor	SS	*df*	MS	*F*	*p*	ηp^2
Corrected model	56.32	6	9.39	3.01	.014*	.273
Sex	11.32	1	11.32	3.63	.063	.070
Age	40.60	1	40.60	13.02	.001**	.213
VO_{2max}	46.13	1	46.13	14.79	< .001***	.236
Sex x Age	10.60	1	10.60	3.40	.071	.066
Age x VO_{2max}	46.92	1	46.92	15.05	< .001***	.239
Sex x VO_{2max}	0.15	1	0.15	0.05	.826	.001

Note. SS = sums of squares; MS = mean square. For the overall model, $R^2 = .27$.
*p < .05. **p < .01. ***p < .001.

Table 9

Univariate General Linear Model: Predicting IIV_{RT} on CRT Session (N = 55)

Predictor	SS	*df*	MS	*F*	*p*	ηp^2
Corrected model	35.45	6	5.91	1.77	.126	.181
Sex	8.00	1	8.00	2.38	.130	.047
Age	17.51	1	17.51	5.23	.027*	.098
VO_{2max}	20.80	1	20.80	6.22	.016*	.115
Sex x Age	8.12	1	8.12	2.43	.126	.048
Age x VO_{2max}	20.40	1	20.40	6.10	.017*	.113
Sex x VO_{2max}	0.38	1	0.38	0.12	.736	.002

Note. SS = sums of squares; MS = mean square. For the overall model, $R^2 = .18$.
*p < .05.

Figure 5 is a graphic depiction of the Age x VO_{2max} interaction in predicting IIV_{RT} on CRT Block 1. Figure 6 is a graphic depiction of the same interaction in predicting IIV_{RT} on CRT Session. The latter figure shows the same linear relationships as the former, but the lines are not as steep. In both Figures, the ‘poor fitness’ group of participants, those who are younger have, on average, lower IIV_{RT} scores than those who are older. In contrast, in the ‘good fitness’ group those who are younger have, on average, higher IIV_{RT} scores than those who are older. The ‘average fitness’ group is somewhat similar to the ‘poor fitness’ group in that, on average, younger people have lower IIV_{RT} scores than those who are older, although the line is flatter (indicating less of a relationship between age and fitness) than that of the ‘poor fitness’ group.

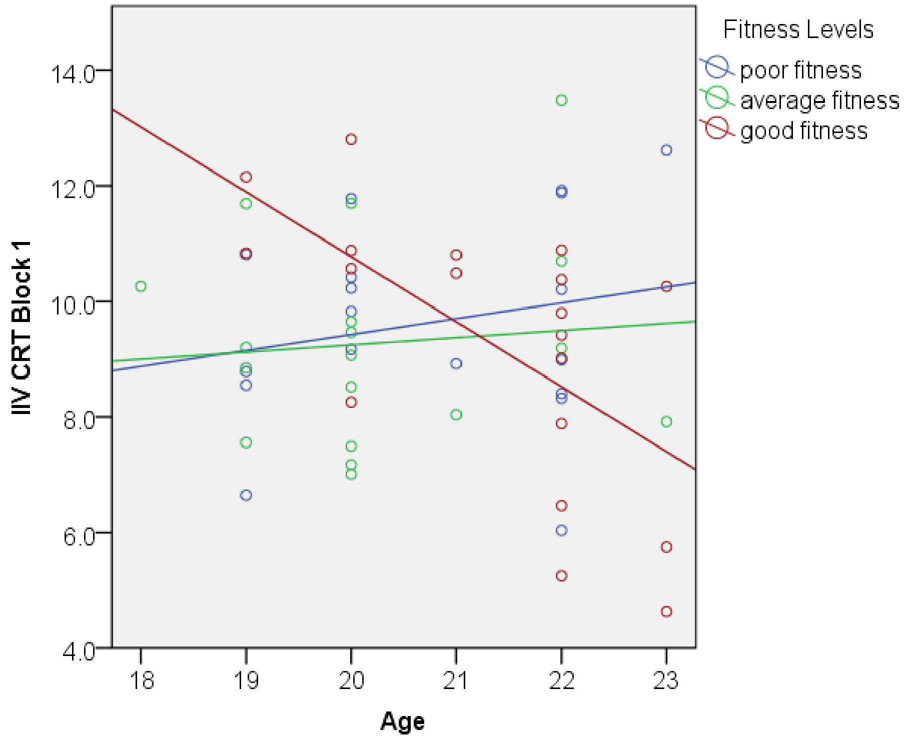

Figure 5. The significant interaction effect between age and MSRT-predicted VO_{2max} (as an indicator of physical fitness) in predicting IIV_{RT} for Choice Reaction Time Block 1 performance (N = 55). Fitness level is classified as follows: 'poor fitness' = VO_{2max} range of 23-34; 'average fitness' = VO_{2max} range of 35-46; 'good fitness' = VO_{2max} range of 47-58.

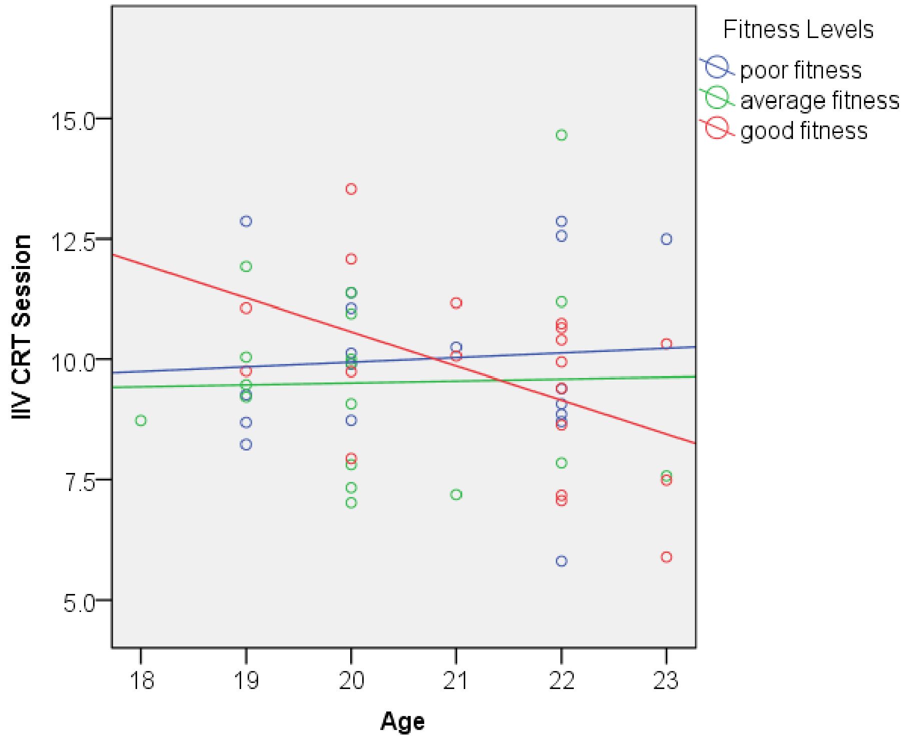

Figure 6. The significant interaction effect between age and MSRT-predicted VO_{2max} (as an indicator of physical fitness) in predicting IIV_{RT} for CRT Session performance (N = 55). Fitness level is classified as follows: 'poor fitness' = VO_{2max} range of 23-34; 'average fitness' = VO_{2max} range of 35-46; 'good fitness' = VO_{2max} range of 47-58.

Discussion

I set out to investigate the relationship between cardiovascular fitness (as measured by a self-report questionnaire and an aerobic task) and intra-individual variability in cognition (as measured by reaction time tasks) in healthy, young adults. Specifically, I tested the hypothesis that fitness is a significant predictor of IIV_{RT}, with increased levels of fitness being negatively associated with IIV_{RT} scores. Although only a small literature describes the relationship between cardiovascular fitness and cognitive performance as indexed by IIV, the studies that have been conducted indicate that cardiovascular fitness is positively associated with cognition (as reflected in lower IIV scores; e.g. Kimura et al., 2013; Wu et al., 2011). However, none of those studies were conducted using samples of healthy, young adults. The present study set out to fill that knowledge gap. Based on previous literature (both that focusing on associations between fitness and mean-based measures of cognitive performance, and that focusing on associations between fitness and IIV-based measures of cognitive performance), I predicted there would be a negative association between cardiovascular fitness and IIV in cognitive performance among university students.

Summary of Results

In the current sample (N = 55; 28 men, 27 women, age range 18-23 years), cardiovascular fitness was significantly negatively associated with cognitive performance as indexed by mean RT scores. In other words, the higher participants' fitness levels, the faster their average reaction time scores were. However, the relationship between fitness and cognitive performance as indexed by IIV_{RT} was not quite as straightforward. There was no significant main effect of fitness on IIV_{RT} scores, but analyses did detect a significant age x fitness interaction effect on IIV_{RT} in SRT Block 1 (p = .023), CRT Block 1 (p = <.001), and CRT Session (p = .017), as well as a significant interaction age x sex interaction effect on IIV_{RT} in SRT Block 1 (p = .049).

Fitness and Mean Cognitive Performance

Previously published research proposes a number of neural mechanisms that might underlie the relationship, as seen in the present study, between cardiovascular fitness and cognition. One popular theory posits that white matter integrity (WMI) is associated with both cognitive performance and cardiovascular fitness, mediating the relationship between the two (Gow et al., 2012; Wu et al., 2011). More generally, cardiovascular fitness has been shown to play a neuroprotective role, maintaining grey and white matter integrity (and, thereby, cognitive function; e.g., Benedict et al., 2013; Colcombe et al., 2003). In terms of specific brain regions and pathways, cardiovascular fitness is associated with less shrinkage of grey matter in the prefrontal, superior parietal, and middle/inferior temporal regions, and less shrinkage of the white matter tracts stretching between the posterior parietal lobes and the frontal lobes (Marks et al., 2007; Voss et al., 2013). One critical shortcoming of this literature, however, it is that it comprises almost entirely only neuroimaging studies of elderly adult samples.

Another strand of research shows that cardiovascular fitness increases neural plasticity, or more specifically the plasticity of the synapses. Plasticity refers to the neural ability to adapt to novel situations and environments, and to the consequences of CNS injury (Åberg et al., 2009). Cardiovascular fitness does not only affect the structure of synapses as well as potentiate their strength, but also strengthens systems such as neurogenesis, metabolism and vascular flow that support plasticity (Colcombe et al., 2004; Green & Bavelier, 2008). This plasticity hypothesis is supported by the few studies that have investigated the fitness-cognition association in young adults (Cotman, Berchtold, & Christie, 2007; Krell-Rösch, 2014).

Significant Interaction Effects

A major caveat in interpreting the significant interaction effects listed above is that the associated effect sizes are small (η_p^2 ranging from .077 to .239), and that therefore the effects do not account for much of the variance in IIV_{RT}. At worst, this could mean that the effects found are simply Type 1 errors, and therefore spurious. However, the fact that the same interaction effect (age x fitness) was a significant predictor of more than one IIV outcome permits at least some interpretation and speculation regarding possible implications.

Interaction of Age and Cardiovascular Fitness. An interpretation of this interaction is that younger participants with poor cardiovascular fitness (i.e., with MSRT-predicted VO_{2max} in the range of 23-34) have, on average, lower IIV_{RT} scores than older participants with the same level of fitness. The observed pattern was similar in participants with average cardiovascular fitness (i.e., with MSRT-predicted VO_{2max} in the range of 35-46), in that younger individuals had, on average, lower IIV_{RT} scores than older ones. In this latter group, however, the association line was flatter (indicating a relatively weaker relationship between age and cardiovascular fitness) than that of the poor-fitness group. In contrast, younger participants with good cardiovascular fitness (i.e., with MSRT-predicted VO_{2max} in the range of 47-58) had, on average, higher IIV_{RT} scores than older participants with the same level of fitness. This pattern of data suggests the possibility that cardiovascular fitness acts as neuroprotective factor as age increases.

This result generally replicates the data patterns described by many previously published studies, and allows interpretation consistent with that presented in previous studies (i.e., that cardiovascular fitness plays a neuroprotective role as one ages; see, e.g., Benedict et al., 2013; Colcombe et al., 2003). However, those previously published studies have, for the most part, used samples of older adults participating in studies aiming to show that cardiovascular fitness can prevent or delay age-related cognitive decline (see e.g., Dik et al., 2003; Kimura et al., 2013; Lautenschlager et al., 2008). Therefore, it is interesting that the present study describes similar interaction effects in a relatively small sample of such young adults, with a very small age range (18-23 years).

The present study consists of both adolescents (18 and 19 years) as well as young adults (20, 21 and 22 years). It has been well-documented that adolescence (defined as the period after puberty during which one develops from a child to an adult, i.e. 10-19 years of age; World Health Organization), is a 'critical period' for the maturation of the neural processes that underlie higher cognitive function (e.g., Lenroot & Giedd, 2006; Giedd, 2004; Yurgelun-Todd, 2007). Moreover though, some research has suggested that maturation of the frontal lobe continues to occur from adolescence to early adulthood, resulting in improved cognitive function over that transitional phase (e.g. Gogtay et al., 2004; Sowell, Thompson, Holmes, Jernigan, & Toga, 1999). So these findings would imply that, in the present study, slightly older participants would show better cognitive performance (lower IIV_{RT} scores). However, this is only seen in the fitter, slightly older participants. A possible reason for this interaction could be that the cardiovascular fitness of individuals influences their degree of neural plasticity as described earlier (Colcombe et al., 2004; Green & Bavelier, 2008). This cognitive plasticity (and hence improved cognitive function) may be what gives the fitter, slightly older participants the edge over the unfit slightly older participants, but it does not go far in explaining the increases in IIV_{RT} scores over time in the unfit participants.

Interaction of Age and Sex. These two sociodemographic variables interacted to significantly predict IIV_{RT} in SRT Block 1. An interpretation of the interaction is that younger women had, on average, lower IIV_{RT} scores than older women, whereas younger men had, on average, higher IIV_{RT} than older men.

Although previous studies have indicated that both age and sex influence IIV_{RT}, these studies usually feature participants spanning a fairly wide age range (Gorus et al., 2008; Jackson et al., 2012; Kimura et al., 2013). However, the age range in the present study is so limited that it is difficult to interpret these results. Moreover, the effect size for this interaction effect was very small (η_p^2 = .077), and it was only a significant predictor of one outcome, and so there is a reasonable chance this is a spurious finding.

Physical activity versus cardiovascular fitness

In the present study, scores on the self-report measure of physical activity (IPAQ-S; measured in MET mins) and cardiovascular fitness (MSTR-predicted VO_{2max}; measured in ml/kg/min) were positively, but non-significantly, correlated, r = .25, p = .066. This weak association is consistent with data presented in previously published studies suggesting that IPAQ-S scores do not correlate exceptionally strongly with scores of VO_{2max} (see, e.g., Fogelholm et al., 2006; Hagströmer et al., 2006).

Additionally, although in the present study cardiovascular fitness was a significant predictor of mean SRT performance, physical activity was not. There are several possible ways to account for this pattern of data. First, it is well-documented in the psychological literature that self-report is not always an accurate reflection of reality; moreover any people aspire to be active and therefore participants could fall prey to social-desirability biases, and not report on their activity truthfully (Chung & Monroe, 2003; Nederhof, 1985). Alternatively, if one assumes that all participants in the present study reported their levels of physical activity accurately, then perhaps the lack of correlation between cardiovascular fitness and physical activity is due to the varied amount of physical activity needed by different individuals to gain the same level of cardiovascular fitness; i.e. some highly active participants may be slightly less fit than participants who are fitter but less active (Astrand, 1992).

Limitations of the Current Study

I hypothesised that there would be a positive association between cardiovascular fitness and IIV_{RT}, but the analyses suggested that cardiovascular fitness on its own (and not in interaction with age or any other purported predictor variable) did not have a significant main effect on IIV_{RT}. This is not to say definitively that there is no association between cardiovascular fitness and IIV_{RT}, but rather that there may be some limitations to the present study.

Using IIV_{RT} as a measure of cognition in young, healthy participants. It is relatively well-established that IIV is sensitive to neurodegeneration and may serve as a potential predictor of cognitive decline – hence the higher IIV scores seen in participants with age-related neural decline or in those with other forms of neuropathology, compared to healthy controls (e.g., Cruise et al., 2011; Gorus et al., 2008; Kimura et al., 2013). IIV also increases with normal aging (Bielak, Cherbuin, Bunce, & Anstey, 2014). However, in young, healthy adults, such as those who participated in the present study, it is unlikely that high IIV_{RT} scores are reflective of underlying neural (and therefore cognitive) decline. Instead, I speculate that higher IIV_{RT} scores observed in some of the present participants might be a consequence of relatively slow responses that occur more frequently as the attention of these individuals lapses (Garrett et al., 2012).

This performance sequence is known, formally, as a time-on-task effect (Li, Huxhold, & Schmiedek, 2004). These time-on-task effects may be especially pertinent given the relative ease of some RT tasks (easier tasks are likely to be more boring for participants). I tried to control for time-on-task effects by ensuring my study included both SRT tasks (which as the name suggests, are very simple) and CRT tasks (which are relatively more difficult, and therefore potentially more engaging; Garrett et al., 2012). Nonetheless, the analyses suggested that participants' mean RT scores were significantly slower on Block 2 than Block 1, for both SRT and CRT tasks. This pattern of data might suggest that participants were engaged in the task at first, but that lapses of attention grew more frequent as they spent more time on the tasks (perhaps as a result of boredom), resulting in slower RTs in the latter blocks of testing.

To control for time-on-task effects, a strand of research advocates for IIV measures (e.g., the *n*-back test of working memory) that engage higher strategic processing (MacDonald et al., 2009). The engagement of such processes might make such tasks more engaging for participants. In turn, this higher level of engagement might make the tasks more sensitive to IIV in cognition in healthy individuals because they are not as vulnerable to performance distortion by attentional lapses (Li et al., 2004). However, while these tests of higher strategic processing may control for maladaptive variability (i.e. variability in cognitive performance owing to factors such as time-on-task effects), some researchers suggest that these tests may result in greater adaptive variability (i.e., variability in cognitive performance as a result of the varied cognitive tactics participants engage to meet the demands of higher strategic processing measures; Allaire & Marsiske, 2005).

Directions for Future Research

Data from the present study seem to suggest that, in fitter people, those who are slightly older will have, on average, lower IIV_{RT} scores than those who are younger, indicating the potential neuroprotective role that cardiovascular fitness plays over time. However, the age range of participants in this study (18-23 years) is quite restricted. Therefore, it would be of great interest for future researchers to conduct similar studies using participants spanning larger age ranges.

Additionally, the present study focused solely on the association of cardiovascular fitness, physical activity, and BMI with IIV in cognitive performance. The literature suggests that other lifestyle factors (e.g., sleep, stress, and alcohol use) may also influence IIV in cognitive performance (Demirci, 1996; Isaacs & Oates, 2008; Sandi, 2013). Therefore, in addition to increasing research focused on cardiovascular fitness and IIV in cognitive performance, future studies should investigate the interactive and separate effects of cardiovascular fitness and other lifestyle factors in influencing cognitive performance (Hillman, Erickson, & Kramer, 2008).

Lastly, perhaps RT was not the best measure for use in a cognitively healthy sample of young adults. These tasks are simple and perhaps not engaging enough for cognitively healthy participants. Future studies should include additional measures of cognition that tap higher strategic processing.

Summary and Conclusion

Few previously published studies examine the association between physical activity, or physical fitness, and cognitive performance in young, healthy adults (Krell-Rösch, 2014). Moreover, to my knowledge, no previously published study has used measures of IIV_{RT} in an investigation of the fitness-cognition relationship in young, healthy adults. Therefore, my study is the first to investigate the relationship between physical fitness (as measured by a self-report questionnaire and an aerobic task) and IIV in cognitive performance (as measured by reaction time tasks) in young, healthy adults.

The present results indicate that cardiovascular fitness is negatively associated with mean reaction-time performance in healthy university students. This finding supports the cardiovascular fitness hypothesis (i.e., the notion that higher fitness levels are associated with better cognitive performance; Åberg et al., 2009). Additionally, the present study suggests that cardiovascular fitness interacts with age to significantly predict IIV_{RT}, which may serve to strengthen the argument that fitness plays a neuroprotective role over time; however, the limited age range in this study make it difficult to draw definitive conclusions and inferences in this regard.

Physical inactivity is a major public health concern, both locally and globally (Hallal et al., 2012; Shisana et al., 2014). The findings presented here make a unique contribution to the literature emphasising the importance of cardiovascular fitness to intraindividual variability in cognitive performance. Moreover, the present results could be used to promote the benefits of physical fitness to sedentary individuals, and to inform policy changes around, for instance, physical activity programmes in schools and universities.

References

Åberg, M. A., Pedersen, N. L., Torén, K., Svartengren, M., Bäckstrand, B., Johnsson, T., ... & Kuhn, H. G. (2009). Cardiovascular fitness is associated with cognition in young adulthood. *Proceedings of the National Academy of Sciences*, *106*, 20906-20911. doi: 10.1073/pnas.0905307106

Allaire, J. C., & Marsiske, M. (2005). Intraindividual variability may not always indicate vulnerability in elders' cognitive performance. *Psychology and Aging*, *20*, 390.

Andel, R., Crowe, M., Pedersen, N. L., Fratiglioni, L., Johansson, B., & Gatz, M. (2008). Physical exercise at midlife and risk of dementia three decades later: A population-based study of Swedish twins. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 63,* 62-66. doi: 10.1093/gerona/63.1.62

Anstey, K. J., Dear, K., Christensen, H., & Jorm, A. F. (2005). Biomarkers, health, lifestyle, and demographic variables as correlates of reaction time performance in early, middle, and late adulthood. *The Quarterly Journal of Experimental Psychology Section A, 58*, 5-21. doi: 10.1080/02724980443000232

Astrand, P. O. (1992). Physical activity and fitness. *The American journal of clinical nutrition*, *55*, 1231-1236.

Basson, R., Mwaba, K., Rossouw, R., Geerts, G., Kotze, T., & Stuhlinger, M. (2010). The significance of sub-threshold symptoms of anxiety in the aetiology of bruxism. *South African Journal of Psychology, 40,* 174-181. doi: 10.1177/008124631004000207

Beck, A. T., Steer, R. A., & Brown, G. K. (1996). *Beck Depression Inventory manual (2nd ed.).* San Antonio, TX: Psychological Corporation. doi: 10.1037/t00742-000

Benedict, C., Brooks, S. J., Kullberg, J., Nordenskjöld, R., Burgos, J., Le Grevès, M., & Schiöth, H. B. (2013). Association between physical activity and brain health in older adults. *Neurobiology of Aging, 34,* 83-90. doi:10.1016/j.neurobiolaging.2012.04.013

Bielak, A. A. M., Hultsch, D. F., Strauss, E., Macdonald, S. W. S., & Hunter, M. A. (2010). Intraindividual variability in reaction time predicts cognitive outcomes 5 years later. *Neuropsychology* 24, 731–741. doi:10.1037/a0019802.

Bielak, A. M., Cherbuin, N., Bunce, D., & Anstey, K. J. (2014). Intraindividual variability is a fundamental phenomenon of aging: Evidence from an 8-year longitudinal study across young, middle, and older adulthood. *Developmental Psychology*, *50*, 143-151. doi:10.1037/a0032650

doi:10.1017/S1355617713000830

Christ, B. U., Thomas, K. G., Combrinck, M. I. (2017). Both reaction time and accuracy measures of intraindividual variability predict cognitive performance in Alzheimer's disease. Frontiers of Human Neuroscience, *1*, 1-25.

Chung, J., & Monroe, G. S. (2003). Exploring social desirability bias. *Journal of Business Ethics, 44*, 291-302. doi: 10.1023/a:1023648703356

Cipriani, G., Lucetti, C., Danti, S., & Nuti, A. (2015). Sleep disturbances and dementia. *Psychogeriatrics, 15*, 65-74. doi:10.1111/psyg.12069

Colcombe, S. J., Erickson, K. I., Raz, N., Webb, A. G., Cohen, N. J., McAuley, E., & Kramer, A. F. (2003). Aerobic fitness reduces brain tissue loss in aging humans. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences, 58*, 176-180. doi: 10.1093/Gerona/58.2.M176

Colcombe, S. J., Kramer, A. F., Erickson, K. I., Scalf, P., McAuley, E., Cohen, N. J., ... & Elavsky, S. (2004). Cardiovascular fitness, cortical plasticity, and aging. *Proceedings of the National academy of Sciences of the United States of America*, *101,* 3316-3321.

Cotman, C. W., Berchtold, N. C., & Christie, L. A. (2007). Exercise builds brain health: key roles of growth factor cascades and inflammation. *Trends in neurosciences, 30,* 464-472. doi: 10.1016/j.tins.2007.06.011

Cruise, K. E., Bucks, R. S., Loftus, A. M., Newton, R. U., Pegoraro, R., & Thomas, M. G. (2011). Exercise and Parkinson's: Benefits for cognition and quality of life. *Acta Neurologica Scandinavica*, *123*, 13-19. doi: 10.1111/j.1600-0404.2010.01338.x

Deary, I. J., Liewald, D., & Nissan, J. (2011). A free, easy-to-use, computer-based simple and four-choice reaction time programme: The Deary-Liewald reaction time task. *Behavior Research Methods*, *43*, 258-268. doi:10.3758/s13428-010-0024-1

Demirci, M. (1996). Channels of the corpus callosum: Evidence from simple reaction times to lateralized flashes in the normal and the split brain. *Brain: A Journal of Neurology*, *119,* 2155-2155. doi: 10.1093/brain/119.6.2155

Dik, M. G., Deeg, D. H., Visser, M., & Jonker, C. (2003). Early life physical activity and cognition at old age. *Journal Of Clinical And Experimental Neuropsychology*, *25*, 643-653. doi:10.1076/jcen.25.5.643.14583

Dozois, D. J. A., Dobson, K. S., & Ahnberg, J. L. (1998). A psychometric evaluation of the Beck Depression Inventory-II. *Psychological Assessment*, 10, 83-89.

Dykiert, D., Der, G., Starr, J. M., & Deary, I. J. (2012). Age differences in intra-individual variability in simple and choice reaction time: Systematic review and meta-analysis. *PLoS One*, *7*. doi: e45759

Erickson, K. I., & Kramer, A. F. (2009). Aerobic exercise effects on cognitive and neural plasticity in older adults. *British Journal of Sports Medicine*, *43*, 22-24. doi:10.1136/bjsm.2008.052498

Etnier, J. L., Nowell, P. M., Landers, D. M., & Sibley, B. A. (2006). A meta-regression to examine the relationship between aerobic fitness and cognitive performance. *Brain Research Reviews*, *52*, 119-130. doi: 10.1016/j.brainresrev.2006.01.002

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. Behavior Research Methods, 39, 175-191. doi:10.3758/BF03193146

Fogelholm, M. I., Malmberg, J. A., Suni, J., Santtila, M. A., Kyröläinen, H., Mäntysaari, M., & Oja, P. (2006). International physical activity questionnaire: Validity against fitness. *Medicine and Science in Sports and Exercise*, *38*, 753-760. doi: 10.1249/01.mss.0000194075.16960.20

Garrett, D. D., MacDonald, S. W. S., & Craik, F. I. M. (2012). Intraindividual reaction time variability is malleable: Feedback- and education-related reductions in variability with age. *Frontiers in Human Neuroscience 6*, 1–10. doi:10.3389/fnhum.2012.00101

Gogtay, N., Giedd, J. N., Lusk, L., Hayashi, K. M., Greenstein, D., Vaituzis, A. C., ... & Rapoport, J. L. (2004). Dynamic mapping of human cortical development during childhood through early adulthood. *Proceedings of the National academy of Sciences of the United States of America*, *101*, 8174-8179.

Goldberg, D. P., & Hillier, V. F. (1979). A scaled version of the General Health Questionnaire. *Psychological medicine*, *9*, 139-145. doi: doi.org/10.1017/s0033291700021644

Goldberg, D. P., Gater, R., Sartorius, N., Ustun, T. B., Piccinelli, M., Gureje, O., & Rutter, C. (1997). The validity of two versions of the GHQ in the WHO study of mental illness in general health care. *Psychological medicine*, *27*, 191-197. doi: 10.1017/s0033291796004242

Gorus, E., De Raedt, R., Lambert, M., Lemper, J. C., & Mets, T. (2008). Reaction times and performance variability in normal aging, mild cognitive impairment, and alzheimer's disease. *Journal of Geriatric Psychiatry and Neurology, 21*, 204–218. doi: 10.1177/0891988708320973

Gow, A. J., Bastin, M. E., Maniega, D. M., Hernández, M. V., Morris, Z., Murray, C., & Wardlaw, J. M. (2012). Neuroprotective lifestyles and the aging brain: Activity, atrophy, and white matter integrity. *Neurology*, *79*, 1802-1808. doi:10.1212/WNL.0b013e3182703fd2

Giedd, J. N. (2004). Structural magnetic resonance imaging of the adolescent brain. *Annals of the New York Academy of Sciences, 1021*, 77-85.

Green, C. S., & Bavelier, D. (2008). Exercising your brain: a review of human brain plasticity and training-induced learning. *Psychology and Aging*, *23*, 692. doi: 10.1037/a0014345

Hagströmer, M., Oja, P., & Sjöström, M. (2006). The International Physical Activity Questionnaire (IPAQ): a study of concurrent and construct validity. *Public health nutrition*, 9, 755-762. Doi: 10.1079/phn2005898

Hallal, P. C., Andersen, L. B., Bull, F. C., Guthold, R., Haskell, W., Ekelund, U. (2012). Global physical activity levels: Surveillance progress, pitfalls, and prospects. *The Lancet*, *380*, 247-257. doi: 10.1016/s0140-6736(12)60646-1

Henry, M., Wolf, P. S., Ross, I. L., & Thomas, K. G. (2015). Poor quality of life, depressed mood, and memory impairment may be mediated by sleep disruption in patients with Addison's disease. *Physiology & Behavior*, *151*, 379-385. doi: 10.1016/j.physbeh.2015.08.011

Hillman, C. H., Erickson, K. I., & Kramer, A. F. (2008). Be smart, exercise your heart: Exercise effects on brain and cognition. *Nature Reviews Neuroscience*, *9*, 58-65. doi: 10.1038/nrn2298

Hultsch, D. F., MacDonald, S. W., & Dixon, R. A. (2002). Variability in reaction time performance of younger and older adults. *The Journals of Gerontology Series B: Psychological Sciences and Social Sciences*, *57*, 101-115. doi: 10.1093/geronb/57.2.p101

Hultsch, D. F., Strauss, E., Hunter, M. A., & MacDonald, S. W. S. (2008). Intraindividual variability, cognition, and aging," in *The Handbook of Aging and Cognition*, eds. F. I. M. Craik and T. A. Salthouse, 491–556.

Isaacs, E., & Oates, J. (2008). Nutrition and cognition: assessing cognitive abilities in children and young people. *European Journal of Nutrition*, *47*, 4-24. doi: 10.1007/s00394-008-3002-y

Jackson, J. D., Balota, D. A., Duchek, J. M., & Head, D. (2012). White matter integrity and reaction time intraindividual variability in healthy aging and early-stage Alzheimer disease. *Neuropsychologia*, *50*, 357-366. doi:10.1016/j.neuropsychologia.2011.11.024

Kavcic, I., Milic, R., Jourkesh, M., Ostojic, S. M., & Ozkol, M. Z. (2012). Comparative study of measured and predicted VO2max during a multi-stage fitness test with junior soccer players. *Kinesiology*, *44*, 18-23.

Kim, H. Y. P., Frongillo, E. A., Han, S. S., Oh, S. Y., Kim, W. K., Jang, Y. A., ... & Oh, S. Y. (2003). Academic performance of Korean children is associated with dietary behaviours and physical status. *Asia Pacific Journal of Clinical Nutrition*, *12*, 186-192.

Kimura, K., Yasunaga, A., & Wang, L. (2013). Correlation between moderate daily physical activity and neurocognitive variability in healthy elderly people. *Archives of Gerontology and Geriatrics*, *56*, 109-117. doi:10.1016/j.archger.2012.10.004

Kramer, A. F., Hahn, S., Cohen, N. J., Banich, M. T., McAuley, E., Harrison, C. R., … & Colombe, A. (1999). Aging, fitness, and neurocognitive function. *Nature*, *400*, 418-419. doi: 10.1038/22682

Krell-Rösch, J. (2014). *Interdependence of Physical (In-) Activity, Fitness and Cognition: A Cross-Sectional Study in Young Adults* (Vol. 5). KIT Scientific Publishing.

Lachaud, C. M., & Renaud, O. (2011). A tutorial for analyzing human reaction times: How to filter data, manage missing values, and choose a statistical model. *Applied Psycholinguistics*, *32*, 389-416. doi: 10.1017/s0142716410000457

Lautenschlager, N. T., Cox, K. L., Flicker, L., Foster, J. K., van Bockxmeer, F. M., Xiao, J., ... & Almeida, O. P. (2008). Effect of physical activity on cognitive function in older adults at risk for Alzheimer disease: a randomized trial. *Jama*, *300*, 1027-1037. doi: 10.1001/jama.300.9.1027

Lambert, E. V., Bohlmann, I., & Kolbe-Alexander, T. (2001). Be active-physical activity for health in South Africa. *South African Journal of Clinical Nutrition*, *14*, 12-16.

Leger, L. A., & Lambert, J. (1982). A maximal multistage 20-m shuttle run test to predict VO2 max. *European journal of Applied Physiology and Occupational Physiology*, *49*, 1-12.

Lenroot, R. K., & Giedd, J. N. (2006). Brain development in children and adolescents: insights from anatomical magnetic resonance imaging. *Neuroscience & Biobehavioral Reviews*, *30*, 718-729.

Li, S. C., Huxhold, O., & Schmiedek, F. (2004). Aging and attenuated processing robustness. *Gerontology*, *50*, 28-34. doi: 10.1159/000074386

MacDonald, S. S., Karlsson, S., Rieckmann, A., Nyberg, L., & Bäckman, L. (2012). Aging-related increases in behavioral variability: Relations to losses of dopamine D_1 receptors. *The Journal of Neuroscience*, *32*, 8186-8191. doi:10.1523/JNEUROSCI.5474-11.2012

MacDonald, S. S., Li, S., & Bäckman, L. (2009). Neural underpinnings of within-person variability in cognitive functioning. *Psychology and Aging*, *24*, 792-808. doi:10.1037/a0017798

MacDonald, S. W. S., Nyberg, L., & Bäckman, L. (2006). Intra-individual variability in behavior: links to brain structure, neurotransmission and neuronal activity. *Trends in Neurosciences,* 29, 474–480. doi: 10.1016/j.tins.2006.06.011

Marks, B. L., Madden, D. J., Bucur, B., Provenzale, J. M., White, L. E., Cabeza, R., & Huettel, S. A. (2007). Role of aerobic fitness and aging on cerebral white matter integrity. *Annals of The New York Academy of Sciences*, *1097*, 171-174. doi:10.1196/annals.1379.022

Moch, S. L., Panz, V. R., Joffe, B. I., Havlik, I., & Moch, J. D. (2003). Longitudinal changes in pituitary-adrenal hormones in South African women with burnout. *Endocrine*, *21*, 267-272. doi: 10.1385/endo:21:3:267

Murphy, K. J., West, R., Armilio, M. L., Craik, F. I., & Stuss, D. T. (2007). Word-list-learning performance in younger and older adults: intra-individual performance variability and false memory. *Aging, Neuropsychology, and Cognition*, *14*, 70-94. doi: 10.1080/138255890969726

Nederhof, A. J. (1985). Methods of coping with social desirability bias: A review. *European journal of social psychology*, *15*, 263-280. doi: 10.1002/ejsp.2420150303

Pretorius, T. B., & Norman, A. M. (1992). Psychometric data on the statistics anxiety scale for a sample of South African students. *Educational and Psychological Measurement*, *52*, 933-937. doi: 10.1177/0013164492052004015

Ruscheweyh, R., Willemer, C., Krüger, K., Duning, T., Warnecke, T., Sommer, J., & Flöel, A. (2011). Physical activity and memory functions: An interventional study. *Neurobiology of Aging, 32*, 1304-1319. doi:10.1016/j.neurobiolaging.2009.08.001

Sandi, C. (2013). Stress and cognition. *Wiley Interdisciplinary Reviews: Cognitive Science*, *4*, 245-261. doi: 10.1002/wcs.1222

Shisana, O., Labadarios, D., Rehle, T., Simbayi, L., Zuma, K., Dhansay, A., ... & Hongoro, C. (2014). *The South African National Health and Nutrition Examination Survey, 2012: SANHANES-1: the health and nutritional status of the nation*. HSRC press.

Sibley, B. A., & Etnier, J. L. (2003). The relationship between physical activity and cognition in children: A meta-analysis. *Pediatric Exercise Science*, *15*, 243-256. doi: 10.1123/pes.15.3.243

Sowell, E. R., Thompson, P. M., Holmes, C. J., Jernigan, T. L., & Toga, A. W. (1999). In vivo evidence for post-adolescent brain maturation in frontal and striatal regions. *Nature neuroscience, 2*, 859-861.

Spielberger, C. D., Gorsuch, R. L., Lushene, R., Vagg, P. R., & Jacobs, G. A. (1983). *Manual for the State-Trait Anxiety Inventory*. Palo Alto, CA: Consulting Psychologists Press.

Spielberger, C. D., & Vagg, P. R. (1984). Psychometric properties of the STAI: A reply to Ramanaiah, Franzen, and Schill. *Journal of Personality Assessment, 48*, 95-97. doi: 10.1207/s15327752jpa4801_16

St Clair Gibson, A., Broomhead, S., Lambert, M. I., & Hawley, J. A. (1998). Prediction of maximal oxygen uptake from a 20-m shuttle run as measured directly in runners and squash players. *Journal of Sports Sciences*, *16*, 331-335. doi:10.1080/026404198808559361

Sterling, M. (2011). General health questionnaire–28 (GHQ-28). *Journal of physiotherapy, 5*, 259. doi: 10.1016/S1836-9553(11)70060-1

Sugarman, M. A., Woodard, J. L., Nielson, K. A., Smith, J. C., Seidenberg, M., Durgerian, S., & Rao, S. M. (2014). Performance variability during a multitrial list-learning task as a predictor of future cognitive decline in healthy elders. *Journal of Clinical and Experimental Neuropsychology*, *36*, 236-243. doi:10.1080/13803395.2013.877875

Tales, A., Leonards, U., Bompas, A., Snowden, R. J., Philips, M., Porter, G., & Bayer, A. (2012). Intra-individual reaction time variability in amnestic mild cognitive impairment: A precursor to dementia? *Journal of Alzheimer's Disease*, *32*, 457-466.

Tomporowski, P. D. (2003). Effects of acute bouts of exercise on cognition. *Acta Psychologica*, *112*, 297-324. doi: 10.1016/S0001-6918(02)00134-8

Voss, M. W., Heo, S., Prakash, R. S., Erickson, K. I., Alves, H., Chaddock, L., & Gothe, N. (2013). The influence of aerobic fitness on cerebral white matter integrity and cognitive function in older adults: Results of a one-year exercise intervention. *Human Brain Mapping*, *34*, 2972-2985. doi:10.1002/hbm.22119

Ward, C. L., Flisher, A. J., Zissis, C., Muller, M., & Lombard, C. (2003). Reliability of the beck depression inventory and the self-rating anxiety scale in a sample of South African adolescents. *Journal of Child and Adolescent Mental Health*, *15*, 73-75. doi: 10.2989/17280580309486550

Wetherbee, K., Kolbe-Alexander, T., Lambert, E. V., Hill, M., Harkins, J., & Noakes, T. D. (2001). The International Physical Activity Questionnaire and Yale Physical Activity

Survey in South African older adults. *Medicine & Science in Sports & Exercise*, *33*, S119. doi: 10.1097/00005768-200105001-00676

World Health Organization (1998). Obesity: Preventing and managing the global epidemic. Geneva, Switzerland: WHO.

Wu, C., Pontifex, M. B., Raine, L. B., Chaddock, L., Voss, M. W., Kramer, A. F., & Hillman, C. H. (2011). Aerobic fitness and response variability in preadolescent children performing a cognitive control task. *Neuropsychology*, *25*, 333-341. doi:10.1037/a0022167

Yurgelun-Todd, D. (2007). Emotional and cognitive changes during adolescence. *Current Opinion in Neurobiology*, *17*, 251-257. doi: doi.org/10.1016/j.conb.2007.03.009

Appendix A

Email advertisement

Participate in Psychology study and stand a chance to win Cavendish Vouchers

Hi Everyone,

I am an honours student running a study through the Department of Psychology. This project aims to investigate the relationship between fitness and intra-individual variability in cognitive performance.

To participate in this study, you need to:

1. Be between the ages of 18-25 years

2. Have no history of psychological, psychiatric or neurological illness (e.g. depression, ADHD, epilepsy etc.)

3. Must NOT be taking any psychoactive medication (e.g. anti-depressant, Ritalin etc.)

If you meet the above criteria, you can complete the short online screening measure, by following this link: https://www.surveymonkey.com/r/LGFF7QW

You will receive feedback as to whether you are eligible for the study within 3 days. If you are eligible, you will be contacted to sign up for the date and time that suits you.

If you decide to participate in this study, you will be asked to complete several paper-and-pencil questionnaires and cognitive tests. These questionnaires will gather information such as your demographics, anxiety levels and sleep quality. You will also be asked to complete some computerised cognitive tests. This should take approximately 45-60 minutes. This session will take place at the UCT ASCENT Lab in the Psychology Department.

Thereafter, you will be required to complete a fitness test at the UCT sports field. This should take about 30 minutes.

For participation in this study you will be entered into a raffle and will stand a chance to win a R250, R500 or R1000 Cavendish voucher.

If you have any further questions, please don’t hesitate to email me: katherinetred@gmail.com.

Thank you!

Kind Regards
Katherine Tredinnick
Psychology Honours Student

Appendix B
SRPP Recruitment Announcement

Announcement

Subject	Get your SRPP points for the semester from this study!
Organiser	Katherine Tredinnick

Hi Everyone,

I am an honours student running a study through the Department of Psychology. This project aims to investigate the relationship between fitness and intra-individual variability in cognitive performance.

To participate in this study, you need to:

1. Be between the ages of 18-25 years

2. Have no history of psychological, psychiatric or neurological illness (e.g. depression, ADHD, epilepsy etc.)

3. Must NOT be taking any psychoactive medication (e.g. anti-depressant, Ritalin etc.)

If you meet the above criteria, you can complete the short online screening measure, by following this link: https://www.surveymonkey.com/r/LGFF7QW

You will receive feedback as to whether you are eligible for the study within 3 days. If you are eligible, you can sign up on the 'sign-up' tab on this site (please take note of the time and date of the slot that you sign up for).

If you are not found to be eligible for the study, you will still be awarded **1 SRPP point** for having completed the online screening measures. Please do not sign up for the study.

If you decide to participate in this study, you will be asked to complete several paper-and-pencil questionnaires and cognitive tests. These questionnaires will gather information such as your demographics, anxiety levels and sleep quality. You will also be asked to complete some computerised cognitive tests. This should take about 45-60 minutes. This session will take place at the UCT ASCENT Lab in the Psychology Department.

Thereafter, you will be required to complete a fitness test at the UCT sports fields. This should take about 30 minutes.

For participation in this study you will receive **3 SRPP points**.

If you have any further questions, please don't hesitate to email me: katherinetred@gmail.com.

Thank you!

Kind Regards
Katherine Tredinnick
Psychology Honours Student

Appendix C

Health Index

1. Have you ever experienced a head injury (e.g., being hit on the head with an object and losing consciousness as a result)?

   YES NO

   If yes, please give details of the injury:

____

____

2. Have you ever been involved in a motor vehicle accident?

   YES NO

If yes, how old were you at the time?

____

If yes, how serious was it? (LOC?, PTA?, admitted to hospital, other injuries?)

____

____

3. Have you ever been referred to a Psychologist/Psychiatric service?

   YES NO

   If yes, please elaborate on the nature of the referral:

____

____

4. Are you diabetic (have high blood sugar)?

YES NO

If yes, what type of diabetes do you have? How long have you had it? Is it under control?

____

____

5. How often do you consume:
    a. Alcohol ________________________________
    b. Cigarettes _____________________________
    c. Other, please specify ___________________

6. Do you now, or have you ever, experienced any of the following medical conditions:
    a. Allergies

       YES NO

If yes, please specify:

    b. Asthma

       YES NO

    c. Tuberculosis

       YES NO

    d. Hypertension (high blood pressure)

       YES NO

    e. Epilepsy (i.e., seizures or fits)

       YES NO

    f. Neurological problems (i.e., Parkinson's, Huntington's, stroke, etc.)

       YES NO

If yes, please specify:

____

g. Depression

YES NO

h. Memory problems

YES NO

If yes, please specify:

____

i. Learning difficulties (dyslexia, ADD/ADHD)

YES NO

If yes, please specify:

____

j. Problems with your vision

YES NO

If yes, please specify:

____

k. Problems with your hearing

YES NO

If yes, please specify:

____

l. Do you have any family history of any of the above medical conditions?

YES NO

If yes, please specify:

____

m. Are you currently taking any prescription medication(s)?

YES NO

If yes, please specify:

____

Appendix D

General Health Questionnaire 28 (GHQ-28)

We would like to know if you have had any medical complaints, and how your health has been in general, *over the past four weeks.* Please answer ALL the questions on the following pages.

Have you recently:

1	Been feeling perfectly well and in good health?	Better than usual	Same as usual	Worse than usual	Much worse than usual
2	Been feeling in need of a good tonic? (vitamins, energiser, booster)	Not at all	No more than usual	Rather more than usual	Much more than usual
3	Been feeling run down and out of sorts?	Not at all	No more than usual	Rather more than usual	Much worse than usual
4	Felt that you were ill?	Not at all	No more than usual	Rather more than usual	Much worse than usual
5	Been getting any pains in your head?	Not at all	No more than usual	Rather more than usual	Much worse than usual
6	Been getting a feeling of tightness or pressure in your head?	Not at all	No more than usual	Rather more than usual	Much worse than usual
7	Been having hot or cold spells?	Not at all	No more than usual	Rather more than usual	Much worse than usual
8	Lost much sleep over worry?	Not at all	No more than usual	Rather more than usual	Much worse than usual
9	Had difficulty in staying asleep once you are off?	Not at all	No more than usual	Rather more than usual	Much worse than usual

10	Felt constantly under strain?	Not at all	No more than usual	Rather more than usual	Much worse than usual
11	Been getting edgy and bad-tempered?	Not at all	No more than usual	Rather more than usual	Much worse than usual
12	Been getting scared or panicky for no good reason?	Not at all	No more than usual	Rather more than usual	Much worse than usual
13	Found everything getting on top of you?	Not at all	No more than usual	Rather more than usual	Much worse than usual
14	Been feeling nervous and strung-up all the time?	Not at all	No more than usual	Rather more than usual	Much worse than usual
15	Been managing to keep yourself busy and occupied?	More so than usual	Same as usual	Rather less than usual	Much less than usual
16	Been taking longer over the things you do?	Quicker than usual	Same as usual	Longer than usual	Much longer than usual
17	Felt on the whole you were doing things well?	Better than usual	About the same	Less well than usual	Much less well than usual
18	Been satisfied with the way you've carried out your tasks?	More satisfied	About same as usual	Less satisfied than usual	Much less satisfied than usual
19	Felt that you were playing a useful part in things?	More so than usual	Same as usual	Less useful than usual	Much less useful than usual
20	Felt capable of making decisions about things?	More so than usual	Same as usual	Less so than usual	Much less capable than usual
21	Been able to enjoy your normal day-to-day activities?	More so than usual	Same as usual	Less so than usual	Much less than usual
22	Been thinking of yourself as a worthless person?	Not at all	No more than usual	Rather more than usual	Much more than usual
23	Felt that life is entirely hopeless?	Not at all	No more	Rather more than usual	Much more than usual

			than usual		
24	Felt that life isn't worth living?	Not at all	No more than usual	Rather more than usual	Much more than usual
25	Thought of the possibility that you might make away with yourself?	Definitely not	I don't think so	Has crossed my mind	Definitely have
26	Found at times you couldn't do anything because your nerves were too bad?	Not at all	No more than usual	Rather more than usual	Much more than usual
27	Found yourself wishing you were dead and away from it all?	Not at all	No more than usual	Rather more than usual	Much more than usual
28	Found that the idea of taking your own life kept coming into your mind?	Definitely not	I don't think so	Has crossed my mind	Definitely have

Appendix E
Beck Depression Inventory-II (BDI-II)

Instructions: This questionnaire consists of 21 groups of statements. Please read each group of statements carefully, and then pick out the one statement in each group that best **describes the way you have been feeling during the past two weeks**, including today. Circle the number beside the statement that you have picked. If several statements in the group seem to apply equally well, circle the highest number for that group. Be sure that you do not choose more than one statement for any group, including Item 16 (Changes in Sleep Pattern) and Item 18 (Changes in Appetite).

1. Sadness

0 I do not feel sad.

1 I feel sad much of the time.

2 I am sad all of the time.

3 I am so sad or unhappy that I can’t stand it.

2. Pessimism

0 I am not discouraged about my future.

1 I feel more discouraged about my future than I used to be.

2 I do not expect things to work out for me.

3 I feel my future is hopeless and will only get worse.

3. Past Failure

0 I do not feel like a failure

1 I have failed more than I should have.

2 As I look back, I see a lot of failures.

3 I feel I am a total failure as a person.

4. Loss of Pleasure

0 I get as much pleasure as I ever did from the things I enjoy.

1 I don't enjoy things as much as I used to.

2 I get very little pleasure from the things I used to enjoy.

3 I can't get any pleasure from the things I used to enjoy.

5. Guilty Feelings

0 I don't feel particularly guilty.

1 I feel guilty over many things I have done or should have done

2 I feel quite most of the time.

3 I feel guilty all of the time.

6. Punishment Feelings

0 I don't feel I am being punished.

1 I feel I may be punished.

2 I expect to be punished.

3 I feel I am being punished.

7. Self-Dislike

0 I feel the same about myself as ever.

1 I have lost confidence in myself.

2 I am disappointed in myself.

3 I dislike myself.

8. Self-Criticalness

0 I don't criticise or blame myself more than usual.

1 I am more critical of myself than I used to be.

2 I criticise myself for all my faults.

3 I blame myself for everything bad that happens.

9. Suicidal Thoughts or Wishes

0 I don't have any thoughts of killing myself.

1 I have thoughts of killing myself, but I would not carry them out.

2 I would like to kill myself.

3 I would kill myself if I had the chance

10. Crying

0 I don't cry anymore than I used to.

1 I cry more than I used to.

2 I cry over every little thing.

3 I feel like crying, but I can't.

11. Agitation

0 I am no more restless or wound up than usual.

1 I feel more restless or wound up than usual.

2 I am so restless or agitated that it's hard to stay still.

3 I am so restless or agitated that I have to keep moving or doing something.

12. Loss of Interest

0 I have not lost interest in other people or activities.

1 I am less interested in other people or things than before.

2 I have lost most of my interest in other people or things.

3 It's hard to get interested in anything.

13. Indecisiveness

0 I make decisions as well as ever.

1 I find it more difficult to make decisions than usual.

2 I have much greater difficulty in making decisions than I used to.

3 I have trouble making any decisions.

14. Worthlessness

0 I do not feel I am worthless.

1 I don’t consider myself as worthwhile and useful as I used to be.

2 I feel more worthless as compared to other people.

3 I feel utterly worthless.

15. Loss of Energy

0 I have as much energy as ever.

1 I have less energy than I used to have.

2 I don’t have enough energy to do very much.

3 I don’t have enough energy to do anything.

16. Changes in Sleep Pattern

0 I have not experienced any change in my sleeping pattern.

1a I sleep somewhat more than usual.

1b I sleep somewhat less than usual.

2a I sleep a lot more than usual.

2b I sleep a lot less than usual.

3a I sleep most of the day.

3b I wake up 1-2 hours early and can’t get back to sleep.

17. Irritability

0 I am no more irritable than usual.

1 I am more irritable than usual.

2 I am much more irritable than usual.

3 I am irritable all the time.

18. Changes in Appetite

0 I have not experienced any changes in my appetite

1a My appetite is somewhat less than usual.

1b My appetite is somewhat more than usual.

2a My appetite is much less than usual.

2b My appetite is much more than usual.

3a I have no appetite at all.

3b I crave food all the time.

19. Concentration Difficulty

0 I can concentrate as well as ever.

1 I can’t concentrate as well as usual.

2 It’s hard to keep my mind on anything for very long.

3 I find I can’t concentrate on anything.

20. Tiredness or Fatigue

0 I am no more tired or fatigued than usual.

1 I get more tired or fatigued more easily than usual.

2 I am too tired or fatigued to do a lot of the things I used to do.

3 I am too tired or fatigued to do most things I used to do.

21. Loss of Interest in Sex

0 I have not noticed any recent change in my interest in sex.

1 I am less interested in sex than I used to be.

2 I am much less interested in sex now.

3 I have lost interest in sex completely.

Appendix F

STAI-Trait Anxiety Inventory

A number of statements which people have used to describe themselves are given below. Read each statement and then select the appropriate number to the right of the statement to indicate how you *generally* feel. There are no right or wrong answers. Do not spend too much time on any one statement but give the answer which seems to describe how you generally feel.

	Almost never	Sometimes	Often	Almost always
1. I feel pleasant	1	2	3	4
2. I feel nervous and restless	1	2	3	4
3. I feel satisfied with myself	1	2	3	4
4. I wish I could be as happy as others seem to be	1	2	3	4
5. I feel like a failure	1	2	3	4
6. I feel rested	1	2	3	4
7. I am "calm, cool, and collected"	1	2	3	4
8. I feel that difficulties are piling up so that I cannot overcome them	1	2	3	4
9. I worry too much over something that really doesn't matter	1	2	3	4
10. I am happy	1	2	3	4
11. I have disturbing thoughts	1	2	3	4
12. I lack self-confidence	1	2	3	4
13. I feel secure	1	2	3	4
14. I make decisions easily	1	2	3	4
15. I feel inadequate	1	2	3	4
16. I am content	1	2	3	4
17. Some unimportant thought runs through my mind and bothers me	1	2	3	4
18. I take disappointments so keenly that I can't put them out of my mind	1	2	3	4
19. I am a steady person	1	2	3	4
20. I get in a state of tension or turmoil as I think over my recent concerns and interests	1	2	3	4

Appendix G
Sociodemographic Questionnaire

QUESTIONNAIRE AND ASSET INDEX

GENERAL INFORMATION

Full name:	
Student number:	
Telephone:	Home: Cell:
Home Language:	
Sex:	
Age:	

HOUSEHOLD INCOME: (Please circle appropriate number)

Household income per year:	1. R0 2. R1 – R5 000 3. R5001 – R25 000 4. R25 000 – R100 000 5. R100 001+

PARENTAL EDUCATION: (Please circle appropriate number; if you do not have a guardian, you do not need to circle anything under that column.)

	Biological mother	Biological father	Guardian
Highest level of education reached? Mark one response for each person as follows:			
1. 0 years (No Grades) = No formal education (never went to school)	1.	1.	1.
2. 1-6 years (Grades 1-6) = Less than primary education (didn’t complete primary school)	2.	2.	2.
3. 7 years (Grade 7) = Primary education (completed primary school)	3.	3.	3.
	4.	4.	4.

4. 8-11 years (Grades 8-11) = Some secondary education (didn't complete high school)	5.	5.	5.
5. 12 years (Grade 12) = Secondary education (completed senior school)	6.	6.	6.
6. 13+ years = Tertiary education (completed university / technikon / college)	7.	7.	7.
7. Don't know			

PARENTAL EMPLOYMENT: (Please circle appropriate number; if you do not have a guardian, you do not need to circle anything under that column.)

	Biological mother	Biological father	Guardian
1. Higher executives, major professionals, owners of large businesses)	1.	1.	1.
2. Business managers of medium sized businesses, trained professions (e.g. nurses, opticians, pharmacists, social workers, teachers)	2.	2.	2.
3. Administrative personnel, managers, minor professionals, owners / proprietors of small businesses (e.g. bakery, car dealership, engraving business, plumbing business, florist, decorator, actor, reporter, travel agent)	3.	3.	3.
4. Clerical and sales, technicians, small businesses (e.g. bank teller, bookkeeper, clerk, draftsperson, timekeeper, secretary)	4.	4.	4.
5. Skilled manual – usually having had training (e.g. baker, barber, chef, electrician, fireman, machinist, mechanic, painter, welder, police, plumber, electrician)	5.	5.	5.
6. Semi-skilled (e.g. hospital aide, painter, bartender, bus driver, cook, garage guard, checker, waiter, machine operator)	6.	6.	6.
7. Unskilled (e.g. attendant, janitor, construction helper, unspecified labour, porter, unemployed)	7.	7.	7.
8. Homemaker	8.	8.	8.
9. Student, no occupation	9.	9.	9.

MATERIAL AND FINANCIAL RESOURCES (ASSET INDEX): (Please circle appropriate number)

Which of the following items, in working order, does your household have?

Items	Yes	No
1. A refrigerator or freezer	1.	1.
2. A vacuum cleaner	2.	2.
3. A television	3.	3.
4. A hi-fi or music player (radio excluded)	4.	4.
5. A microwave oven	5.	5.
6. A washing machine	6.	6.
7. A video cassette recorder or DVD player	7.	7.

Which of the following do you have in your home?

Items	Yes	No
1. Running water	1.	1.
2. At least one car	2.	2.
3. A flushing toilet	3.	3.
4. A built-in kitchen sink	4.	4.
5. An electric stove or hotplate	5.	5.
6. A working telephone	6.	6.

Appendix H

International Physical Activity Questionnaire (IPAQ)

We are interested in finding out about the kinds of physical activities that people do as part of their everyday lives. The questions will ask you about the time you spent being physically active in the **last 7 days**. Please answer each question even if you do not consider yourself to be an active person. Please think about the activities you do at work, as part of your house and yard work, to get from place to place, and in your spare time for recreation, exercise or sport.

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week**

   ☐ No vigorous physical activities → ***Skip to question 3***

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**

   _____ **minutes per day**

   ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

_____ **days per week**

☐ No moderate physical activities → ***Skip to question 5***

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

_____ **days per week**

☐

No walking → ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **week day**?

_____ **hours per day**

_____ **minutes per day**

☐ Don't know/Not sure

Appendix I

Ethical Approval

University of Cape Town

Department of Psychology

UNIVERSITY OF CAPE TOWN

Department of Psychology

University of Cape Town Rondebosch 7701 South Africa
Telephone (021) 650 3417
Fax No. (021) 650 4104

25 August 2017

Katherine Tredinnick
Department of Psychology
University of Cape Town
Rondebosch 7701

Dear Katherine

I am pleased to inform you that ethical clearance has been given by an Ethics Review Committee of the Faculty of Humanities for your study, *The Relationship between Fitness and Intra-Individual Variability in Cognitive Performance in UCT Students*. The reference number is PSY2017-037.

I wish you all the best for your study.

Yours sincerely

Lauren Wild (PhD)
Associate Professor
Chair: Ethics Review Committee

Appendix J

Consent Form

University of Cape Town

Department of Psychology

Research Project: Intra-individual Variability, Cognition, and Fitness

Purpose

I am a UCT Psychology Honours student. My research investigates fitness and intra-individual variability (IIV) in cognitive performance. (IIV is a way to measure how differently people perform on cognitive tests if those tests are given on several different occasions.)

Procedure

If you decide to participate in this study, you will be asked to complete several paper-and-pencil questionnaires and cognitive tests. These questionnaires will gather information about your background, education, anxiety levels, and sleep quality. You will also be asked to complete some computerised cognitive tests. This should take approximately 40 minutes, and will take place at the ACSENT Lab in the UCT Psychology Department. After that test session, you will be asked to complete a fitness test at the UCT Sports Centre. This should take about 20 minutes. The test requires you to run between lines that are 20 metres apart and stop in time to a recorded beep from a CD. You will start at a speed of 8.5 km/h, with the speed increasing slightly as time progresses. You stop when you can no longer keep up with the pre-recorded beeps and your maximum speed is recorded.

Possible Risks

There are no risks of physical, psychological, or psychosocial harm associated with participation in this study. You may, however, feel out of breath and tired after the exercise, and you might experience slight physical discomfort from exerting yourself.

Possible Benefits

Psychology undergraduate students will be awarded 3 SRPP points for participating in the study. Other UCT students will be entered into a prize-giving draw. First prize is a R1000 Cavendish gift voucher; second prize is a R500 voucher; the third prize is a R250 voucher.

Voluntary Participation

Your participation in this study is completely voluntary. You may refuse to answer any question without having to give a reason. Your decision to participate in this study (or not) will not affect your grades or academic career. If you decide to participate, you are free to change your mind and stop at any time without any negative consequences.

Confidentiality

All information obtained about you for this study will be kept strictly confidential. It will be kept, along with this consent form, in locked file cabinets. There will be no link between your consent form and your data from the questionnaires and cognitive tests. The results of the cognitive and fitness tests will not be available to your university, any current or future employers, or anyone else. Any reports or publications of this study will not identify you.

Questions

If you have any questions or problems, please feel free to contact me or one of my supervisors:

Katherine Tredinnick	katherinetred@gmail.com
Dr Kevin Thomas (Supervisor)	kevin.thomas@uct.ac.za
Bjorn Christ (Supervisor)	chrbjo001@myuct.ac.za

If you have questions about your rights as a study participant, or any comments or complaints about the study, please contact Rosalind Adams at the UCT Department of Psychology, 021 650 3417, rosalind.adams@uct.ac.za.

I have read the above and am satisfied with my understanding of the study and its possible benefits and risks. My questions about the study have been answered. I hereby voluntarily consent to participation in the research study as described.

____

Name of Participant

________________________ ____________________________________

Signature of Participant Date

Appendix K

Debriefing Form

University of Cape Town

Department of Psychology

Research Project: The Relationship between Fitness and Intra-Individual Variability in Cognitive Performance in UCT Students

Debriefing Form

Thank you for participating in this research study.

This form gives you more information about the study in which you have just participated. It also explains the methods of collection of data for this research study.

1. **Title of Research Study**

The Relationship between Fitness and Intra-Individual Variability in Cognitive Performance in UCT Students

2. **Principal Investigators, Ethics Committee, and Contact Details**

Katherine Tredinnick
Department of Psychology
University of Cape Town
katherinetred@gmail.com

Dr Kevin Thomas
Department of Psychology
University of Cape Town
kevin.thomas@uct.ac.za

Björn Christ
Department of Psychology
University of Cape Town
chrbjo001@myuct.ac.za

3. **What is the purpose of this research study?**

The purpose of this research study is to better understand the relationship between fitness and the differences in individual performance on reaction time tests.

4. **What was done during this research study?**

During this study, you were required to complete several questionnaires, enquiring about your general health, sleep, physical activity, and mood. You were also required to complete several computer-based cognitive tests. Your fitness was assessed using the Multi-Stage Run Test, more commonly known as the beep test.

5. Was there any deception used in this research study?

No.

6. Is there anything further required of you?

Please do not disclose information about the research sessions to anyone else, as this may bias future participants and their performance. If you feel at all stressed at the end of the research study, you can contact UCT-SADAG Student Careline (**0800 24 25 26** free from a Telkom line or send an SMS to **31393** for a call-me-back), Student Wellness Services (021 650 1017/1020), or Lifeline Western Cape (021 461 1111).