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Investigating the effect of low and high intensity exercise on cognitive function with the use of a correlational design.

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ABSTRACT

Engagement in exercise has been found to be one of the biggest predictors of cognitive health (Elwood et al, 2013). This study intends to build on this by investigating the relationship between exercise intensity and cognitive function in sixty healthy participants aged 18-75. The present study used a cross sectional design to assess the association between high and low intensity exercise and performance on memory and executive function tasks. This was investigated at the same time point to assess the relationship in current cognitive health. Multiple regression analyses revealed that high intensity exercise can uniquely and significantly predict cognitive performance in each of the two domains. Furthermore it suggests that high intensity exercise is positively associated with current cognitive health and suggests that participation in high intensity exercise produces an all-encompassing benefit on cognition. However there was no association discovered between low intensity exercise and cognitive function. Analysis indicated that low intensity exercise cannot significantly predict cognitive performance when assessed at the same time point. Therefore future research must investigate this relationship using objective measurement of intensity over a longer period of time. To conclude, the current findings have implications for the future study of pathological and non-pathological aging.

KEY WORDS:	HIGH INTENSITY	LOW INTENSITY	COGNITIVE FUNCTION	MEMORY	EXECUTIVE FUNCTION

Introduction

The growing aging population and increasing prevalence of neurodegenerative disorders have sparked an interest in cognitive wellbeing and age related cognitive decline (Hillman et al, 2016). A number of physical, intellectual and social factors have been identified which are believed to promote cognitive performance and minimise cognitive decline (Richards et al, 2003). These include physical activity (Kramer et al, 1999; Kramer & Erickson, 2007), educational attainment (Bennett et al, 2003), social networks and relationships (Fratiglioni et al, 2000; Umberson & Montez, 2010) and health behaviours (Barnes & Yaffe, 2011; Crowe et al, 2003). However it is difficult to isolate these components from each other (Richards et al, 2003).

Developing strategies to improve neurocognitive function have incredibly important public health implications. Cognitive deficits are associated with an increased risk of cognitive impairment and neurodegenerative disorders such as Alzheimer’s disease (Smith et al, 2010). Pathological aging brings considerable individual and societal costs (Monin & Schulz, 2009) therefore, understanding the biological pathways to neural development is extremely important. Thus strategies can be created to minimise cognitive decline (Richards et al, 2003) and slow the onset of cognitive impairment with advancing age (Ballard et al, 2011; Currell et al, 2014).

One approach, which has gained increased attention, is the use of physical exercise to enhance cognitive function (Colcombe & Kramer, 2003; Hillman et al, 2006; Smith et al, 2010). In a review of the psychological aspects of exercise a high correlation was found to exist between exercise, memory and intellectual capabilities (Anthony, 1991). If it is true that physical activity can positively influence cognition then this would infer that a more physically active lifestyle may lower the risk of poor cognition and delay the onset of neurodegenerative disorders (Young et al, 2015). The cognitive benefits of physical exercise have been well documented (Christensen & Mackinnon, 1993; Lindwall et al, 2008; Newson & Kemps, 2005) however before discussing these findings it is important to first consider the neurobiological mechanisms responsible for the positive effects of exercise on cognition.

The cognitive reserve hypothesis emanated from inadequate correlations between brain pathology and clinical symptoms (Léon et al, 2014). It suggests that there are individual differences in susceptibility to age related brain changes (Stern, 2002), which lie within the neural networks underlying task performance. Therefore some individuals can tolerate brain changes more than others (Stern, 2009).

Reserve is typically classified into passive and active models. Active models such as cognitive reserve suggests that the brain actively tries to cope with brain damage and focuses on cognitive processes that allow individuals to maintain cognitive function (Stern, 2002). Brain reserve however is a passive model where reserve derives from bran size or synaptic count and suggests that there are individual differences in brain reserve capacity (Stern, 2009). Research proposes that aspects of life experience including exercise may result in more efficient cognitive networks and in turn increase cognitive reserve (Scarmeas & Stern, 2003).

Physical exercise provides protection against cognitive decline by acting as a physiological stimulus to initiate protective brain mechanisms (Cotman & Engesser-Cesar, 2002). Exercise induces a cascade of cellular and molecular processes, which are important for supporting brain plasticity and function (Coelho et al, 2013), therefore enhancing the brain's ability to adapt to environmental change (Knaepen et al, 2010). Additionally, exercise also increases the synthesis and release of the brain-derived neurotrophic factor (BDNF), which has a broad range of neurotrophic and neuroprotective properties (Knaepen et al, 2010). BDNF enhances the efficiency of synapses (McAuley et al, 2004) by supporting the survival, differentiation and growth of neurons (Coelho et al, 2013). This promotes neuroplasticity through enhanced learning and memory (McAuley et al, 2004).

Physical exercise significantly increases BDNF levels in humans and animals (Dinoff et al, 2016, Huang et al, 2014, Cotman & Engesser-Cesar, 2002), particularly in acute exercise programmes. After only 30 minutes of acute exercise, BDNF concentrations had increased in panic disorder patients (Ströhle et al, 2010) and plasma BDNF concentrations had shown an increase of 69% in healthy participants (Knaepen et al, 2010). Additionally, endurance training has effectively enhanced BDNF release in humans and animals (Seifert et al, 2009). The resting release of BDNF in the human brain was enhanced after 3 months of endurance training alongside an increase in BDNF mRNA expression in the hippocampus of 8 mice.

Furthermore when examining the effects of exercise intensity on BDNF and memory, high intensity exercise significantly enhanced memory performance and BDNF concentration after 12 weeks of training. Collectively these findings suggests that those who are more physically active may possess higher BDNF levels so are more likely to maintain cognitive health in age and are at a lower risk of developing neurodegenerative disease.

However these studies only demonstrate a temporary increase therefore long term effects of exercise on BDNF levels need to be investigated. Furthermore when examining exercise and BDNF, there is no consensus about the sufficient blood processing conditions to standardise assessment (Pareja-Galeano et al, 2015). Consequently researchers do not distinguish between the different blood conditions however Pareja-Galeano et al (2015) has recently highlighted the importance of blood sample selection in research due to the huge variability in BDNF concentration. Moreover in the study of BDNF up-regulation, exercise has only increased levels in whole blood and serum coagulated for 24 hours (Pareja-Galeano et al, 2015). Plasma samples showed no significant results, which therefore questions the reliability of previous research and demonstrates the importance of blood processing conditions when evaluating the effects of exercise on BDNF concentrations.

A recent large-scale study (Elwood et al, 2013) discovered that engagement in exercise was found to be one of the biggest predictors of cognitive health.
These findings base the question of whether this is relevant to all forms of exercise and all measures of cognitive function. Mounting evidence indicates that engagement in physical exercise is associated with enhanced cognitive function and this association particularly occurs in measures of executive function and memory (Zhu et al, 2015; Dregan & Gulliford, 2013). Support for this idea has primarily been gained through cross sectional and intervention research in elderly populations.

A vast amount of cross sectional research has suggested that an active lifestyle promotes successful cognitive aging (Newson & Kemps, 2005). Earlier research initially discovered that inactivity was associated with poor performance in fluid intelligence measures (Christensen et al, 1996). However this association was only significant in the older rather than younger elderly participants (Christensen & Mackinnon, 1993). More recent research however has shown that long term regular exercise was strongly associated with enhanced cognitive performance in a larger sample of adults aged 30-55 (Weuve et al, 2004).

This relationship has been found significant in measures of executive function (Hillman et al, 2006) and memory (Richards et al, 2003), suggesting that exercise may be beneficial to both general and selective aspects of cognition. Similarly meta-analytic research on intervention studies has found significant associations between aerobic exercise training and improvements in attention, memory and executive function (Smith et al, 2010; Colcombe & Kramer, 2003). These findings suggest a direct link between exercise and cognition and highlight its role as a significant brain protective factor against cognitive decline (Sofi et al, 2011).

There appears to be a general consensus among researchers that physical exercise is associated with enhanced cognitive performance and reduced rate of cognitive decline. Thus it has been questioned whether this is dependent on the intensity of the exercise. Angevaren et al (2007) assessed the association between the duration and intensity of exercise and cognitive function in a population of 1927 healthy participants. Exercise intensity and cognitive function were positively correlated, with significant improvements exhibited in processing speed, memory and mental flexibility.

Kramer et al (1999) first shaped the field of research on low intensity exercise and cognitive function in an intervention study assessing 124 previously sedentary adults aged 60-75. Participants were randomly assigned to an aerobic (walking) or anaerobic (stretching) exercise condition for a period of 6 months. Walking was significantly associated with multiple aspects of cognition, in particular executive function. Significantly larger relationships have been found for tasks assessing executive function, suggesting that executive control processes are more sensitive to low intensity exercise than other cognitive domains.

Furthermore when this relationship has been assessed in older women, those who were more physically active at baseline were less likely to show cognitive decline in the follow up (Yaffe et al, 2001). Similarly (Tierney et al, 2010) also confirmed this relationship when examining life-long physical activity and later life cognition. A significant positive association was discovered between moderate activity and cognitive performance, indicating that low intensity exercise may provide long-term protection against cognitive decline. Strenuous activity however, significantly reduced cognitive performance; suggesting participation in high intensity exercise reduces cognitive health in old age.

Whilst the positive influence of low intensity exercise on cognitive function is evident (Lindwall et al, 2008), the effect of low intensity exercise is often smaller than that observed in high intensity exercise. There substantial evidence of a lifelong association between physical exercise and cognitive function in middle aged (Barnes et al, 2003; Dregan & Gulliford, 2013) and elderly populations (Kerr et al, 2013). Although this is evident in all levels of intensity, there is strong indication of a dose response relationship. In a cross sectional study, participation in high intensity exercise resulted in greater cognitive ability and reduced risk of cognitive decline (Zhu et al, 2015). Furthermore, when physical exercise has been measured objectively, higher intensity levels are associated with a 36% lower risk of cognitive impairment and greater maintenance of memory and executive function (Zhu et al, 2016).

Taken together, the research discussed presents compelling evidence for the beneficial effects of exercise on cognitive health. However are inconsistencies in findings (Stroth et al, 2009; Young et al, 2015) and there is huge variation in the magnitude of improvement in cognitive function associated with physical exercise (Cox et al, 2016; Chen & Rigenbach, 2016). Whilst initial associations between exercise and cognition have been found, effect sizes are entirely dependent on experimental rigor (Etnier et al, 1997) and coefficients have been considerably reduced, below significance levels, when confounding factors have been controlled for (Sturman et al, 2005).

Additionally, the validity of conclusions drawn from cross sectional and correlational research has been questioned. Etnier et al (1997) stated that exercise might not truly be the cause of differences in cognitive function in relation to physical activity. Instead pre-exercise cognitive differences are associated with those who adopt a lifelong participation in exercise. Furthermore the lack of consensus regarding how to retrospectively measure exercise intensity could significantly affect estimations on the lifelong impact of exercise on cognitive performance (Miller et al, 2012).

However, dose response relationships between physical activity and cognitive function have still been established in studies that have objectively measured exercise intensity (Kerr et al, 2013; Marinac et al, 2015). Higher levels of accelerometer-measured exercise are associated with greater maintenance of memory and executive function and lower risk of cognitive impairment (Zhu et al, 2016). This suggests that retrospective assessment can still be effective in measuring physical activity.

This study aims to examine the association between exercise intensity and cognitive function in a diverse sample. Engagement in exercise has recently been determined as one of the biggest predictors of cognitive health (Elwood et al, 2013) and this study intends to build upon this by investigating whether the intensity of the exercise influences cognitive performance in healthy participants of a wider age range. To date, the majority of previous research has focused on older populations (Christensen et al, 1996; Newson & Kemps, 2005) and there is little known about the association between exercise and cognitive function across the life span. Several studies investigating exercise and cognitive function practice longitudinal methods, requiring a base-line measure of fitness (Barnes et al, 2003; Yaffe et al, 2001) and assessment of cognitive function at a later date.

Furthermore, engagement in exercise is also often self-reported (Tierney et al, 2010) however studies are often limited by the lack of consensus regarding how to retrospectively measure exercise intensity (Miller et al, 2012). This study however, is a real world examination of what is currently occurring in the participant's everyday life and will assess cognitive function and levels of physical activity at the same time point. This is expected to reduce the chance of inaccuracies related to self-report measures. A composite score will be produced from the results on four cognitive tasks sampling two of the cognitive domains and the individual influence of low and high intensity exercise on executive function and memory will be assessed. This research intends to act as a foundation for future research into healthy aging and risk factors for cognitive impairment and Alzheimer's disease. The research hypotheses are as follows:

H1: Both low and high intensity exercise will have an influence on cognitive function.

H2: High intensity exercise will have a significantly greater impact on cognitive function.

Methods

Design

This is a cross sectional study assessing exercise engagement and cognitive function in a group of people recruited from researcher contacts. A correlational design was used to assess the relationship between exercise intensity and performance on a set of four cognitive tasks across two cognitive domains: memory and executive function. Executive function was comprised of a digit span test, verbal fluency and digit symbol substitution whilst memory was assessed using verbal recall. Low intensity exercise focused specifically on walking and was measured in miles whereas high intensity exercise was measured in hours. This design was chosen because previous research has typically assessed exercise habits using questionnaires (Hillman et al, 2006) and verbal fluency and memory are commonly used when measuring cognitive function (Dregan & Gulliford, 2013).

Participants

A total of 60 participants, aged between 18-75 took part in this research. The sample consisted of 35 females and 25 males, who were all healthy and had no known cognitive impairment. Healthy participants were required as this study focused on the impact of exercise on cognitive function in healthy adults to act as a foundation for future research into cognitive decline and risk factors for Alzheimer's disease. A fairly large, diverse sample was needed which consisted of a range of participants of various ages, genders and backgrounds so this could be representative of a natural sample of the population.

Measures

The questionnaire

The self constructed questionnaire (APPX 8), which consisted of 10 questions, was administered to determine the amount of exercise the participants had done in their past week. The first 5 questions investigated the predictor variable 'low intensity exercise' and required participants to state, in miles, how much they had walked in their past week. This included questions such as 'Have you walked to work/university? If yes, approximately how far?' and 'Have you gone on leisurely walks? If yes, approximately how far?'. The remaining 5 questions investigated the predictor variable 'high intensity exercise' and required participants to note, in hours, how much high intensity exercise they had done in the past week. This included questions such as 'Have you participated in any group/individual running? If yes, how long for?' and 'Have you gone to the gym? If yes, how long for?'. These scores were then totalled to create overall scores for low and high intensity exercise.

The cognitive tests

The criterion variable (cognitive function) was measured using 4 cognitive tests, which assess memory and executive function. Memory was assessed using the verbal recall task (APPX 9; APPX 10) and the measures of executive function were verbal fluency (APPX 11), digit span (APPX 13) and digit symbol substitution (APPX 12). Each of these will be described below.

To assess verbal recall participants were provided with a list of 20 neutral words (APPX 9) derived from the MRC psycholinguistic database **(**Coltheart, 1981). These were chosen, as memory for emotional words is often better than memory for neutral words (Talmi & Moscovitch, 2004; Doersken & Shimamura, 2001). Participants were given 3.5 minutes to learn the words and then given the same period of time for immediate recall. Participants are asked to recall the words again after a delayed amount of time (after completing the other 3 cognitive tests). The total verbal recall scores were created from the total amount of words correctly recalled in both the immediate and delayed recall tasks.

`Verbal fluency was assessed semantically and phonemically (APPX 11). Participants were required to say as many words as possible from a category in 60 seconds. The semantic category first required participants to name animals and fruits, followed by the phonemic category which required words beginning with the letters P, S and A. A total verbal fluency score was created from the total number of correct answers in each verbal fluency task.

The digit symbol substitution test (Wechsler, 1958) (APPX 12) was administered as a pen and paper task. The provided digit-symbol code shows the pairings of 9 digits and 9 symbols. Participants were then required to draw the corresponding symbols to the series of digits in the columns below. Participants had 90 seconds to draw as many as they could. The number of correct symbols drawn was totalled to create an overall digit symbol substitution score.

The digit span test (Wechsler, 1997) (APPX 13) required the participant to listen to a series of numbers read out by the researcher and repeat them back in the same order. The researcher speaks in a monotone voice and numbers are spoken one second apart. The first series was 3 numbers '2-6-5', followed by a series of 4 numbers '1-5-2-3' and the series increased by 1 number until it reached a series of 9 numbers. With every correct recall, the researcher continued onto the next series of numbers until the answer was incorrect. This was carried out twice with different numbers and the highest series of numbers correctly recalled were recorded. This was carried out again however participants were then asked to recall the numbers backwards. The first series was 2 numbers '2-1', followed by a series of 3 '5-8-4' and the series increased by 1 until it reached a series of 8 numbers. Again, the researcher continued onto the next series of numbers until the answer was incorrect and carried this out twice. The total scores were the highest number series reached in both the digit span forwards and backwards test.

Permission has been sought through email for the use of any materials and questionnaires that have been generated by someone else. This includes the materials needed for the digit symbol substitution, digit span test and neutral word list for the verbal recall task.

Procedure

Before conducting the study the researcher received training by a supervisor in order to ensure all cognitive tests were carried out accurately and effectively.

Prospective participants had been provided with the invitation letter (APPX 4) detailing what the study would involve. Those who were willing to participate proceeded to contact the researcher and were provided with the participant information sheet (APPX 5), which contained further details regarding the study. Before participating participants signed a consent form (APPX 6) confirming that they understood what the study entailed and were happy to participate. The questionnaire was first administered and required participants to answer 10 questions about their levels of physical activity in the past week. The age and gender of the participant was also recorded. The age was recorded so this could be controlled for when later analysing results.

The four cognitive tests were next carried out*. It is important that verbal recall is the first cognitive test carried out to ensure there is a considerable duration of time between immediate and delayed recall. Upon completion of the study participants were provided with the debrief sheet (APPX 7) containing the aims of the study and anonymous code generator which they are required to fill in and use if they wish to withdraw from the study or request research summaries.
(*Full details of the cognitive tasks can be found in the measures section)

Analysis

All data was analysed using SPSS (Version 24) and only correct scores were included when the data was being prepared for analysis. Three multiple regression analyses were employed to assess the extent to which low and high intensity exercise (predictor variables) predicted cognitive function (criterion variable). This allowed for assessment of the overall contribution and predictive power of exercise to cognitive performance and the examination of the individual contributions of low and high intensity exercise on memory, executive function and total cognitive function. The multiple regression analyses were computed using the composite scores of these measures. The composite memory score consisted of total immediate recall and total delayed recall scores. The composite executive function score consisted of total verbal fluency score, total digit span and total digit symbol substitution. Finally total cognitive function was derived from the totals of both of these scores.

Ethical considerations

The present study adhered to the guidelines stated by the British Psychological Society and was granted ethical approval by the Manchester Metropolitan University. Therefore this research followed the correct procedures with regard to consent, deception, debriefing and confidentiality.

This study did not involve vulnerable participants as all they were all over the age of 18 and were of sound mind and ability to give consent to participate. A gatekeeper was required due to the potential relationship between the participants and researcher. Participants were provided with the correct information prior to the study, signed a consent form confirming they were aware of the aims and the right to withdraw and were provided with a debrief upon completion. This explained how their data would be used for analysis and given the opportunity to create a unique code to ensure anonymity. All data was stored in compliance with the Data Protection Act (1998).

Results

Demographics & Cognitive scores

Descriptive statistics were created for the participants in the study. Table 1 summarises the demographics of the participants and their cognitive scores. They were a mean age of 36 and the mean total cognitive function score was 161.18.

Table 1
Demographics & Cognitive scores

	Mean (n=60)	Standard deviation (n=60)
Age	36.00	15.51
Memory	19.23	7.43
Executive function	141.95	24.12
Total cognitive function	161.18	28.85

Correlational analysis

A partial correlation was first carried out to measure the strength and direction of the relationship between exercise intensity and cognitive function. Correlations were tested between high and low intensity exercise, memory, executive function and total cognitive function (see methods section for calculation). Age was also entered as a control variable in each of these correlations. The results of the correlation can be seen in table 2.

Table 2
Correlational analysis

Control variables			Low intensity exercise	High intensity exercise	Memory	Executive function	Total cognitive function
Age	Low intensity exercise	Correlation	1.00	.23	.00	.02	.02
	High intensity exercise	Correlation	.23	1.00	.45*	.42*	.47*

*Correlations are significant at p < .001

The following scatter plots demonstrate the relationships between exercise intensity and measures of cognitive function.

The results from the correlations show that the relationships between high intensity exercise and measures of cognitive function were all significant at a range of (*r* = 0.42 – 0.47, *n* = 60, *p* < .05, one-tailed)

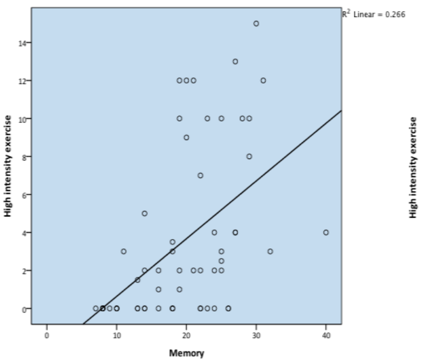

Figure 1.1: Graph showing the correlation between high intensity exercise and memory

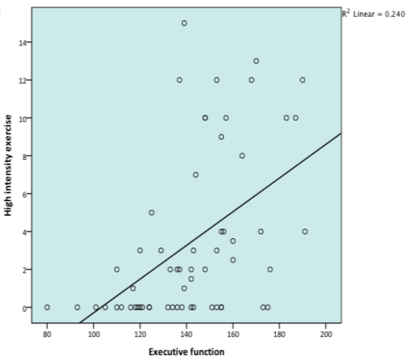

Figure 1.2: Graph showing the correlation between high intensity exercise and executive function

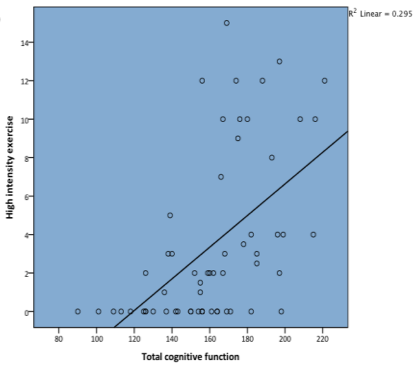

Figure 1.3: Graph showing the correlation between high intensity exercise and total cognitive function

Multiple regression analysis

Three multiple regression analyses were conducted using the enter method to investigate the extent to which exercise intensity can predict measures of cognitive function including memory and executive function. The results from the multiple regression analyses can be seen in the tables below.

Table 3
Regression coefficients for each predictor variable in predicting memory performance

Variable	B	SE B (Std. Error)	β (Beta score)	*Sig. (p)*
Constant	19.08	2.62		
Age	-.06	.06	-.12	.33
Low intensity exercise	-.07	.08	-.10	.39
High intensity exercise	.82	.21	.49	.00**

Note: R^2 = .29

* P < .001

A regression analysis was first performed to test the extent to which exercise intensity was predictive of memory performance. Using the 'enter' method, a significant model emerged (f (3,56) = 7.73, p < .001). The relationship between the variables was strong (R^2=0.29) which suggests that the model could explain approximately 26% (adjusted R^2 = 25.5%) of variance in memory performance. Out of the variables only high intensity exercise significantly predicted memory performance (t(56) = 3.85, p < .001: 95% CI .40 – 1.25).

Table 4
Regression coefficients for each predictor variable in predicting executive function performance

Variable	B	SE B (Std. Error)	β (beta score)	*Sig. (p)*
Constant	142.63	8.67		
Age	-.22	.20	-.14	.27

Low intensity exercise	-.16	.25	-.08	.53
High intensity exercise	2.47	.71	.45	.00**

Note R^2 = .27

*P < .001

Next a regression analysis was carried out to test the extent to which exercise intensity was predictive of executive function performance. Using the 'enter' method a significant model emerged (f (3,56) = 6.75, p < .001). The relationship between the variables was strong (R^2 = 0.27) which suggests the model could explain approximately 23% (adjusted R^2 = 22.6%) of variance in executive function performance. Only high intensity exercise was found to be predictive of executive function performance (t(56) = 3.49, p = .001: 95% CI 1.05 – 3.88).

Table 5
Regression coefficients for each predictor variable in predicting total cognitive function

Variable	B	SE B (Std. Error)	β (beta score)	*Sig. (p)*
Constant	161.71	9.94		
Age	-.28	.23	-.15	.23
Low intensity exercise	-.023	.29	-.09	.44
High intensity exercise	3.29	.81	.50	.00*

Note: R^2 = .29

*P < .001

Finally a regression analysis was then carried out to test the extent to which exercise intensity was predictive of total cognitive function. Using the 'enter' method a significant model emerged (f (3,56) = 8.99, p < .001). The relationship between the variables was strong (R^2=0.33) which suggests the model could explain for approximately 29% (adjusted R^2 = 28.9%) of variance in cognitive function performance. Only high intensity was found to be predictive of total cognitive function performance (t(56) = 4.06, p < .001: 95% CI 1.67 – 4.91).

Discussion

The purpose of this study was to investigate the relationship between physical exercise and cognitive function. The primary aim was to determine whether exercise intensity influences cognitive performance on four tasks sampling each of the cognitive domains (such as memory and executive function). It was expected that both high and low intensity exercise would be positively correlated with cognitive performance however high intensity exercise would have a significantly greater impact on cognitive function. These hypotheses were successfully explored and a partial correlational analysis revealed that only high intensity exercise was positively correlated and there was no significant relationship between low intensity exercise and cognitive function. Furthermore multiple regression analyses demonstrated that high intensity exercise could positively influence cognitive performance, despite any influence of low intensity exercise. The current findings suggest that high intensity exercise can significantly and uniquely predict cognitive performance in each of the cognitive domains.

Low intensity exercise and its relation to cognitive function

The analysis of the present study discovered that there was no significant association between low intensity exercise and cognitive function. This was consistent across both measures (memory and executive function), suggesting that low intensity exercise has no direct influence on enhancing cognitive performance. Therefore this is inconsistent with the research expectations and conclusions drawn from previous research.

Low intensity exercise has frequently been discovered to be significantly and positively associated with enhanced memory (Richards et al, 2003), executive function, and long-term protection against decline (Tierney et al, 2010). Walking in particular has had a positive influence on multiple aspects of cognition and reduced risk of cognitive decline in elderly samples (Kramer et al, 1999; Yaffe et al, 2001).

Therefore one would expect that these findings could extend to a wider age range and that exercise could also be related to current cognitive health. Although this was not the case, the current study is not unique in finding insignificant results. Research in this field is also mixed and several studies have only found small positive effects, which are dependent on experimental rigour (Etnier et al, 1997). The current study coincides with previous research by Young et al (2015) who also found no evidence of cognitive benefits in relation to the levels of physical activity in healthy adults.

Contrary to expectations, the current study suggests there is no association between low intensity exercise and cognitive function in both young and old populations. The present findings revealed that low intensity exercise did not significantly predict cognitive performance when assessed at the same point in time. This indicates that it is not associated with current cognitive health and therefore may not be protective against cognitive decline. However before concluding that the proposed relationship does not exist, the range and breadth of research that consistently reveal the cognitive benefits of low intensity exercise must be considered. The vast amount of supportive literature indicates that the reason for the inconsistencies with previous findings may lie within potential limitations of the current methodology, rather than a non-existent relationship. These will be described further below.

High intensity exercise and its relation to cognitive function

The analysis of the current research also discovered a significant association between high intensity exercise and cognitive function, which was consistent across both memory and executive function performance. The relationship remained significant even when age was accounted for, suggesting that high intensity exercise uniquely predicts cognitive performance. These outcomes are therefore consistent with the research expectations and are in line with previous findings.

The findings of the present study are in accordance with a number of previous cross sectional studies. A dose response relationship between high intensity exercise and cognitive function has consistently been established in elderly populations (Zhu et al, 2016). The current results also lend support to Zhu and colleagues (2015) in that higher levels of intensive exercise were associated with enhanced performance in both memory and executive function. Furthermore the present findings support the notion of a lifelong association between high intensity exercise and cognition (Dregan & Gulliford, 2013) and its role in long-term protection against cognitive decline.

The current study also lends itself to research concerning the cognitive reserve hypothesis. This hypotheses focuses on cognitive processes that allow individuals to maintain cognitive function and suggests that there are individual differences in susceptibility to age related brain changes (Stern, 2002). Therefore it proposes that participation in exercise, along with other aspects of life experience, may result in more efficient cognitive networks, which in turn increase cognitive reserve and benefit cognitive function. Although the current research cannot confirm this, and further study is needed to establish the exact processes involved, the significant influence of high intensity exercise exhibited on cognitive performance in the current participants, does suggest that exercise is an important factor in increasing cognitive network efficiency and cognitive reserve.

Taken together, these findings suggest a significant positive association between high intensity exercise and cognitive function in both young and old participants. This supports the work of previous studies in this field and clarifies the importance of exercise intensity when enhancing cognitive performance. Given that significant results were only obtained for the high intensity condition, this suggests that the relationship only exists when a certain level of intensity is reached. Additionally this study has extended previous findings by providing evidence of this relationship in a young and old sample. This is a finding that has not always been consistent (Hillman et al, 2006).

In conclusion the current findings have revealed that high intensity exercise can uniquely and significantly predict cognitive performance when assessed at the same point in time, indicating that intensive exercise is positively associated with current cognitive health. Therefore this research suggests that participation in high intensity exercise produces an all-encompassing benefit on cognition and may be protective against age related cognitive decline.

Limitations

Whilst the results of this study are in agreement with a number of previous studies, they are also open to several limitations. A limitation of this research was the use of a self-report method to measure exercise. Therefore there was no objective measure of exercise intensity and reporting bias may have occurred due to accidental overestimation or underestimation of activity levels. This could explain the lack of significant effect observed for low intensity exercise as it was observed that participants found greater difficulty in reporting their exercise levels in miles (low intensity exercise) than in hours (high intensity exercise).

In addition to accidental inaccuracies, social desirability bias may occur as physical exercise is considered a socially desirable behaviour so is often over reported (Brenner & DeLamater, 2014). Consequently the validity of the conclusions may be threatened as the bias may mask the natural relationship between the variables (Podsakoff et al, 2003). Future research could overcome this limitation by objectively measuring activity using an accelerometer. This has only been previously studied in elderly participants (Zhu et al, 2016) and should be used in a wider population.

Another limitation of the study is the attribution of causality. Whilst this research suggests that high intensity exercise promotes cognitive health, it is possible that individuals with higher cognitive ability are more likely to engage in physical exercise.

Evidence of a bidirectional relationship between executive function and physical activity has been discovered (Daly et al, 2015). Interestingly, the magnitude of the relationship was strongest in the direction from executive function to physical activity. This suggests that the relationship between high intensity exercise and executive function found in this study may not be in the direction assumed.

Additionally, this research did not control for other factors, which may moderate or account for the relationship between physical exercise and cognitive function. It has been reported that mental health (Vance et al, 2016), social relationships (Umberson & Montez, 2010), intellectual ability, and socioeconomic status contribute to the maintenance of cognitive function (Gold et al, 1995). Moreover, regular participation in intellectually engaging activities provides protection against cognitive decline (Hultsch et al, 1999). When cognitive stimulation has been controlled for in previous research, the effect of exercise on cognitive function has been found non-significant (Sturman et al, 2005).

Furthermore, the relationship between exercise and cognitive performance may have been influenced by educational and occupational attainment. Higher educational attainment levels have been linked to enhanced performance on neuropsychological tests (Fritsch et al, 2002) and occupational attainment is often a significant predictor of memory, information processing speed and executive function (Ghaffer et al, 2012). Therefore due the evidence of this existing association with cognitive function, these factors should have been accounted for in the present study.

Further research

With regards to studying this topic further, it would be useful to also consider the potential moderating factors, as mentioned above. Assessing exercise intensity, along with intellectual, social and physical factors, will guide theory on the interaction between exercise, individual differences and cognition. Knowledge of this interaction would be extremely beneficial for the formulation of public health recommendations with regards to the maintenance of cognitive health in older age.

The longitudinal assessment of exercise intensity and cognitive function would allow for researchers to explore whether the current cognitive health benefits exhibited in the present study, could extend into a lifelong protection against cognitive decline. Furthermore, to overcome the limitations of self-report and social desirability bias, an accelerometer should be used to objectively measure participation in low and high intensity exercise throughout the life span. An interesting area for future study could be to investigate whether the outcomes observed in longitudinal research, correlates with both enhanced cognitive health and a dose-response relationship with BDNF levels. This would not only enhance knowledge on the lifelong benefits of exercise, but the underlying brain mechanisms responsible for this protective quality and the relationships between them.

Conclusion

The purpose of this study was to examine the relationship between physical exercise and cognitive function in a healthy sample of young to old participants. Specifically, the effects of low and high intensity exercise were studied on performance in memory and executive function. This research discovered that only high intensity exercise significantly and uniquely predicts cognitive performance in each of the cognitive domains. Given the present findings of this relationship, this has many public health implications. Evidence of the relationship between high intensity exercise and cognitive function proposes that government health policies should advocate the importance of regular participation in high intensity exercise to encourage cognitive health in society. However government health policy decisions rely on accurate information (Brenner et al, 2014) therefore future research should investigate exercise intensity using objective measurement of activity levels.

In summary, these findings suggest that participation in high intensity exercise enhances cognitive function and is positively associated with current cognitive health. This indicates that intensive exercise has an all-encompassing cognitive benefit and highlights its promising protective factor against cognitive decline. However low intensity exercise was not significant in enhancing cognitive performance, suggesting that this relationship needs to be studied in further detail using objective measures of intensity. To conclude, this research consequently has implications for the future study of pathological and non-pathological aging and the associated risk factors.

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