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Physical activity and sedentary behavior associated with learning outcomes and cognition in adult distance learners

Preliminary article for the research school ICO (ICO National Fall School)

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Abstract

Physical activity and sedentary behavior appear to be related to learning outcomes in children and to cognition across the whole lifespan. Research in adults, concerning physical activity and sedentary behavior and their relationship with learning outcomes, is not apparent. Therefore, we investigated if and how they are related in adults participating in distance education. The study was executed among Open University (NL) students in a cross-sectional survey-research. Opposed to our hypothesis physical activity was a negative predictor for learning outcomes. Possibly, time spent on physical activity in this specific group of students could detract from the time they spent on learning, as it is likely that their spare time is limited. Also, opposed to our hypothesis, sedentary behavior was positively associated with learning outcomes. As spare time is likely to be scarce it could be that time spent learning adds to the time spent sitting, as it is highly likely that most students will study sitting. Thus, possibly resulting in sedentary behavior being a positive predictor for learning outcomes. As expected, physical activity and sedentary behavior appeared to be each independent and separate constructs as they both added uniquely to the regression model. These results ask for more elaboration on the exact effects of physical activity and sedentary behavior on learning in adults.

Keywords: learning outcomes, physical activity, sedentary behavior, cognition, executive functions

Introduction

Physical activity has a positive effect on academic achievement in children (Fedewa & Ahn, 2011). In addition, physical activity has positive effects on cognitive performance, as has been shown in children as well as in adults (Barenberg, Berse, & Dutke, 2011). Physical activity and its relation with cognition is evaluated in older adults mostly (Kramer, Erickson, & Colcombe, 2006), while research in younger adults is lacking (Gligoroska et al., 2012). Better cognitive performance could lead to better learning outcomes (Hillman, Kamijo, & Scudder, 2011). However, there is no research that concerns the relation between physical activity and learning outcomes in an adult population. Goal of this study is to evaluate (1) the relation of physical activity and sedentary behavior with learning outcomes; (2) the relation of physical activity and sedentary behavior with cognition; and (3) whether cognition mediates the relation with learning outcomes. This preliminary article focuses on the first hypothesis only.

Different mechanisms could be responsible for the advantages of physical activity on learning (for detailed overview see: Barenberg et al., 2011). Physical activity increases cerebral blood flow, which heightens the blood supply, possibly enhancing learning (Timinkul et al., 2008). Also, the release and production of neurotransmitters and neurotrophins is a result of physical activity (Winter et al., 2007). This release in turn leads to elevated levels of neurogenesis, synaptic plasticity, spine density, angiogenesis and vascular growth factors (van Praag, 2009). These neurophysiological changes often are caused by epigenetic changes following physical activity, which lead to a higher transcription and as a result a higher release of these growth factors, neurotransmitters, and neurotropic factors. The ultimate result is an increase in brain plasticity (Kaliman et al., 2011), a benefit for learning.

Burkhalter and Hillman (2011) state in their review that there is no clear consensus yet on the relation between physical activity and academic achievement in children. Research indicates either a positive relationship between physical activity and academic achievement or no relationship. Despite this fact, physical activity still can be regarded beneficial as time spent on it does not impair academic achievement (Spitzer & Hollmann, 2013) and improves health and physical function (Keeley & Fox, 2009). To this point, research suggests possible benefits of physical activity on academic achievement but this cannot firmly be concluded (see: Shephard, 1996; Taras, 2005; Tomporowski, Davis, Miller, & Naglieri, 2008). A more recent, and more comprehensive meta-analysis, executed over 59 studies of which 39 with an experimental design, revealed a significant and positive effect of physical activity on academic achievement and cognition in children (Fedewa & Ahn, 2011). Summarizing, despite the lack of a clear consensus we feel it is safe to state that physical activity has a beneficial effect on academic performance in children, as also suggested by other researchers (see recent reviews of Hillman et al., 2011; Singh, Uijtdewilligen, Twisk, Mechelen, & Chinapaw, 2012).

Next to summarizing the effects of physical activity on academic achievement in children we will also evaluate the effects of physical activity on cognitive performance in adults. We believe cognitive functions are a prerequisite for learning. A meta-analytic review examining 134 interventional and cross-sectional studies showed that physical activity has a positive effect on cognitive performance, across all ages (Etnier et al., 1997). A meta-analytic study from 1966-2001, solely containing interventional studies performed amongst healthy but sedentary adults (55-80 years old), extended the findings of Etnier and colleagues (1997). It revealed that the positive effect on cognitive performance is global because it is visible along different cognitive processes. However, the effect is also specific as it is most predominant in the executive domain (Colcombe & Kramer, 2003). These authors were not the first to discover this preferential benefit for executive functions following aerobic exercise, as this hypothesis was already postulated in a review by Hall, Smith, and Keele (2001). Opposed to these conclusions, Newson and Kemps (2006) showed that cardiorespiratory fitness, a fitness measure which is enhanced by aerobic exercise, is stronger associated with simple cognitive functions than with more complex cognitive functions. The simple cognitive functions are lower-order processing functions such as speed and working memory, the more complex cognitive functions on the other hand are higher-order functions such as executive functions. These findings were found in adults of 18-92 years old in a cross-sectional study. A reason for this difference in results could be that this study only evaluated the association between physical activity and a measure of fitness, while Colcombe and Kramer (2003) evaluated effects of exercise on cognitive functioning. Another reason, suggested by Newson and Kemps (2006), for the results found could be that variance in executive functions could be explained in part by contextual factors (e.g. knowledge or experience). Also, the results of Newson and Kemps (2006) are based on one cross-sectional study, while the findings from Colcombe and Kramer (2003) are based on 18 interventional studies. Still, these findings ask for more research elaborating on the association between physical activity and cognition in adults. A review of Kramer and colleagues (2006) evaluated the effects of exercise on cognition by evaluating cross-sectional and interventional studies. The authors focused on physical activity and later cognitive functioning and the literature reviewed suggests a causal relationship. However, some studies failed to find this relationship. The authors suggest a number of reasons why these inconsistent results are apparent. These will be discussed below.

Opposite to physical activity, there is sedentary behavior. Sedentary behavior can be seen as part of physical activity. However, recently, sedentary behavior is more and more viewed as a separate construct largely independent of physical activity. In children, more sedentary behavior is negatively associated with academic achievement, independent of physical activity (Tremblay et al., 2011). Two different sedentary behaviors were associated with executive functioning in a large cross-sectional study of middle-aged adults. TV viewing was negatively associated with executive functioning. Computer use however, was positively associated with verbal memory and executive function, when compared to non-users. In addition, longitudinal results over six years showed that an increase in computer use was associated with better verbal memory and executive functioning compared with people who decreased there computer use (Kesse-Guyot et al., 2012). These results indicate that sedentary behavior can be an important predictor for learning outcomes and cognition.

As stated earlier, there are inconsistent findings apparent in the relationships between physical activity and learning outcomes or cognition. We will discuss reasons for these inconsistencies here. First, executive functions seem to benefit most from physical activity, as compared to other cognitive functions (e.g. Colcombe & Kramer, 2003; Masley, Roetzheim, & Gualtieri, 2009). However, despite these findings, there is no consensus on this preferential benefit for executive functions as research also demonstrates opposite findings (Newson & Kemps, 2006). This means that lower- and higher-order cognitive functions should be investigated to evaluate which cognitive functions benefit most from physical activity. Second, objective measures of physical activity provide more reliable results. Physical activity questionnaires have limited reliability and validity (Shephard, 2003). Especially important is that self-report data assesses duration, intensity, and frequency of the activities (Kramer et al., 2006). This is also suggested by researchers focusing on the development of better physical activity questionnaires (Wendel-Vos, Schuit, Saris, & Kromhout, 2003). Last, the relation between physical activity, and academic performance in children (Shephard, 1996), and cognition in adults (Colcombe & Kramer, 2003), seems to be stronger for women than for men.

The present study evaluated the association between physical activity and sedentary behavior on the one hand and learning outcomes and cognition on the other hand in adults participating in distance education. To our knowledge there is no research that concerns the relationship between physical activity and learning outcomes in an adult aging population. This is especially important because the level of physical activity decreases with increasing age. The decrease in the level of physical activity is most apparent when young adults move from secondary education to university level (Gligoroska et al., 2012). In addition, younger adults are rarely the subject of investigation within physical activity research in relation to cognition, as stressed by multiple researchers (e.g. Gligoroska et al., 2012; Hillman, Erickson, & Kramer, 2008). The population investigated in this article mainly consists of this age group. Also, because of increasing longevity (United Nations, 2012), there is an ongoing demand for people to develop their professional knowledge and experience far into adult age (Eurydice, 2011). Therefore, it is of interest to know how physical activity and sedentary behavior are associated with learning outcomes in adults. We hypothesize that (1) physical activity in general is positively associated with learning outcomes and cognition; (2) sedentary behavior is negatively associated with learning outcomes and cognition; (3) cognition is a mediator in the relation of physical activity and sedentary behavior with learning outcomes; (4) interaction effects are expected for age, sex and aerobic activity, as compared to anaerobic activity. For this preliminary article we will focus on the first two hypotheses without the inclusion of cognition.

Methods

Design

The current study had an observational cross-sectional design. Data were retrieved from the Adult Learning Open University Determinants study (ALOUD). In ALOUD different factors that could determine learning outcomes in adult distance learners were investigated. Other measures collected but not included in this article were measures of sleep, nutrition, and psychological factors. An online digital survey was used to measure physical activity, sedentary behavior and covariates. Cognition was measured with an objective online digital neuropsychological test battery. After six months, learning outcomes were measured using data from the exam registration office.

Participants

During 1 year (Sep. 2012 – Aug. 2013), all new students of the Open University (NL) that individually bought one or more regular bachelor or master courses were invited to participate. At the Open University (NL) students can register and start throughout the year as the education is modular, open to everyone (with an age of at least 18 years old), and the curriculum is not fixed. The approached population size was 4945. 31.87 % of the sample (N=1576) fully participated. A bigger proportion finished only the survey, but did not concluded the cognitive tests (N=2005). One criterion for assuring a baseline measurement was participation within 8 weeks (t=8) after receiving the first invitation. Later entries were not included in the analyses (N=66). Not all participants could be included in the current analyses as learning outcomes were the dependent measure. The learning outcomes were calculated over a six months period. So only participants who studied for six months already were included in the current manuscript (N=1111). Other exclusion criteria were: learning restrictions (N=150); outliers within physical activity (N=63) or sedentary behavior (N=56; listwise N=236)). The definite sample on which the preliminary analyses were performed consisted of 875 people.

Procedures

Participants were invited (t=0) automatically via e-mail systems of the university 14-21 days after successful registration. The 7 days range is because a bulk mailing was sent weekly. Students received a reminder two weeks (t=2) after the initial invitation and one week later a last reminder (t=3) by e-mail. Four weeks after the initial invitation, a phone call was made (t=4) in which potential participants were asked whether they were still interested in participating. If so, they received the original invitation once more when needed, and a reminder 6,5 weeks after the initial invitation (t=6,5). Participants only received reminders or a telephone call if no full response was recorded.

All tests were administered online, most likely at the participant's home or work place. Full participation lasted 45 to 60 minutes on average and it was possible to stop and continue later, offering the participants more freedom in their participation to spread the time burden. Participants who fully participated could win (5% chance) a gift voucher of € 20,-. ALOUD was ethically approved by the local ethical committee of the Open University (Heerlen, The Netherlands). Each participant signed a digital informed consent form. This informed the participant on the use of personal data, voluntary participation and giving permission to use the data for the described goals. Participants had to click a check box to agree with the terms mentioned above. This was a mandatory action in order to start the survey.

Materials

Independent measures

The Short Questionnaire to ASsess Health-enhancing physical activity (SQUASH) was used to measure physical activity. The SQUASH has a reasonable reliability (r=0.58) and validity (r=0.45) (Wendel-Vos et al., 2003). Sedentary behavior was measured using a self-developed questionnaire based on the principle of the SQUASH. Questions on sedentary behavior included work, transportation, leisure time (i.e. on work and free days), and resting and sleeping. Physical activity was calculated as a weekly activity score, an accumulated product score of intensity of the activity multiplied by the minutes spent on the activity. Sedentary behavior was calculated as a total score of minutes of sitting, lying, and sleeping per week.

Dependent measures

Learning outcomes were operationalized as study progress: the number of European Credits (EC's) a half year after the date of registration. Cognition was measured by an online digital neuropsychological test battery. As it was digital it was possible to also record reaction times, which is normally not possible in pen and paper tests. This provides extra information about speed, which is actually very useful in tests where ceiling effects are present as explained below. The following three tests were administered: (1) the Trail Making Test (TMT) (Army Individual Test Battery, 1944); (2) the Substitution Test (ST), which resembles the symbol digit modalities test (Smith, 1991), however, other symbols were used than in the original; (3) and the N-back task (NBT) (Lezak, Howieson, & Loring, 2004). The TMT resulted in a measure for the executive function shifting, measured via the B-A part. The outcome measure in the ST was the number of items correctly substituted in 90 seconds, it is a measure of information processing speed. In the NBT the number of correctly remembered items is a measure for working memory and for the executive function updating. A ceiling effect is present in this data, as it is fairly easy for a number of participants to attain the maximum score. Therefore, a product score was created in which one divided by the average reaction time was multiplied with the score. One dividing by the actual reaction time led to a score in which the fastest had the highest score. This way the representation was equal to the score on the NBT, in which the best also had the highest score. Multiplying both these scores led to a meaningful product score.

Covariates

The covariates included in this study were the number of working hours per week, expected average of invested study hours per week, age, sex, nationality, mother tongue, body mass index (BMI; computed from self-reported weight and height), level of education (dichotomized into low and high), computer skills (measured via a self-developed questionnaire mapping attitude, confidence, and skills towards the use of a computer), study motive (personal or professional), study intention (e.g. one course or a complete bachelor degree), study goal (specific number of modules a half year after the survey), alcohol, smoking, health related quality of life (RAND-36) (Hays & Morales, 2001) and life satisfaction (Diener, Emmons, Larsen, & Griffin, 1985). Not all covariates mentioned above were used in the analyses performed in this preliminary article. The covariates which were expected to be influential were included in these first analyses.

Analyses

The data were inspected before analyses on normal distribution, homogeneity of variance, whether data was measured at interval level, and independence. The data were analyzed with multiple regression analyses. An alpha of 0.05 was considered to be significant. The multiple regression analyses were executed with the ‘Enter’ method. First, model A was tested with all covariates. Then, model B was tested with the physical activity, to evaluate the change in R^2. Then, model C was tested, this was model A with the addition of sedentary behavior. And last, model D was tested, this was model A with both physical activity and sedentary behavior to see if both construct were independent. In the analyses the assumptions were checked: normality, normally distributed residuals, and linearity.

Results

Descriptive statistics of the sample are shown in table 1. The multiple regression analysis is shown in table 2. In model B, physical activity was negatively associated with study progress. This means that more physical activity, or more intense physical activity, or a combination, indicates a lower study progress. In model C, sedentary behavior was positively associated, more time spent sitting indicated a higher study progress. In model D, entering physical activity as well as sedentary behavior showed that both constructs added uniquely to the model. The beta’s of both predictors did not change and the exact sum of the changed explained variance of model B and C was present, indicating no multicollinearity as also shown in the collinearity statistics provided with the analysis (data not shown).

Further, in all models the covariates provided roughly the same results. The strongest predictor was the expected amount of study hours per week. The more hours one expects to study per week, the higher the study progress. Sex was negatively associated, meaning that females booked less progress than men. Educational level was positively associated, thus the people at university level (or university preparatory level) performed better than people with a lower education. Mother tongue and study motive were not significant. BMI was negatively associated with study progress, thus people with a higher BMI had a lower study progress.

Discussion

We hypothesized that (1) physical activity in general is positively associated with learning outcomes; and that (2) sedentary behavior is negatively associated with learning outcomes. In the regression model it was shown that both physical activity and sedentary behavior were a significant addition to the model. Also, when combined in one regression model (see model D, table 2) physical activity and sedentary behavior appeared to be independent constructs. The explained variance was an addition of the changed explained variance of model B and C and the beta's did not change, indicating them to be independent predictors. However, the directions of the results were opposite to the hypothesized direction. Physical activity is negatively associated with study progress, while sedentary behavior is positively associated with study progress (see table 2). In addition, adding physical activity and sedentary behavior to the model increased the explained variance with roughly 1%. This is not much but clearly states that being physically active or not is related to learning outcomes.

Unfortunately, due to the fact that no research is executed within the target group investigated here, it is difficult to relate these findings to comparable literature. Regarding children, these results are not congruent with most literature available on the association of physical activity with learning outcomes (e.g. Hillman et al., 2008). However, there is also literature reporting roughly the same results. Tremblay, Inman, and Willms (2000) found a trivial negative relationship with academic achievement in children. Despite the trivial relationship Tremblay and colleagues (2000) argue that physical activity could improve academic achievement "up to some optimal level", but that more time spent on it could detract from academic time. This led us to think that it is possible that the adult students investigated here do not have as much spare time as regular, younger aged, students. As a consequence, it could be that time spent on physical activity leads to less time left for actual studying. In this case, being physically active could lead to negative learning outcomes. Vice versa, spending more time sitting, could lead to better learning outcomes, as one studies most likely sitting.

The strengths of this study are the heterogeneous group, which allows for a very broad evaluation and extrapolation of the results. The study involves a big sample. The outcome variables are objectively measured. The limitations of this study do not permit firm conclusions as this concerns cross-sectional data from which no causal conclusions can be drawn. Further, it has to be noted that the data collected on the independent variables was self-report data, which can be subject to social desirability and recall bias (Slootmaker, Schuit, Chinapaw, Seidell, & van Mechelen, 2009). High intense physical activity is likely to be overestimated (Chinapaw, Slootmaker, Schuit, van Zuidam, & van Mechelen, 2009), while light intensity physical activity is likely to be underestimated (Bassett, Cureton, & Ainsworth, 2000). Future research should focus on the relation between physical activity and sedentary behavior on the one hand and learning on the other hand in adults. Especially experimental research with objective measurements could shed more light on the results found here.

Conclusion

This study provides new insights in the possible contribution of physical activity and sedentary behavior to learning outcomes in adult students. Opposed to our expectations physical activity was a negative predictor for learning outcomes. Possibly, time spent on physical activity in this specific group of students could detract from the time they spent on learning, as it is likely that their spare time is limited. Also, opposed to our expectations, sedentary behavior was positively associated with learning outcomes. As spare time is likely to be scarce it could be that time spent learning adds to the time spent sitting, as it is highly likely that most students will study sitting. Thus, possibly resulting in sedentary behavior being a positive predictor for learning outcomes. Interesting, and in line with expectations based on the literature, physical activity and sedentary behavior are two separate independent constructs as they each add uniquely to the regression model.

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Table 1. Descriptive statistics of the study sample.

Variable	**N (%)**	**Mean (SD)**	**Range**
Age (years)	875	37.14 (11.22)	18-80
Sex			
Male	360 (41.1%)		
Female	515 (58.9%)		
Educational level			.
Lower	137 (15.7%)		
University	738 (84.3%)		
Living situation			
At parents	106 (12.1%)		
Alone	149 (17.0)		
Alone with children	36 (4.1%)		
With partner	234 (26.7%)		
With partner & children	327 (37.4%)		
Employment			
Not	121 (13.8%)		
Part-time	289 (33.0%)		
Full-time	465 (53.1%)		
Faculty			
Learning Sciences	64 (7.3%)		
Environment & Nature	35 (4.0%)		
Law	201 (23.0%)		
Management	126 (14.4%)		
Psychology	299 (34.2%)		
Informatics	84 (9.6%)		
Culture	89 (10.2%)		
Nationality			
Dutch	767 (87.7%)		
Non-Dutch	108 (12.3)		
Mother tongue			
Dutch	825 (94.3%)		
Non-Dutch	50 (5.7%)		

Table 2. Multiple regression results of physical activity or/and sedentary behavior with study progress .

Predictor variable	**β (standardized)**
*Step A (R^2=0.072)***	
Expected study hours	0.227**
Sex (0=male; 1=female)	-0.070*
Age	-0.074*
Educational level	0.070*
Mother tongue	0.046
Study motive (0=personal; 1=professional)	0.016
Body mass index	-0.071*
*Step B (ΔR^2=0.005)**	
Expected study hours	0.222**
Sex (0=male; 1=female)	-0.073*
Age	-0.065
Educational level	0.068*
Mother tongue	0.046
Study motive (0=personal; 1=professional)	0.016
Body mass index	-0.072*
Physical activity	-0.073*
*Step C (ΔR^2=0.004)**	
Expected study hours	0.235**
Sex (0=male; 1=female)	-0.069*
Age	-0.069*
Educational level	0.072*
Mother tongue	0.044
Study motive (0=personal; 1=professional)	0.013
Body mass index	-0.078*
Sedentary behavior	0.067*
*Step D (ΔR^2=0.010)**	
Expected study hours	0.230**
Sex (0=male; 1=female)	-0.071*
Age	-0.060
Educational level	0.071*
Mother tongue	0.044
Study motive (0=personal; 1=professional)	0.012
Body mass index	-0.080*
Physical activity	-0.073*
Sedentary behavior	0.067*

*$p < 0.05$; ** $p < 0.01$.