Preventive Medicine Reports 16 (2019) 101006

Contents lists available at ScienceDirect

Preventive Medicine Reports

journal homepage: www.elsevier.com/locate/pmedr

Physical activity mediates the relationship between outdoor time and mental health

Mathieu Bélanger[a,b,c,*], François Gallant[b], Isabelle Doré[d], Jennifer L. O'Loughlin[d], Marie-Pierre Sylvestre[d], Patrick Abi Nader[b,d], Richard Larouche[e], Katie Gunnell[f], Catherine M Sabiston[g]

[a] Department of Family Medecine, Université de Sherbrooke, 2500 boul. de l'Université Sherbrooke, Québec J1K 2R1, Canada
[b] Centre de formation médicale du Nouveau-Brunswick, 100 rue des Aboiteaux, Moncton, New Brunswick E1A 7R1, Canada
[c] Research Services, Vitalité Health Network, Moncton, New Brunswick, Canada
[d] Department of Social and Preventive Medicine, École de santé publique, Université de Montréal, 7101 avenue du Parc, Montréal, Québec H3N 1X9, Canada
[e] Faculty of Health Sciences, University of Lethbridge, 4401 University Drive, Lethbridge, Alberta T1K 3M4, Canada
[f] Faculty of Arts and Social Sciences, Carleton University, 330 Paterson Hall, 1125 Colonel By Drive, Ottawa, Ontario K1S 5B6, Canada
[g] Faculty of Kinesiology and Physical Education, University of Toronto, 27 King's College Circle, Toronto, Ontario M5S 1A1, Canada

ARTICLE INFO

Keywords:
Physical activity
Outdoor time
Mental health
Adolescence
Mediation

ABSTRACT

Both spending time outdoors and participating in physical activity improve mental health. Given that the outdoor environment provides an ideal location for physical activity, better understanding of the relationships among time spent outdoors, physical activity and positive mental health is needed to help guide interventions. The aim was to examine if physical activity moderates or mediates the relationship between outdoor time and positive mental health. Two-hundred-forty-two participants (15 ± 1 years old, 59% girls) from New Brunswick, Canada were included in the current analysis. Youth self-reported time spent outdoors and moderate-to-vigorous physical activity (MVPA) three times between October 2016 and June 2017. Data on their mental health were collected in October 2017. Values of outdoor time and MVPA were averaged across the three time points to represent the exposure and mediator variables, respectively. Mental health, dichotomized as flourishing/not flourishing, was the outcome in the mediation analysis. An interaction term tested if the mediation effect depended on outdoor time. Analyses were undertaken in 2019 using the mediation package in R. In univariate analyses, both MVPA ($p < 0.001$) and outdoor time ($p = 0.05$) were positive predictors of flourishing mental health. In mediation analyses, a small indirect mediation (OR: 1.02, 95% CI: 1.01–1.04) and no direct (1.00, 0.98–1.05) effect were noted, suggesting that MVPA mediates the effect of outdoor time on positive mental health. This effect did not vary as a function of outdoor time (interaction: 1.00, 0.99–1.01). Physical activity mediates the relationship between outdoor time and positive mental health. Outdoor time could promote positive mental health among youth through increases in physical activity.

1. Introduction

Over 10% of children and adolescents worldwide have a mental disorder (Kato et al., 2015), which can impact child development, social interactions and educational outcomes negatively (Patel et al., 2007; World Health Organization, 2019). If untreated, these disorders can become chronic and increase in severity later in life (Benjet et al., 2016; Costello et al., 2006). Approximately three-quarters of adult mental disorders begin before age 25 years (Kessler et al., 2005) and the majority of mental health disorders found among adolescents had origins in early childhood years(Thomson et al., 2019). Mental disorders decrease in prevalence as positive mental health increases (Keyes, 2006; Keyes et al., 2012), which supports calls to protect and promote positive mental health among youth in order to prevent mental disorders (Gilmour, 2014; Keyes et al., 2010).

There is increasing evidence that more outdoor time is associated with enhanced positive mental health in adults (Song et al., 2016). Beyer et al., (2014) reported an association between more exposure to green space and lower levels of anxiety and stress among adults. The same author (Beyer et al., 2016) also described that increased time

* Corresponding author at: Centre de formation médicale du Nouveau-Brunswick, Pavillon J.-Raymond-Frenette, 100 Des Aboiteaux St, Moncton, NB E1A 7R1, Canada.
E-mail address: mathieu.f.belanger@usherbrooke.ca (M. Bélanger).

https://doi.org/10.1016/j.pmedr.2019.101006
Received 21 May 2019; Received in revised form 19 August 2019; Accepted 1 October 2019
Available online 21 October 2019

spent outdoors was linked to fewer depression symptoms in a population-based sample of adults. In children, spending additional time outdoors relates to improvements in attention (Ulset et al., 2017) and cognition (Faber Taylor and Kuo, 2009), as well as reductions in symptoms of attention deficit/hyperactivity disorder (Faber Taylor and Kuo, 2011). In a nationally representative study of Canadian children, every hour spent outdoors per day was associated with a 31% reduction in the odds of reporting peer relationship problems and a 22% lower odds of reporting psychosocial difficulties (Larouche et al., 2016).

An additional benefit of outdoor time with respect to positive mental health is that the outdoor environment provides a context for increasing physical activity (Shanahan et al., 2016). Time outdoors is positively associated with levels of moderate-to-vigorous physical activity (MVPA) in youth (Gray et al., 2015; Larouche et al., 2016; Schaefer et al., 2014). For every hour per day spent outdoors, children accumulate 7 additional minutes of MVPA (Larouche et al., 2016). This is important because increasing MVPA is associated with improvements in mental health and self-esteem as well as with reductions in depression and anxiety symptoms (Biddle and Asare, 2011; Carson et al., 2016; Doré et al., 2016; Mammen and Faulkner, 2013). These associations, however, raise the question of whether MVPA moderates or mediates (at least partially) the association between outdoor time and positive mental health.

Experimental and cross-sectional studies in adults show that outdoor physical activity appears more advantageous for mental health than indoor physical activity (Bailey et al., 2018; Mitchell, 2013; Pasanen et al., 2014). Similarly, a review of experimental studies in adults suggested that additional mental health benefits are typically observed when physical activities are undertaken in an outdoor natural environment relative to indoors (Thompson Coon et al., 2011). Puett et al. (2014) found that adults reporting more outdoor exercise had a lower odds of reporting a poor emotional outlook (Puett et al., 2014).

However, associations among MVPA, outdoor time and mental health in youth have received less research attention and the potential for an interaction or a mediation effect has not been assessed directly. Specifically, although separate studies have shown that: (1) time spent outdoors is strongly and positively related to MVPA (Gray et al., 2015; Schaefer et al., 2014); and that (2) MVPA is associated with improved mental health (Biddle and Asare, 2011; Doré et al., 2016), no study in youth has examined whether MVPA is a moderator or a mediator of the link between outdoor time and positive mental health. Given that the onset of mental disorders is often in adolescence (Biddle and Asare, 2011; Gilmour, 2014) when MVPA begins to decline (Corder et al., 2019; Dumith et al., 2011; Sallis, 2000), there is a need to investigate the relationships among outdoor time, MVPA and positive mental health during this period. The objective of this analysis was to examine if MVPA moderates or mediates the relationship between outdoor time and positive mental health in adolescents.

2. Methods

2.1. Participants

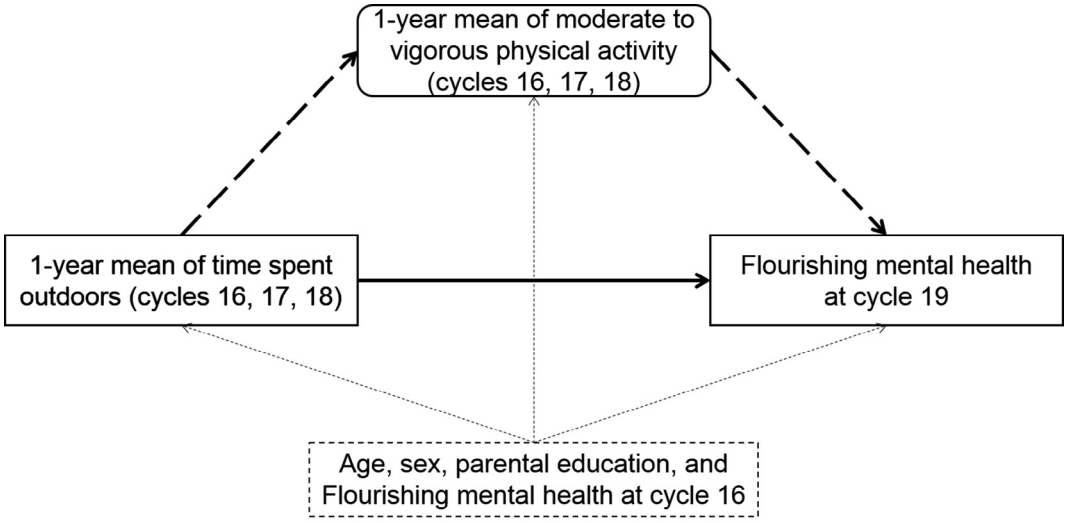
We used data from the Monitoring Activities of Teenagers to Comprehend their Habits (MATCH) study, an ongoing prospective study designed to increase understanding of physical activity behaviors in children and adolescents. Methodological details are reported elsewhere (Bélanger et al., 2013). Briefly, Grades 5 or 6 students (age 10.3 ± 0.6 years on average) were recruited in 17 English and French elementary schools in 2011 in the province of New Brunswick, Canada. In the first year of data collection, 806 participants were recruited and completed baseline questionnaires. Other students from participating schools could join the study after the first year; a total of 937 children (55% female) took part in at least one survey cycle. Participants were invited to complete questionnaires at four-month intervals in three data collection cycles per school year. We restricted the current analyses to participants in survey cycles 16 (October 2016, participants were 15.3 ± 0.7 years on average) and 19 (October 2017) since the measure of positive mental health was available in these cycles only. All participants provided written and informed assent and parents provided written informed consent. Ethics approval was obtained from the Université de Sherbrooke ethics committee (11–025).

3. Measures

Outdoor time. Participants reported the time they usually spent outdoors on week and weekend days in two items: "*On an average weekday (Monday to Friday) during the past month, how much time did you usually spend outside?*" and "*On an average weekend day (Saturday or Sunday) during the past month, how much time did you usually spend outside?*". For both items, response options were: none, < 15 min, 15 to 30 min, 30 to 60 min, 1–2 h, 2–4 h, 4–6 h and more than 6 h. Outdoor time was estimated with the procedure used in Statistics Canada's Canadian Health Measures Survey among same-age participants (Larouche et al., 2016). Specifically, the midpoint of each response option (i.e., 0, 7.5, 22.5, 45, 90, 180, 300, and 360 min, respectively) was used. Minutes spent outdoors per week were computed as [(5*outdoor time on weekdays) + (2*outdoor time on weekend days)]. To convert this estimate to hours per day, we divided the estimate by 420 (60 min * 7 days per week). In previous work by our team, administering these questions 2-weeks apart yielded a weighted kappa of 0.56 (95% CI = 0.36–0.76) for weekdays and of 0.63 (95% CI = 0.45–0.81) for weekend days(Larouche et al., 2018). For analyses, we averaged outdoor time across cycles 16, 17 and 18 to represent usual outdoor time for the year, accounting for seasonal variation.

MVPA. Participants reported participation in MVPA in a two-item questionnaire developed for adolescents (Prochaska et al., 2001). Briefly, participants read the following statement: "Physical activity is an activity that increases your heart rate and makes you get out of breath some of the time. Physical activity can be done in sports, playing with friends, or walking to school. Some examples of physical activity are running, brisk walking, rollerblading, biking, dancing, skateboarding, swimming, soccer, basketball, football, and surfing" and were then asked: "Over the course of the week (past 7 days), how many days were you physically active for a total of at least 60 min per day?" and "Over the course of a typical or usual week, how many days are you physically active for a total of at least 60 min per day?". Response options ranged from 0 to 7 (days). The average of the two items was used to create an overall MVPA score. This measure has test-retest reliability (intra-class correlation = 0.77) and is moderately correlated with accelerometer-measured MVPA (Pearson correlation = 0.40) in 12-year olds (Prochaska et al., 2001). For analyses, MVPA scores were averaged across cycles 16, 17 and 18 to represent usual level of MVPA for the year, accounting for seasonality.

Mental health. Positive mental health was assessed with the Mental Health Continuum-Short Form (MHC-SF) questionnaire in cycles 16 (Fall 2016) and 19 (Fall 2017). The MHC-SF comprises 14 items assessing emotional well-being (3 items), social well-being (5 items) and psychological well-being (6 items) (Keyes, 2005). Responses were scored on a 6-point Likert scale (0–5): *never, rarely, a few times, often, most of the time, all the time.* As proposed by Keyes (2005), mental health was categorized as *flourishing* if the participant responded "always" or "most of the time" to at least one of the three emotional well-being items, and at least six of the 11 positive functioning items (i.e. social and psychological well-being). Mental health for all other participants was categorized as *not flourishing.* The three-factor structure and sex-invariance of the MHC-SF structure have been demonstrated among youth (Doré et al., 2017; Lamers et al., 2011), and MHC-SF subscales have good internal consistency and reliability in the current sample (Cronbach's α 0.90 to 0.94), as did scores for the total scale (α = 0.97).



The solid line represents the direct effect of time spent outdoors on flourishing mental health. The dashed line represents the mediation effect of time spent outdoors on flourishing mental health through physical activity. The dotted line represents potential confounding variables.

Fig. 1. Directed Acyclic Graph of the hypothesized associations.

3.1. Statistical analysis

We estimated mediation models using a causalinference analysis approach (Imai et al., 2010a). In contrast to traditional mediation analyses (i.e., products and difference methods (Baron and Kenny, 1986)), this method is based on a counterfactual framework. It takes the interaction between the exposure and mediator into account and it permits estimating the total, direct and mediated effects (Imai et al., 2010a). In the current analysis, the exposure variable was the 1-year mean of outdoor time (cycles 16–18), the mediator was the 1-year mean of MVPA (cycles 16–18) and the outcome variable was mental health (flourishing, not flourishing) in cycle 19 (4 months after the MVPA and outdoor time measures; Fig. 1). The models estimated the odds ratios associated with the total effect (i.e., combined estimated effect of outdoor time and MVPA on positive mental health), average mediation effect (i.e., estimated indirect effect of outdoor time on positive mental health through MVPA) and the average direct effect (i.e., estimated direct effect of outdoor time on positive mental health). All of these odds ratios were estimated simultaneously in a single model such that they were fully adjusted for one another. Since the exposure variable (i.e., outdoor time) is continuous and to contrast between two levels of exposure, we set the control value at the mean of the sample (i.e., 1.8 h per day), and the exposure value at the mean plus one unit (2.8 h per day) so that the resulting odds ratio (OR) can be interpreted as representing the effect of one additional hour of outdoor time.

To assess the presence of moderation, we ran a model assuming no interaction between outdoor time and MVPA as a first step in this series of mediation analyses. As a second step, we investigated the presence of an interaction by allowing the average mediation effect to depend on outdoor time. Through the default approach in the *mediation* package in R, standard errors were estimated in 1000 iterations of quasi-Bayesian Monte Carlo experiments based on normal approximation (King et al., 2000). The mediated portion of the association, expressed as the ratio of the average mediation effects on the total effect, was also computed. Finally, to satisfy the sequential ignorability assumption on which the mediation analysis relies (Imai et al., 2010a), we first included age, sex, parental education and mental health at cycle 16 to account for them as potential pre-exposure confounding variables, as determined through directed acyclic graphs. Second, we ran sensitivity analyses based on estimates of the correlation between error terms of the mediator and outcome models, where a large value of rho would suggest the presence of important unobserved confounding (Imai et al., 2010a,b; Tingley et al., 2014). Analyses were conducted with the *mediation* package (Tingley et al., 2014) in *R* (version 3.5.1, R Foundation for Statistical Computing, Vienna, Austria).

4. Results

A total of 242 participants (59% female) provided data on mental health in cycles 16 and 19. The average age of participants in cycle 16 was 15 (standard deviation, SD = 1) years. Over half of participants (57%, n = 139) reported flourishing mental health in cycle 16; this declined to 49% (n = 119) one year later, in cycle 19. Overall, participants reported taking part in at least 60 min of MVPA an average of 4.2 (SD = 1.9) days per week. They also reported engaging in an average of 1.8 (SD = 1.4) hours of outdoor time per day. Baseline characteristics of participants are presented by mental health status at cycle 19 in Table 1. Participants excluded from the analysis because of missing data (n = 290) were less likely to have flourishing mental health in cycle 19 (X^2 p = 0.02) and they reported lower parental education (X^2 p = 0.06). However, participants excluded were not different from those included (see Appendix) in age (*t*-test p = 0.6), sex (X^2 p = 0.4), MVPA (*t*-test p = 0.3), outdoor time (*t*-test p = 0.6), or mental health in cycle 16 (X^2 p = 0.3).

The correlation between MVPA and outdoor time was 0.3 ($p < 0.001$). In unadjusted analyses, the levels of MVPA (4.6 vs 3.7 days per week, *t*-test $p < 0.001$) and of outdoor time (2.0 vs 1.6 h per day, *t*-test p = 0.05) were higher in participants with flourishing vs not flourishing mental health in cycle 19.

In the first mediation analysis model, which accounted for age, sex, parental education and mental health at cycle 16 as pre-exposure potential confounding variables, and which assumed no interaction between outdoor time and MVPA, the total effect and the average direct effect were both positive, but neither were statistically significant at $p = 0.05$. Nevertheless, a small and statistically significant average mediation effect was noted (Fig. 2a). The presence of a mediation effect and the absence of a statistically significant total effect may result from a combination of a small direct effect, residual confounding and a small sample size. Results from this model suggest that increases in outdoor time were associated with increases in MVPA, which translated into

Table 1
Characteristics of participants included in the analyses.

		Mental health status at cycle 19	
	All participants (n = 242) Mean (sd) or %	Not Flourishing (n = 123) Mean (sd) or %	Flourishing (n = 119) Mean (sd) or %
Age (years)	15.3 (0.7)	15.2 (0.7)	15.3 (0.7)
Sex (female)	59.1	65.3	51.3
Flourishing mental health at cycle 16	57.4	43.6	70.6
MVPA (days per week ≥60 min)	4.2 (1.9)	3.7 (1.8)	4.6 (1.8)
Outdoor Time (hours per day)	1.8 (1.4)	1.6 (1.4)	2.0 (1.4)
Mother education (≥post-secondary)	50.8	51.5	50

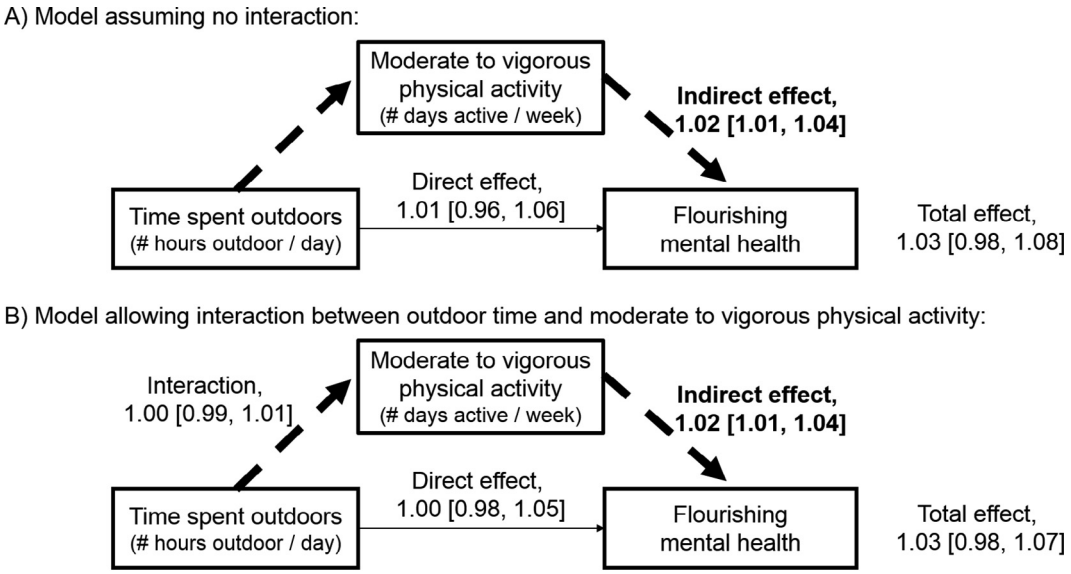
increases in the probability of reporting flourishing mental health. The odds ratio for the indirect effect can be interpreted as indicating that the odds of reporting flourishing mental health were increased by 2% (95% confidence interval: 1–4%) for every additional day of the week participants reported attaining at least 60 min of MVPA. Estimates also indicate that 54% of the total effect of outdoor time on mental health was explained by increased MVPA.

Results of the second mediation analysis, which allowed for interaction between outdoor time and MVPA, were consistent with the findings of the first mediation analysis. Specifically, results indicated that the likelihood of flourishing mental health did not vary with differences in outdoor time, but that increases in outdoor time were associated with increases in MVPA, which led to increases in the probability of reporting flourishing mental health (Fig. 2b). In this analysis, the interaction term was not statistically significant (p = 0.4), indicating that the relationship between MVPA and mental health did not vary across different amounts of outdoor time. The sensitivity analyses suggested that model estimates were robust because there was negligible indication of unobserved confounding (rho at which a mediation effect would be null = 0.2).

5. Discussion

Adolescence is a life period often characterized by declines in physical activity and time spent outdoors, as well as in the prevalence of flourishing mental health. The current study supports that these attributes may be inter-connected by suggesting that spending more time outside is associated with higher physical activity levels, which in turn increase the probability of flourishing mental health. This longitudinal study therefore provides insight into relationships for which prior evidence originated primarily from cross-sectional studies (Gray et al., 2015; Larouche et al., 2016). Our results align with previous reports of a positive relationship between exposure to outdoor environments and mental health, but clarify that this relationship may be mediated by participation in MVPA.

Although our results support the mediation hypothesis, they did not provide evidence of a direct relationship between outdoor time and mental health. It is possible that our measure of outdoor time did not capture aspects of outdoor time that contribute positively to mental health, but rather included a mix of time spent in nature, busy urban environments and other settings which may have differential effects on mental health (Thompson Coon et al., 2011). Spending outdoor time in areas with high traffic volumes might not contribute positively to mental health (Appleyard, 2017), whereas exposure to nature is beneficial (Chawla, 2015; Tillmann et al., 2018). Using measures of outdoor time more specific to the natural environment (Mitchell and Popham, 2008) (i.e., undeveloped land with natural vegetation) or greenness might have yielded different results. In addition to collecting data on the type of outdoor environment, future studies should document the specific activities in which adolescents engage in while outdoors. In a large survey of US children and youth, the most common outdoor activities included “playing or simply hanging out”, “using electronic



The solid line represents the direct effect of time spent outdoors on flourishing mental health. The dashed line represents the mediation effect of time spent outdoors on flourishing mental health through physical activity.

Fig. 2. odds ratios and 95% confidence intervals from mediation analysis estimating the direct and indirect effect of outdoor time and physical activity on flourishing mental health among adolescents in the MATCH study.

media outdoors", and "reading or studying while sitting outdoors" (Larson et al., 2011). Although outdoors, the benefits associated with these sedentary activities likely differ from outdoor activities that involve physical activity. Future studies should also consider using objective measures of both outdoor time and of MVPA. Although we did identify statistically significant associations in the current analyses, it is possible that well-powered studies with measures less prone to measurement error would identify clear relationships among outdoor time, MVPA and mental health. For example, wearable devices with integrative technologies capturing geographic coordinates, accelerometry and ambient light and air could provide a more comprehensive overview of these relationships.

Consistent with our finding that outdoor time is associated with MVPA, being outdoors has been associated with increases in physical activity (Cleland et al., 2008; Pearce et al., 2014). The current high prevalence of physical inactivity among children and adolescents around the globe (Aubert et al., 2018; Cooper et al., 2015) could be partly attributable to a large proportion of free-time spent indoors (Bassett et al., 2015; Gray et al., 2015). Given that most youth do not meet the recommended guidelines for physical activity, one could hypothesize that increasing time spent outdoors might increase total physical activity in youth, which could contribute to flourishing mental health. From an intervention perspective, this could imply that promoting outdoor time at school and in the community could improve mental health in youth. Supporting this, "park prescriptions", where health-care providers write prescriptions for outdoor physical activity in parks, have already been shown to be feasible and potentially effective in helping children and youth increase their outdoor time and physical activity (Zarr et al., 2017). Specifically, park prescriptions have been linked to a 15% increase in parent-reported physical activity among children and adolescents (Zarr et al., 2017). It has also been documented that providing more outdoor time during the school day is associated with higher physical activity levels among students. For example, holding physical education classes outdoors instead of indoors is associated with 25% higher levels of accelerometer measured MVPA whereas having recess outdoors instead of in a gymnasium is linked to over 40% greater step counts (Pagels et al., 2016; Tran et al., 2013).

Although the estimated effect of MVPA on mental health we identified was small, previous studies identified important associations between these variables(Biddle, 2016), suggesting that further investigations and interventions based on such associations should be pursued. However, how MVPA positively influences mental health is not clearly delineated. In addition to physiological (van der Zwan et al., 2015) and social (Eime et al., 2013; Jewett et al., 2014) mechanisms, there is support for the "distraction hypothesis" which posits that physical activity represents a diversion from the sources and symptoms of negative mental health (Bahrke and Morgan, 1978). Experimental studies have demonstrated that physical activity is as good as relaxation in distracting people away from negative mental health triggers and for improving mood (Brown et al., 1993; van der Zwan et al., 2015). Similar to physical activity, the outdoors can provide rich sensory experiences with positive effects on mental health (Lawton et al., 2017). Therefore, and even if we did not find that physical activity modifies the effect of outdoor time on mental health, future studies should continue to investigate the potential combined benefits of physical activity and outdoor time on positive mental health.

6. Limitations

Strengths of this analysis include that we used prospective methods and that physical activity and outdoor time were assessed three times over one year accounting for seasonality. Limitations inherent in self-reports should be acknowledged when interpreting our results. In particular, it is possible that participants overestimated the number of days on which they attained the recommended minimum of 60 min of MVPA and the number of hours they spent outdoors. Outdoor time reported by participants in our study is higher than that captured by objective measures in previous studies (Cooper et al., 2010; Pearce et al., 2018, 2014). However, the estimates of MVPA are similar to those reported using objective measures in a representative sample of Canadian youth (Colley et al., 2011). It is also possible that lack of statistical power, resulting from potential misclassification and a relatively small sample, limited the ability to detect direct and total effects of outdoor time. Nevertheless, investigating the presence of mediation despite the absence of an exposure-outcome association was well justified (Agler and De Boeck, 2017; Rucker et al., 2011; Zhao et al., 2010) since the mediation hypothesis was supported by previous reports documenting that increases in outdoor time relate to increased MVPA in youth (Cleland et al., 2008; Larouche et al., 2016) and that MVPA is positively associated with mental health (Biddle and Asare, 2011).

In conclusion, this study suggests that an increased probability of flourishing mental health is mediated by increases in physical activity resulting from increases in outdoor time in adolescents. Albeit a small association, this finding has public health implications because it identifies a potential actionable mechanism underpinning positive mental health.

Acknowledgements

The MATCH study is supported by the New Brunswick Health Research Foundation (No. 20130729) and by the Social Sciences and Humanities Research Council (No. 435-2016-0888) and Sport Canada through the joint Sport Participation Research Initiative (Nos. 862-2010-0001 and 862-2014-0002). The MATCH study has received ethical approval by the Université de Sherbrooke ethics committee (11-025).

All authors helped in developing the research objectives. MB designed the main study, oversaw the analyses, and interpreted the results. FG conducted the literature review, conducted the initial draft of the manuscript and ran the analyses. ID, MPS and CS contributed to developing the analysis strategy, to interpreting results and and identified points of discussion. JOL, RL, KG and PAN participated in interpreting results and critically reviewed the manuscript for intellectual content.

Competing interests

No competing interests were reported by the authors of this paper.

Funding

The MATCH study is supported by the New Brunswick Health Research Foundation, Canada (No. 20130729) and by the Social Sciences and Humanities Research Council, Canada (No. 435-2016-0888) and Sport Sport Canada (through the joint Sport Participation Research Initiative), Canada (Nos. 862-2010-0001 and 862-2014-0002).

Financial disclosure

No financial disclosures were reported by the authors of this paper.

Appendix

Comparison of characteristics of participants retained for the analyses and those excluded.

	Included (n = 242) Mean (sd) or %	Excluded (n = 290) n*	Mean (sd) or %	P value
Age at cycle 16	15.3 (0.78)	290	15.3 (0.7)	0.65[A]
MVPA (cycles 16, 17, 18)	4.2 (1.9)	261	4.0 (2.1)	0.28[A]
Outdoor time (cycles 16, 17, 19)	1.8 (1.4)	260	1.7 (1.5)	0.58[A]
Flourishing at cycle 16	56.8	143	51.1	0.29[B]
Flourishing at cycle 19	49.0	142	34.5	**0.02**[B]
Female	58.7	290	55.0	0.37[B]
Mom education (% post secondary)	50.8	231	41.56	0.06[B]

* Information on some characteristics was not available for some of the participants excluded from the analyses.
[A] Difference between means was calculated using an independent sample *t*-test.
[B] Proportion comparison was conducted using Chi-Square analysis; bold represents a statistically significant difference.

References

Agler, R., De Boeck, P., 2017. On the interpretation and use of mediation: multiple perspectives on mediation analysis. Front. Psychol. 8, 1984. https://doi.org/10.3389/fpsyg.2017.01984.

Appleyard, B., 2017. The meaning of livable streets to schoolchildren: An image mapping study of the effects of traffic on children's cognitive development of spatial knowledge. J. Transp. Heal. 5, 27–41. https://doi.org/10.1016/J.JTH.2016.08.002.

Aubert, S., Barnes, J.D., Abdeta, C., Abi Nader, P., Adeniyi, A.F., Aguilar-Farias, N., Andrade Tenesaca, D.S., Bhawra, J., Brazo-Sayavera, J., Cardon, G., Chang, C.-K., Delisle Nyström, C., Demetriou, Y., Draper, C.E., Edwards, L., Emeljanovas, A., Gába, A., Galaviz, K.I., González, S.A., Herrera-Cuenca, M., Huang, W.Y., Ibrahim, I.A.E., Jürimäe, J., Kämppi, K., Katapally, T.R., Katewongsa, P., Katzmarzyk, P.T., Khan, A., Korcz, A., Kim, Y.S., Lambert, E., Lee, E.-Y., Löf, M., Loney, T., López-Taylor, J., Liu, Y., Makaza, D., Manyanga, T., Mileva, B., Morrison, S.A., Mota, J., Nyawornota, V.K., Ocansey, R., Reilly, J.J., Roman-Viñas, B., Silva, D.A.S., Saonuam, P., Scriven, J., Seghers, J., Schranz, N., Skovgaard, T., Smith, M., Standage, M., Starc, G., Stratton, G., Subedi, N., Takken, T., Tammelin, T., Tanaka, C., Thivel, D., Tladi, D., Tyler, R., Uddin, R., Williams, A., Wong, S.H.S., Wu, C.-L., Zembura, P., Tremblay, M.S., 2018. Global matrix 3.0 physical activity report card grades for children and youth: results and analysis from 49 countries. J. Phys. Act. Heal. 15, S251–S273. https://doi.org/10.1123/jpah.2018-0472.

Bahrke, M.S., Morgan, W.P., 1978. Anxiety reduction following exercise and meditation. Cognit. Ther. Res. 2, 323–333. https://doi.org/10.1007/BF01172650.

Bailey, A.W., Allen, G., Herndon, J., Demastus, C., 2018. Cognitive benefits of walking in natural versus built environments. World Leis. J. 60, 293–305. https://doi.org/10.1080/16078055.2018.1445025.

Baron, R.M., Kenny, D.A., 1986. The moderator–mediator variable distinction in social psychological research: conceptual, strategic, and statistical considerations. J. Pers. Soc. Psychol. 51, 1173–1182. https://doi.org/10.1037/0022-3514.51.6.1173.

Bassett, D.R., John, D., Conger, S.A., Fitzhugh, E.C., Coe, D.P., 2015. Trends in physical activity and sedentary behaviors of United States Youth. J. Phys. Act. Heal. 12, 1102–1111. https://doi.org/10.1123/jpah.2014-0050.

Bélanger, M., Caissie, I., Beauchamp, J., O'Loughlin, J., Sabiston, C., Mancuso, M., 2013. Monitoring activities of teenagers to comprehend their habits: study protocol for a mixed-methods cohort study. BMC Public Health 13, 649. https://doi.org/10.1186/1471-2458-13-649.

Benjet, C., Borges, G., Méndez, E., Albor, Y., Casanova, L., Orozco, R., Curiel, Teresa, Fleiz, C., María, Medina-Mora, E., 2016. Eight-year incidence of psychiatric disorders and service use from adolescence to early adulthood: longitudinal follow-up of the Mexican Adolescent Mental Health Survey. Eur. Child Adolesc. Psychiatry 25, 163–173. https://doi.org/10.1007/s00787-015-0721-5.

Beyer, K.M.M., Kaltenbach, A., Szabo, A., Bogar, S., Nieto, F.J., Malecki, K.M., 2014. Exposure to neighborhood green space and mental health: evidence from the survey of the health of Wisconsin. Int. J. Environ. Res. Public Health 11, 3453–3472. https://doi.org/10.3390/ijerph110303453.

Beyer, K.M.M., Szabo, A., Nattinger, A.B., 2016. Time spent outdoors, depressive symptoms, and variation by race and ethnicity. Am. J. Prev. Med. 51, 281–290. https://doi.org/10.1016/j.amepre.2016.05.004.

Biddle, S., 2016. Physical activity and mental health: evidence is growing. World Psychiatry 15, 176–177. https://doi.org/10.1002/wps.20331.

Biddle, S.J.H., Asare, M., 2011. Physical activity and mental health in children and adolescents: a review of reviews. Br. J. Sports Med. https://doi.org/10.1136/bjsports-2011-090185.

Brown, D.R., Morgan, W.P., Raglin, J.S., 1993. Effects of exercise and rest on the state anxiety and blood pressure of physically challenged college students. J. Sports Med. Phys. Fitness 33, 300–305.

Carson, V., Hunter, S., Kuzik, N., Gray, C.E., Poitras, V.J., Chaput, J.-P., Saunders, T.J., Katzmarzyk, P.T., Okely, A.D., Connor Gorber, S., Kho, M.E., Sampson, M., Lee, H., Tremblay, M.S., 2016. Systematic review of sedentary behaviour and health indicators in school-aged children and youth: an update. Appl. Physiol. Nutr. Metab. 41, S240–S265. https://doi.org/10.1139/apnm-2015-0630.

Chawla, L., 2015. Benefits of nature contact for children. J. Plan. Lit. 30, 433–452. https://doi.org/10.1177/0885412215595441.

Cleland, V., Crawford, D., Baur, L.A., Hume, C., Timperio, A., Salmon, J., 2008. A prospective examination of children's time spent outdoors, objectively measured physical activity and overweight. Int. J. Obes. 32, 1685–1693. https://doi.org/10.1038/ijo.2008.171.

Colley, R.C., Garriguet, D., Janssen, I., Craig, C.L., Clarke, J., Tremblay, M.S., 2011. Physical activity of Canadian adults: accelerometer results from the 2007 to 2009 Canadian Health Measures Survey. Health Reports 22, 15–23.

Cooper, A.R., Goodman, A., Page, A.S., Sherar, L.B., Esliger, D.W., van Sluijs, E.M., Andersen, L.B., Anderssen, S., Cardon, G., Davey, R., Froberg, K., Hallal, P., Janz, K.F., Kordas, K., Kreimler, S., Pate, R.R., Puder, J.J., Reilly, J.J., Salmon, J., Sardinha, L.B., Timperio, A., Ekelund, U., 2015. Objectively measured physical activity and sedentary time in youth: the International children's accelerometry database (ICAD). Int. J. Behav. Nutr. Phys. Act. 12, 113. https://doi.org/10.1186/s12966-015-0274-5.

Cooper, A.R., Page, A.S., Wheeler, B.W., Hillsdon, M., Griew, P., Jago, R., 2010. Patterns of GPS measured time outdoors after school and objective physical activity in English children: the PEACH project. Int. J. Behav. Nutr. Phys. Act. 7, 31. https://doi.org/10.1186/1479-5868-7-31.

Corder, K., Winpenny, E., Love, R., Brown, H.E., White, M., van Sluijs, E., 2019. Change in physical activity from adolescence to early adulthood: a systematic review and meta-analysis of longitudinal cohort studies. Br. J. Sports Med. https://doi.org/10.1136/bjsports-2016-097330.

Costello, E.J., Foley, D.L., Angold, A., 2006. 10-year research update review: the epidemiology of child and adolescent psychiatric disorders: II. Developmental epidemiology. J. Am. Acad. Child Adolesc. Psychiatry 45, 8–25. https://doi.org/10.1097/01.chi.0000184929.41423.c0.

Doré, I., O'Loughlin, J.L., Beauchamp, G., Martineau, M., Fournier, L., 2016. Volume and social context of physical activity in association with mental health, anxiety and depression among youth. Prev. Med. (Baltim) 91, 344–350. https://doi.org/10.1016/j.ypmed.2016.09.006.

Doré, I., O'Loughlin, J.L., Sabiston, C.M., Fournier, L., 2017. Psychometric Evaluation of the Mental Health Continuum-Short Form in French Canadian Young Adults. Can. J. Psychiatry 62, 286–294. https://doi.org/10.1177/0706743716675855.

Dumith, S.C., Gigante, D.P., Domingues, M.R., Kohl, H.W., 2011. Physical activity change during adolescence: a systematic review and a pooled analysis. Int. J. Epidemiol. 40, 685–698. https://doi.org/10.1093/ije/dyq272.

Eime, R.M., Young, J.A., Harvey, J.T., Charity, M.J., Payne, W.R., 2013. A systematic review of the psychological and social benefits of participation in sport for children and adolescents: informing development of a conceptual model of health through sport. Int. J. Behav. Nutr. Phys. Act. 10, 98. https://doi.org/10.1186/1479-5868-10-98.

Faber Taylor, A., Kuo, F.E., 2009. Children with attention deficits concentrate better after walk in the park. J. Atten. Disord. 12, 402–409. https://doi.org/10.1177/1087054708323000.

Faber Taylor, A., Kuo, F.E.M., 2011. Could exposure to everyday green spaces help treat ADHD? evidence from children's play settings. Appl. Psychol. Heal. Well-Being 3, 281–303. https://doi.org/10.1111/j.1758-0854.2011.01052.x.

Gilmour, H., 2014. Positive mental health and mental illness. Heal. Reports 25, 3–9.

Gray, C., Gibbons, R., Larouche, R., Sandseter, E., Bienenstock, A., Brussoni, M., Chabot, G., Herrington, S., Janssen, I., Pickett, W., Power, M., Stanger, N., Sampson, M., Tremblay, M., 2015. What is the relationship between outdoor time and physical activity, sedentary behaviour, and physical fitness in children? a systematic review. Int. J. Environ. Res. Public Health 12, 6455–6474. https://doi.org/10.3390/ijerph120606455.

Imai, K., Keele, L., Tingley, D., 2010a. A general approach to causal mediation analysis. Psychol. Methods 15, 309–334. https://doi.org/10.1037/a0020761.

Imai, K., Keele, L., Yamamoto, T., 2010b. Identification, inference and sensitivity analysis for causal mediation effects. Stat. Sci. 25, 51–71. https://doi.org/10.1214/10-STS321.

Jewett, R., Sabiston, C.M., Brunet, J., O'Loughlin, E.K., Scarapicchia, T., O'Loughlin, J., 2014. School sport participation during adolescence and mental health in early adulthood. J. Adolesc. Heal. 55, 640–644. https://doi.org/10.1016/j.jadohealth.2014.04.018.

Kato, N., Yanagawa, T., Fujiwara, T., Morawska, A., 2015. Prevalence of children's mental health problems and the effectiveness of population-level family interventions. J. Epidemiol. 25, 507–516. https://doi.org/10.2188/jea.JE20140198.

Kessler, R.C., Berglund, P., Demler, O., Jin, R., Merikangas, K.R., Walters, E.E., 2005. Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the national comorbidity survey replication. Arch. Gen. Psychiatry 62, 593. https://doi.org/10.1001/archpsyc.62.6.593.

Keyes, C.L.M., 2006. Mental health in adolescence: is America's youth flourishing? Am. J. Orthopsychiatry 76, 395–402. https://doi.org/10.1037/0002-9432.76.3.395.
Keyes, C.L.M., 2005. Mental illness and/or mental health? investigating axioms of the complete state model of health. J. Consult. Clin. Psychol. 73, 539–548. https://doi.org/10.1037/0022-006X.73.3.539.
Keyes, C.L.M., Dhingra, S.S., Simoes, E.J., 2010. Change in level of positive mental health as a predictor of future risk of mental illness. Am. J. Public Health 100, 2366–2371. https://doi.org/10.2105/AJPH.2010.192245.
Keyes, C.L.M., Eisenberg, D., Perry, G.S., Dube, S.R., Kroenke, K., Dhingra, S.S., 2012. The relationship of level of positive mental health with current mental disorders in predicting suicidal behavior and academic impairment in college students. J. Am. Coll. Heal. 60, 126–133. https://doi.org/10.1080/07448481.2011.608393.
King, G., Tomz, M., Wittenberg, J., 2000. Making the most of statistical analyses: improving interpretation and presentation. Am. J. Pol. Sci. 44, 341–355.
Lamers, S.M.A., Westerhof, G.J., Bohlmeijer, E.T., ten Klooster, P.M., Keyes, C.L.M., 2011. Evaluating the psychometric properties of the mental health Continuum-Short Form (MHC-SF). J. Clin. Psychol. 67, 99–110. https://doi.org/10.1002/jclp.20741.
Larouche, R., Garriguet, D., Gunnell, K.E., Goldfield, G.S., Tremblay, M.S., 2016. Outdoor time, physical activity, sedentary time, and health indicators at ages 7 to 14: 2012/2013 Canadian Health Measures Survey. Heal. Reports 27, 3–13.
Larouche, R., Leduc, G., Trudeau, F., Faulkner, G., Tremblay, M.S., 2018. Test-retest reliability and construct validity of parental reports of children's outdoor time, in: Active Living Research Conference. Banff, AB.
Larson, L.R., Green, G.T., Cordell, H.K., 2011. Children's time outdoors: results and implications of the national kids survey. J. Park Recreat. Admi. 29, 1–20.
Lawton, E., Brymer, E., Clough, P., Denovan, A., 2017. The relationship between the physical activity environment, nature relatedness, anxiety, and the psychological well-being benefits of regular exercisers. Front. Psychol. 8, 1058. https://doi.org/10.3389/fpsyg.2017.01058.
Mammen, G., Faulkner, G., 2013. Physical Activity and the Prevention of Depression. Am. J. Prev. Med. 45, 649–657. https://doi.org/10.1016/j.amepre.2013.08.001.
Mitchell, R., 2013. Is physical activity in natural environments better for mental health than physical activity in other environments? Soc. Sci. Med. 91, 130–134. https://doi.org/10.1016/j.socscimed.2012.04.012.
Mitchell, R., Popham, F., 2008. Effect of exposure to natural environment on health inequalities: an observational population study. Lancet 372, 1655–1660. https://doi.org/10.1016/S0140-6736(08)61689-X.
Pagels, P., Raustorp, A., Guban, P., Fröberg, A., Boldemann, C., 2016. Compulsory school in- and outdoors-implications for school children's physical activity and health during one academic year. Int. J. Environ. Res. Public Health 13. https://doi.org/10.3390/ijerph13070699.
Pasanen, T.P., Tyrväinen, L., Korpela, K.M., 2014. The relationship between perceived health and physical activity indoors, outdoors in built environments, and outdoors in nature. Appl. Psychol. Heal. Well-Being 6, 324–346. https://doi.org/10.1111/aphw.12031.
Patel, V., Flisher, A.J., Hetrick, S., McGorry, P., 2007. Mental health of young people: a global public-health challenge. Lancet (London, England) 369, 1302–1313. https://doi.org/10.1016/S0140-6736(07)60368-7.
Pearce, M., Page, A.S., Griffin, T.P., Cooper, A.R., 2014. Who children spend time with after school: associations with objectively recorded indoor and outdoor physical activity. Int. J. Behav. Nutr. Phys. Act. 11, 45. https://doi.org/10.1186/1479-5868-11-45.
Pearce, M., Saunders, D.H., Allison, P., Turner, A.P., 2018. Indoor and outdoor context-specific contributions to early adolescent moderate to vigorous physical activity as measured by combined diary, accelerometer, and GPS. J. Phys. Act. Heal. 15, 40–45. https://doi.org/10.1123/jpah.2016-0638.
Prochaska, J.J., Sallis, J.F., Long, B., 2001. A physical activity screening measure for use with adolescents in primary care. Arch. Pediatr. Adolesc. Med. 155, 554–559.
Puett, R., Teas, J., España-Romero, V., Artero, E.G., Lee, D., Baruth, M., Sui, X., Montresor-López, J., Blair, S.N., 2014. Physical activity: does environment make a difference for tension, stress, emotional outlook, and perceptions of health status? J. Phys. Act. Heal. 11, 1503–1511. https://doi.org/10.1123/jpah.2012-0375.
Rucker, D.D., Preacher, K.J., Tormala, Z.L., Petty, R.E., 2011. Mediation analysis in social psychology: current practices and new recommendations. Soc. Personal. Psychol. Compass 5, 359–371. https://doi.org/10.1111/j.1751-9004.2011.00355.x.
Sallis, J.F., 2000. Age-related decline in physical activity: a synthesis of human and animal studies. Med. Sci. Sports Exerc. 32, 1598–1600.
Schaefer, L., Plotnikoff, R.C., Majumdar, S.R., Mollard, R., Woo, M., Sadman, R., Rinaldi, R.L., Boulé, N., Torrance, B., Ball, G.D.C., Veugelers, P., Wozny, P., McCargar, L., Downs, S., Lewanczuk, R., Gleddie, D., McGavock, J., 2014. Outdoor time is associated with physical activity, sedentary time, and cardiorespiratory fitness in youth. J. Pediatr. 165, 516–521. https://doi.org/10.1016/j.jpeds.2014.05.029.
Shanahan, D.F., Franco, L., Lin, B.B., Gaston, K.J., Fuller, R.A., 2016. The benefits of natural environments for physical activity. Sport. Med. 46, 989–995. https://doi.org/10.1007/s40279-016-0502-4.
Song, C., Ikei, H., Miyazaki, Y., 2016. Physiological effects of nature therapy: a review of the research in Japan. Int. J. Environ. Res. Public Health 13. https://doi.org/10.3390/ijerph13080781.
Thompson Coon, J., Boddy, K., Stein, K., Whear, R., Barton, J., Depledge, M.H., 2011. Does participating in physical activity in outdoor natural environments have a greater effect on physical and mental wellbeing than physical activity indoors? a systematic review. Environ. Sci. Technol. 45, 1761–1772. https://doi.org/10.1021/es102947t.
Thomson, K.C., Richardson, C.G., Gadermann, A.M., Emerson, S.D., Shoveller, J., Guhn, M., 2019. Association of childhood social-emotional functioning profiles at school entry with early-onset mental health conditions. JAMA Netw. Open 2, e186694. https://doi.org/10.1001/jamanetworkopen.2018.6694.
Tillmann, S., Tobin, D., Avison, W., Gilliland, J., 2018. Mental health benefits of interactions with nature in children and teenagers: a systematic review. J. Epidemiol. Community Health 72, 958–966. https://doi.org/10.1136/jech-2018-210436.
Tingley, D., Yamamoto, T., Hirose, K., Keele, L., Imai, K., 2014. mediation: R package for causal mediation analysis. UCLA Stat. Stat. Assoc. 59. https://doi.org/10.18637/jss.v059.i05.
Tran, I., Clark, B.R., Racette, S.B., 2013. Physical activity during recess outdoors and indoors among urban public school students, St. Louis, Missouri, 2010–2011. Prev. Chronic Dis. 10, 130135. https://doi.org/10.5888/pcd10.130135.
Ulset, V., Vitaro, F., Brendgen, M., Bekkhus, M., Borge, A.I.H., 2017. Time spent outdoors during preschool: Links with children's cognitive and behavioral development. J. Environ. Psychol. 52, 69–80. https://doi.org/10.1016/J.JENVP.2017.05.007.
van der Zwan, J.E., de Vente, W., Huizink, A.C., Bögels, S.M., de Bruin, E.I., 2015. Physical activity, mindfulness meditation, or heart rate variability biofeedback for stress reduction: a randomized controlled trial. Appl. Psychophysiol. Biofeedback 40, 257–268. https://doi.org/10.1007/s10484-015-9293-x.
World Health Organization, 2019. Child and adolescent mental health [WWW Document]. URL https://www.who.int/mental_health/maternal-child/child_adolescent/en/ (accessed 8.19.19).
Zarr, R., Cottrell, L., Merrill, C., 2017. Park prescription (DC Park Rx): a new strategy to combat chronic disease in children. J. Phys. Act. Heal. 14, 1–2. https://doi.org/10.1123/jpah.2017-0021.
Zhao, X., Lynch, J.G., Chen, Q., 2010. Reconsidering Baron and Kenny: myths and truths about mediation analysis. J. Consum. Res. 37, 197–206. https://doi.org/10.1086/651257.