



Commentary

On mindful and mindless physical activity and executive function: A response to Diamond and Ling (2016)

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We read with great interest Diamond and Ling's (2016) review of the effects of 'mindful' and 'mindless' physical activity on executive control, as well as their perspectives on the state of research within the field of kinesiological cognitive neuroscience. However, with such a review comes the responsibility to accurately describe the literature and provide a balanced discussion. In the spirit of measured scientific debate, we challenge the Diamond and Ling review on several issues where we believe the authors to have fallen short. Specifically, the authors omit several highly relevant articles, failing to create a balanced perspective, mischaracterize the methodology (including the type of interventions) of several studies, and misinterpret the results of other publications. As a result, it is our position that their review is an inaccurate representation of the state of the field.

Prior to detailing the issues associated with the authors' "evidence-based" beliefs regarding physical activity and executive control, we will briefly discuss the topic of 'mindful' vs. 'mindless' physical activity, which is at the crux of their argument. We agree with the authors that it is possible that physical activity containing a more demanding cognitive component may lead to greater gains in executive control than physical activity with a lesser cognitive component. However, this is largely hypothetical as little empirical evidence exists to support such a claim (see Moreau et al., 2015 for a notable exception; but also see below for further discussion of the authors' misrepresentation of the findings). Rather, the vast majority of evidence for favorable effects of

physical activity on cognitive and brain outcomes comes from studies that do not have a clear cognitive component (i.e., walking). Given the lack of empirical support for 'mindful' physical activity improving executive control in general, we must entertain the possibility that such a form of exercise may in fact lead to smaller gains or even hinder performance gains expected to accrue through 'mindless' physical activity. As indicated, this is only a possibility, but until an empirical evidence base emerges in the literature we argue that 'mindful' physical activity may either benefit or hinder executive control; thus, Diamond and Ling's (2016) stance on this topic is hypothetical; it currently is not supported by the literature, and requires future, well-designed randomized controlled trial research to substantiate it. Accordingly, we recognize this empirical question as being important to shaping the future direction of the field, and look forward to the emerging literature in the coming years.

Further, we disagree with Diamond's use of the dichotomous (and apparently mutually exclusive) terms 'mindful' and 'mindless' to describe physical activity, as these terms are misleading in their suggestion that there are modes of physical activity that can be performed in the absence of any deliberate and conscious thought. In fact, this is not the case, as patterns of brain activation underlying 'mindless' physical activity have been identified from both fine and gross (e.g., walking) motor actions (e.g., Dum et al., 2002). In addition, neural circuits that support many aspects of motor function and motor learning including

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the cerebellum, basal ganglia, motor cortex, supplementary motor area, and cingulate cortex are intimately linked with brain circuits supporting executive function and other higher order cognitive functions (Caligiore et al., 2017; Lanciego et al., 2012; Strick et al., 2009). More importantly, however, is the use of the term ‘mindful’. Multiple anecdotal reports from athletes exist to suggest that they operate in very engaging and effortful, complex competitive environments, yet when queried about their thought process during performance, they cannot recall what they were thinking about during competition. This may suggest that deliberate and planned thought and action may not be as closely tied during ‘mindful’ physical activities that according to the authors’ definition clearly engage executive control. Best (2010) theorized on this very topic several years prior, and used the term ‘cognitively-engaging’ physical activity to describe the gradient of activities that range from more automatic behaviors to more complex and consciously controlled skilled activities. This may be a more accurate descriptor of the relationship between the amount and type of cognitive effort required to perform certain physical activity behaviors. Accordingly, Diamond and Ling’s (2016) discussion of mindful and mindless behaviors is an oversimplification of motor behavior and physical activity. In fact, much of the human brain is in some way dedicated to motor control and function (e.g., motor cortex, premotor, supplementary motor, anterior cingulate, cerebellum, basal ganglia, thalamus, etc.). Humans have evolved to move and our brains support that behavior (Bramble and Lieberman, 2004; Campos et al., 2000). Further, empirical research by Pesce et al. (2016) has detailed the synergistic effects of motor and cognitive intervention on executive control in preadolescent children. Thus, the oversimplification of the human motor system, and brain networks supporting them, is at the very heart of the misguided nature of Diamond and Ling’s review.

1. Misrepresentation of the state of the science due to omitted literature

Unfortunately, it is difficult to agree with the authors’ perspective that ‘mindful’ physical activity promotes executive function beyond that of ‘mindless’ physical activity (which they suggest has little impact at all) when several important and high quality articles, demonstrating the exact opposite relationship to that which the authors describe, are absent from their review. Most notably, (Kramer et al., 1999) conducted one of the first randomized controlled trial in the literature demonstrating that a walking intervention (i.e., ‘mindless’ physical activity) delivered three days per week for 1-h led to selective benefits to executive control performance on tasks of inhibition, working memory, and cognitive flexibility among older adults. Since publication, multiple replications using randomized controlled designs have been published in the literature using ‘mindless’ walking interventions in both healthy individuals and those with preexisting cognitive issues (e.g., mild cognitive impairment) (e.g., Erickson et al., 2011; Leckie et al., 2014).

Beyond simply illustrating differences in executive control behavior following ‘mindless’ walking interventions, randomized controlled trials have also demonstrated changes in the structure (Colcombe et al., 2006; Erickson et al., 2011; Jonasson et al., 2016; Maass et al., 2015; Niemann et al., 2014; Rosano et al., 2010; ten Brinke et al., 2015) and function (Chirles et al., 2017; Colcombe et al., 2004; Hsu et al., 2017; Smith et al., 2013; Voss et al., 2013) of neural networks underlying executive control and other higher order cognitive processes in older adults (note that similar findings have been observed in diverse populations ranging from children (e.g., Chaddock-Heyman et al., 2013; Davis et al., 2011) to individuals with schizophrenia (e.g., Vancampfort et al., 2014). Further support may be found in the non-human animal literature demonstrating that ‘mindless’ wheel running promotes structural changes in the hippocampus as well as better performance on spatial navigation, learning, and memory tasks beyond the gains observed from environmental enrichment (i.e., cognitive-engaging environments that include access to a running wheel) (Kobilo et al., 2011;

see Voss et al., 2013 for a review). Stated differently, Kobilo et al. (2011) demonstrated that wheel running promoted changes in the hippocampus to a larger extent than wheel running + environmental enrichment, indicating that the ‘mindless’ physical activity component was the necessary condition promoting changes in brain and cognition. Although the authors would likely argue that rodents are not humans, and memory is not executive control, their own review places importance on the neural network underlying the development of executive control, and details the importance of executive control to scholastic performance and related aspects of cognition such as memory and learning, which are dependent upon the hippocampus.

The above aging and non-human animal findings are among the strongest evidence opposing Diamond and Ling’s (2016) perspective, and their failure to include these articles, which are among the most highly cited in the field, demonstrates not only a lack of consideration for the empirical evidence opposing their view and lack of fidelity in their literature review, but also considerable bias leading to misrepresentation of the existing state of the field.

2. Misinterpretation of the cited literature

We believe that Diamond and Ling’s (2016) review of the literature in support of evidence opposing ‘mindless’ physical activity misrepresents the literature in its entirety. Their eighth section: “Aerobic exercise, or resistance training, without a cognitive component produces little or no EF benefit” includes support from seven studies meeting their inclusion criteria. However, these inclusion criteria are not well described in the review (i.e., undefined search terms, absent description of the search process, no PRISMA diagram, etc.), and omit several highly relevant articles. Most notably, a meta-analysis by Colcombe and Kramer (2003) included only randomized controlled trials of ‘mindless’ physical activity interventions and demonstrated generalized effects on cognition that were selectively greater for tasks or task components requiring greater amounts of executive control. Further, findings were enhanced when the intervention included strength training (also considered ‘mindless’ by Diamond and Ling, 2016).

A more recent meta-analysis of 36 randomized controlled physical activity trials in adults 50+ years of age (Northey et al., 2017) provides additional support in that significant effects were observed for aerobic exercise, resistance training, multicomponent training, and tai chi on cognitive function. Importantly, Northey et al. (2017) determined that mode, duration, and intensity of the physical activity intervention were important moderating factors benefiting cognition. Specifically, significant findings were reported across physical activity modes (with the exception of yoga), when the duration was 45–60 min per session, and the intensity was at least moderate. Such considerations for the characterization of the physical activity interventions is largely absent from Diamond and Ling’s (2016) review, as there is no discussion of mode, intensity, or duration of the interventions employed in each of the studies described, nor is there discussion of whether the interventions achieved changes in fitness, how documentation of adherence and compliance were monitored, whether it was a home-based or supervised exercise regimen, or the quality of the cognitive assessments. Failure to acknowledge these important elements of the physical activity interventions serves to treat all interventions as equal, despite differences in experimental rigor. It is well-established that significant heterogeneity in the quality of studies exists and can influence study outcomes, as can other factors that may moderate the effects of physical activity interventions on cognitive outcomes.

As noted above, Northey et al. (2017) observed that yoga did not relate to any aspect of cognition (but see Gothe et al., 2017), and resistance training did relate to executive function, two findings that specifically counter Diamond and Ling’s (2016) beliefs regarding ‘mindful’ and ‘mindless’ physical activity. However, Gothe and McAuley (2015), in a recent meta-analysis, report significant effects for

yoga training and acute bouts of yoga on executive function. Given that aerobic and resistance training both were related to improved cognition, Northey et al. (2017) concluded that exercise guidelines for this age group should include both aerobic and resistance training to specifically improve cognitive function. Finally, while significant findings were observed for tai chi (an example of Diamond & Ling's 'mindful' physical activity classification), Northey et al. (2017) cautions against the small number of studies in their analysis, specifically calling for more randomized controlled studies to confirm their findings. Other notable systematic reviews and meta analyses are absent from the Diamond and Ling's review that focus on children (e.g., Donnelly et al., 2016) and elderly (e.g., Scherder et al., 2014 who conducted a meta-analysis of walking interventions on executive functions).

Further, Diamond and Ling misrepresent the Smith et al. (2010) findings, suggesting that they do not find a relationship with executive function: "Consistent with this, two meta-analyses of randomized control trials in adults (mostly older adults) found little or no EF benefits from aerobic activity (Angevaeren et al., 2008 [which included 11 studies]; Smith et al., 2010 [which included 17 studies])." (Diamond and Ling, 2016, P. 37). However, Smith et al. (2010) clearly report the opposite result in their abstract: "Twenty-nine studies met inclusion criteria and were included in our analyses, representing data from 2049 participants and 234 effect sizes. Individuals randomly assigned to receive aerobic exercise training demonstrated modest improvements in attention and processing speed ($g = 0.158$ [95% CI: 0.055–.260], $P = .003$), executive function ($g = 0.123$ [95% CI: 0.021–.225], $P = .018$), and memory ($g = 0.128$ [95% CI: 0.015 – 0.241], $P = .026$)." (Smith et al., 2010, P. 239). Further, in the results section they again clearly indicate the exact opposite of Diamond and Ling's claim: "Nineteen studies assessed the effects of aerobic exercise on executive function. Aerobic exercise was associated with modest improvements in executive function ($g = 0.123$ [95% CI: 0.021–.225], $P = .018$) (Fig. 2), and effects were of similar magnitude across studies ($Q18 = 13.418$, $P = .766$)" (Smith et al., 2010, P.243). Additional misrepresentation of the literature may be found in their description of the Krafft et al. (2014) study, which Diamond and Ling (2016) cite to support their position. However, inspection of the results demonstrates greater change in brain activation in the neural network supporting inhibitory control for the aerobic exercise group compared to the attentional control group (Krafft et al., 2014).

3. Mischaracterizations of study methods

We disagree with Diamond and Ling's (2016) characterization of various physical activity interventions. Specifically, their critique of Hillman et al. (2014) and Kamijo et al. (2011) as examples of 'mindless' physical activity demonstrating no effects on executive control is a clear indicator of the authors' failure to understand the composition of the physical activity intervention employed in these studies. That is, such characterization of the physical activity intervention, as detailed in Hillman et al. (2014) could not be further from the truth, as the afterschool program included a focus on building cardiorespiratory fitness, along with learning new skills and appropriate social interaction. As stated in the Supplemental Information (<http://pediatrics.aappublications.org/content/pediatrics/suppl/2014/09/24/peds.2013-3219.DCSupplemental/peds.2013-3219SupplementaryData.pdf>): "The primary goal of the FITKids afterschool program was to increase cardiovascular fitness through participation in developmentally appropriate PA. Given the stage of development, secondary goals focused on experientially increasing motor skill competence (e.g., dribbling a basketball) and social responsibility (e.g., fair play, cooperation) within a PA setting." (Hillman et al., 2014, P. S11). To achieve these goals the intervention consisted of game play, team-based exercise requiring cooperation, as well as goal setting and self-regulation of physical activity behaviors, which would clearly fall within Diamond and Ling's 'mindful' physical activity classification scheme. Accordingly, the very

interventions they identify to argue against 'mindless' physical activity are indeed quite 'mindful' in their execution.

A similar clarification of Krafft et al.'s (2014) intervention is needed, because Krafft et al. clearly indicate that participation in physical activity games (requiring social interaction, understanding of rules, planning, strategizing, and coordinating behaviors to perform within games, etc.) was an essential component of the intervention. In fact, nowhere is it stated that these physical activity interventions were 'mindless', as typical forms of 'mindless' exercise that adults can engage in (i.e., walking), would not hold the interest, or be sufficiently motivational, to keep children engaged over an extended intervention period lasting weeks to months. Thus, the very studies that Diamond and Ling (2016) use as the pillars of their argument that 'mindless' physical activity does not promote changes in executive function are in fact quite 'mindful' in their design, and are incorrectly classified. Additionally, Diamond's assumptions concerning Tae Kwon Do versus regular physical education (Lakes and Hoyt, 2004) lack merit, as physical education has been routinely demonstrated to be both cognitively engaging and demanding given the requirement to plan and learn complex motor skills, game/competition strategy and rules, regulate physical behaviors, and social interaction. At the base of these errors in classification is perhaps a core misunderstanding of the complexities of physical activity.

4. Misinterpretation of statistical analyses

Diamond and Ling's interpretation of the data described in Kamijo et al. (2011) and Hillman et al. (2014) as depicted in Figs. 3 and 4, respectively are without statistical basis. That is, they indicate that the physical activity intervention group (which we have now clarified as 'mindful' physical activity) started out more poorly and merely caught up to the control group at post-test. However, the statistical analyses do not support their claim, as the groups were not statistically different at baseline (with the sole exception of one outcome; Hillman et al., 2014). Despite not finding significant between-group differences at post-test, the physical activity intervention group demonstrated significantly greater within-group improvements in performance from pre- to post-test; an effect that was not observed in the control group (Hillman et al., 2014; Kamijo et al., 2011). Similar within-group findings were observed in Krafft et al. (2014). Accordingly, Diamond and Ling's description of these studies is not consistent with the statistical analyses reported in the papers, and selectively reports the results as the brain function outcomes in these papers were not described. Further, Diamond and Ling (2016) also incorrectly attribute a post-test effect in the 1-back condition of Kamijo et al. (2011), when indeed no such difference was reported in the article.

5. Randomized controlled trials vs. cluster randomized controlled trials

In formulating their argument, Diamond and Ling state: "For that reason, real world activities such as martial arts and certain school curricula (that train diverse EF abilities) have shown more widespread cognitive benefits than targeted computerized training" (Diamond and Ling, 2016, P. 36). However, the martial arts (Lakes and Hoyt, 2004) and school curricula (e.g., Blair et al., 2014) studies cited were randomized at the classroom level, yielding a cluster randomization, rather than a subject-by-subject randomization, reducing causal inference. For example, based on their own description of the published articles using the Tools of the Mind curricula to train executive function, Diamond and Ling (2016) note that this intervention (Diamond et al., 2007) had greater success than that of others. They also argue the need for effective leadership to insure intervention fidelity (i.e., "Whether EF gains are seen depends on the way an activity is presented and conducted", Diamond and Ling, 2016, P. 37). In doing so, they inadvertently cast doubt on the causal link for their own Tools of the Mind intervention.

Specifically, the use of cluster randomized designs reduces their ability to establish causation (in this case for the Tools of the Mind curricula) as a competing variable in the intervention is leadership effectiveness within each classroom. Thus, it is possible that the instructors in their Tools intervention were more effective classroom leaders than those in the comparison group. To that end, not all randomized controlled trials are created equal and much of the details described in [Diamond's and Ling's \(2016\)](#) 'mindless' vs. 'mindful' physical activity comparison are glossed over.

6. Control groups

The issue of what are the appropriate control groups with which to compare the observed effects from a given intervention is important. Several possibilities for comparison exist, and within the physical activity intervention literature, this is an area of significant debate. [Diamond and Ling \(2016\)](#) take issue with the use of non-contact control groups to compare against intervention groups. Although such a perspective that favors a more active control group receiving a benign intervention is meritorious for a number of important reasons, it should never be assumed that this is the best comparison for all studies. Although we do not disagree with [Diamond and Ling's \(2016\)](#) perspective, there can be significant value in the use of non-contact control groups. For example, the use of a non-contact control condition in research on children offers the opportunity to compare an intervention against typical development, which is not possible with active control groups. In this manner, a physical activity intervention that promotes change in executive function over a period of several months is being compared against a group that is experiencing typical growth and development. Thus, a non-contact control condition serves as a 'moving-target' for comparison, making it more difficult to exhibit group-wise differences as a function of an intervention. As such, within group differences promoted by an intervention become increasingly more interesting. Regardless, clearly one important avenue for future research is to conduct randomized controlled trials containing multiple comparison groups.

7. Conclusions

[Diamond and Ling's \(2016\)](#) review of factors that improve executive functions is both important and timely. The review addresses important questions relevant to how executive functions may be improved and how sustainable these improvements could be. Further, an important focus is placed on best practices for improving executive functions. Unfortunately, the review of the literature used to formulate their argument favoring 'mindful' physical activity, as well as their referenced literature arguing against 'mindless' physical activity is fraught with errors. Highly cited relevant articles are omitted; the reporting of findings is selective; study findings are misrepresented; and the detail of intervention methods is ignored. It is unfortunate that [Diamond and Ling \(2016\)](#) failed to capitalize on the opportunity to provide further support for [Best's \(2010\)](#) theory of cognitively-engaging exercise to improve executive function, and place a positive challenge to the field to garner support for this theoretical perspective. In a similar vein, perhaps the collective goal of scientists studying the physical activity-executive function relationship should be the harnessing of our collaborative efforts and energies to identify those boundary conditions that influence this relationship. That is, what independent and conjoint effects, for example, of exercise dose, modality, demographic and genetic parameters, motivational status, etc. moderate the exercise and executive function relationship (see [Pesce et al., 2016](#) for an example). In short, our objectives should not be to selectively identify data that supports our own perspectives. Rather, we should be directing our energies at cultivating a coherent theoretical framework to serve as a blueprint or roadmap to guide scientific inquiry in this area for decades to come. The field of kinesiological cognitive neuroscience is expanding

dramatically but much is left to accomplish. We trust that our dialogue will assist in its continued development.

Conflict of interest

None.

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