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Review article

The effect of active video games on cognitive functioning in clinical and non-clinical populations: A meta-analysis of randomized controlled trials

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ABSTRACT

Physically-active video games ('exergames') have recently gained popularity for leisure and entertainment purposes. Using exergames to combine physical activity and cognitively-demanding tasks may offer a novel strategy to improve cognitive functioning. Therefore, this systematic review and meta-analysis was performed to establish effects of exergames on overall cognition and specific cognitive domains in clinical and non-clinical populations. We identified 17 eligible RCTs with cognitive outcome data for 926 participants. Random-effects meta-analyses found exergames significantly improved global cognition ($g = 0.436$, 95% CI = 0.18–0.69, $p = 0.001$). Significant effects still existed when excluding waitlist-only controlled studies, and when comparing to physical activity interventions. Furthermore, benefits of exergames where observed for both healthy older adults and clinical populations with conditions associated with neurocognitive impairments (all $p < 0.05$). Domain-specific analyses found exergames improved executive functions, attentional processing and visuospatial skills. The findings present the first meta-analytic evidence for effects of exergames on cognition. Future research must establish which patient/treatment factors influence efficacy of exergames, and explore neurobiological mechanisms of action.

1. Introduction

Cognition can be broadly defined as the actions of the brain involved in understanding and functioning in our external environment (Hirschfeld and Gelman, 1994). As it is generally accepted that cognition requires multiple mental processes, this broader concept has been theoretically separated into multiple 'cognitive domains' (Hirschfeld and Gelman, 1994). Although definitions vary, and the boundaries between domains often overlap, examples of distinct areas of cognitive functioning include the processes for learning and remembering verbal and spatial information, attentional capacities, response speed, problem-solving and planning (Strauss et al., 2006).

Various neuropsychological tests have been developed as tools for assessing and quantifying an individual's overall cognitive functioning (or 'global cognition') along with their performance within the separable domains of cognition (Strauss et al., 2006). Performance in these various cognitive tests has been found to be relatively stable over time in healthy adults, and moderately accurate predictors of real-world functioning and occupational performance (Chaytor and Schmitter-Edgecombe, 2003; Hunter, 1986). Furthermore, neuropsychological tests can detect the deficits in cognitive functioning which arise as a consequence of various psychiatric and neurological diseases (Mathuranath et al., 2000; Nuechterlein et al., 2004). For example, people with Parkinson's disease show marked impairments in planning and memory tasks (Dubois and Pillon, 1996), whereas those with schizophrenia have cognitive pervasive deficits, 1–2 standard deviations below population norms, which also predict the severity of disability in this population (Green et al., 2000). Additionally, cognitive abilities decline naturally in almost all people during healthy ageing (Van Hooren et al., 2007). In an ageing population, the functional consequences of cognitive decline may ultimately have a severe social and economic impact. Thus, interventions which improve cognition

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hold promise for the treatment of psychiatric and neurological diseases, an have positive implications for population health.

Fortunately, interventions which stimulate the brain and/or body can improve cognition, or attenuate decline. For instance, physical exercise has been shown to significantly improve global cognition, along with working memory and attentional processes, in both clinical and healthy populations (Firth et al., 2016; Smith et al., 2010; Zheng et al., 2016). Interventions can also be designed to target cognition directly, as computerized training programs for memory and other functions have been found to provide significant cognitive benefits, at least in the short term (Hill et al., 2017; Melby-Lervåg and Hulme, 2013). Furthermore, 'gamification' of cognitive training programs can maximize their clinical effectiveness, as more complex and interesting programs are capable of better engaging patients in cognitively-demanding tasks while also training multiple cognitive processes simultaneously (Anguera et al., 2013).

Previous studies have found that providing both aerobic exercise and cognitive training together may have additive effects, preventing ageing-related cognitive decline more effectively (Shatil, 2013). This may be due to aerobic and cognitive activity stimulating neurogenesis through independent but complementary pathways; as animal studies show that while exercise stimulates cell proliferation, learning tasks support the survival of these new cells (Kempermann et al., 2010), such that combining these two types of training results in 30% more new neurons than either task alone (Fabel et al., 2009).

Rather than delivering aerobic and cognitive training in separate training sessions, recent advances in technology has presented an opportunity for combining physical activity with cognitively-challenging tasks in a single session through 'exergames'. Exergames are considered as interactive video-games which require the player to produce physical body movements in order to complete set tasks or actions, in response to visual cues (Oh and Yang, 2010). Common examples include the 'Nintendo Wii' (along with 'Wii Fit' or 'Wii Sports software') or the 'Microsoft Xbox Kinect'. Additionally, virtual reality systems which use exercise bikes and/or treadmills as a medium for players to interact with three-dimensional worlds have also been developed to provide immersive training experiences (Sinclair et al., 2007).

Along with their popular usage for leisure and entertainment, there is growing interest in the application of exergame systems to improve clinical outcomes. Recent systematic reviews and meta-analyses of this growing literature have provided preliminary evidence that exergames can improve various health-related outcomes, including reducing childhood obesity, improving balance and falls risk factors in elderly adults, facilitating functional rehabilitation in people with parkinson's disease, and even reduce depression (Barry et al., 2014; Li et al., 2016; van't Riet et al., 2014). However, the effects of exergames on cognitive functioning have not been systematically reviewed, despite many individual studies in this area.

Therefore, the aim of this study was to systematically review all existing trials of exergames for cognition, and apply meta-analytic techniques to establish the effects of exergames on global cognition along with individual cognitive domains. We also sought to (i) examine the effects of exergames on cognition in healthy and clinically-impaired populations, and (ii) investigate if the effects of exergames differed from those of aerobic exercise alone, by comparing exergames to traditional physical activity control conditions.

2. Methods

This meta-analysis followed the PRISMA statement (Moher et al., 2009) to ensure comprehensive and transparent reporting of methods and results.

2.1. Search strategy

An electronic database search of Cochrane Central Register of Controlled Trials, Health Technology Assessment Database, Allied and Contempory Medicine, Embase, Health Management Information Consortium, MEDLINE and PsycINFO was conducted on 4th January 2017. A search algorithm was developed to identify all RCTs assessing the effects of exergames and similar technologies on cognitive functioning. The terms used in the algorithm are presented in Supplement 1. The reference lists of retrieved articles were also searched and a further search of Google Scholar was also conducted using the same keywords to identify any additional relevant articles.

2.2. Selection criteria

Only English-language research articles published in peer-reviewed journals were included. No restrictions were placed on populations studied or sample type. For the purpose of this review, exergames were defined as any video game for which required upper- or lower-body physical activity for user interaction. Video games controlled entirely via joysticks or handheld controllers were not classified as exergames. Eligible studies were randomized controlled trials (RCTs) which compared the effects of exergame interventions to non-exergame control conditions on performance in untrained cognitive tasks (i.e. performance in cognitive tasks which varied from those directly practiced within the exergame itself). This includes clinically-validated measures of global cognition, or specific tests of individual domains of cognitive functioning. Studies which combined exergaming with other therapeutic aspects were also eligible for inclusion, provided that (a) the exergame was identified as a primary component of a multi-modal intervention, and (b) the intervention dedicated as much/more time to the exergame component as any other aspect of the intervention. Single-session studies which examined acute effects of exergames on cognitive functioning were excluded from this review.

2.3. Data extraction

Articles were screened for eligibility by two independent reviewers (JF and BS). Disagreements were resolved through discussion until consensus was reached. Where further information or study data was required to determine eligibility or for meta-analyses, the corresponding authors of respective articles were contacted twice over the period of 1 month to request this. A systematic tool was used to extract the following data from each study:

(i) Primary outcome − Global cognition: This was defined as total change in any clinically-validated measures of overall cognitive functioning following an exergame intervention (or control condition). Where the total change in an overall measure of cognition was not reported, a composite change score was calculated as a combined average of the mean change (and variance) across all individual cognitive outcomes/tasks reported in the study. This method for calculating overall changes in cognition has widely been applied in previous meta-analyses examining cognitive outcomes of various training interventions (Hill et al., 2017).

(ii) Secondary outcomes − Individual cognitive domains: Effects of exergames in individual cognitive domains were examined with respect to the categories established by accepted neuropsychological domains (Strauss et al., 2006). Where cognitive tasks used in the studies were not listed by accepted neuropsychological categorization, the most suitable cognitive domain was determined through discussion between two reviewers (JF and BS) and consulted with senior reviewer (ES) for agreement to be reached. Executive functioning was examined as an individual domain, with subdomain analyses performed for individual executive functions of working memory, inhibitory control, task switching/flexibility and reasoning/problem solving. Other cognitive domains included visuospatial skills, verbal learning and memory, visual learn-