Computers & Education 82 (2015) 432–441

Contents lists available at ScienceDirect

Computers & Education

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

The role of executive control in young children's serious gaming behavior

Eva van de Sande*, Eliane Segers, Ludo Verhoeven

Behavioural Science Institute, Radboud University Nijmegen, The Netherlands

ARTICLE INFO

Article history:
Received 12 July 2014
Received in revised form
1 December 2014
Accepted 2 December 2014
Available online 10 December 2014

Keywords:
Action control
Attentional control
Behavior
Children
Serious games

ABSTRACT

The present study examined (1) how executive control contributed to in-game behaviors in young children while playing a serious game, (2) whether the levels of control changed when the game was played repeatedly, and (3) how the first experience with the game mediated the role of executive control to in-game behaviors when the game was repeated. Attentional and action control were directly assessed in 106 kindergartners, who played a single-leveled serious game twice. During their gameplay, the following behaviors were registered: time, number of scaffolds needed, mistakes, verbal expressions, questions, irrelevant game activities (drawings), and off-task behavior. The results for the first game round showed that time, expressions, and the need for scaffolds were predicted by attentional control. In the second round, a strong role for action control was found to overcome off-task behavior and irrelevant drawings. Verbal expressiveness was again influenced by attentional control. Moreover, mediation effects of attentional control to efficient in-game behaviors in the second gameplay were evidenced via scaffolding and expressiveness in the first gameplay. It is concluded that in new games children's attentional control contributes to formulating strategies and problem-solving, while their action control underlies sustained and goal-directed learning over time.

1. Introduction

Gamification in education opens up an interactive and open environment that allows children to be more in control of their learning paths. Although this constructivist type of learning can enhance motivation, it also demands more autonomous learning. This can lead to less efficient task behavior (Bavelier et al., 2011; Ketamo & Kiili, 2010). The reason is that the nature of serious games requires high monitoring to formulate game strategies and to maintain engaged learning over time, especially during repetitive plays (Bavelier et al., 2011). Indeed, despite proven gains to the enhancement of problem-solving abilities, social-emotional behavior, and vocabulary (Granic, Lobel, & Engels, 2014), the effects of serious games do not always fit the initially high expectations (Falloon, 2013; Klein, Nir-Gal, & Darom, 2000). Self-initiated and constructive learning thus places a heavy burden on executive control, especially in young children whose prefrontal cortexes have not yet matured (Ramscar & Gitcho, 2007). To ensure effective game designs, insights into the contributions of executive control in young children playing serious games over the course of time are necessary (Karle, 2011). Therefore, the current study examines how different types of executive control (i.e., attentional and action control) uniquely foster in-game behaviors while playing with a serious game, how these behavioral patterns change over the course of two repetitive games, and how the first game experience mediates the role of attentional and action control to follow-up gaming behavior.

Computer games are flooding the educational market, which makes it favorable to embed educational goals in them (Girard, Ecalle, & Magnant, 2012). *Serious games* provide such an opportunity. They are designed with a focus on learning goals like problem-solving, vocabulary, and social-emotional skills. These games provide children with simulations of daily routines and social interactions in a playful context, which allows them to experience new words and social-emotional skills in a safe and amusing environment (Susi, Johannesson, & Backlund, 2007). Moreover, the interactivity and autonomous choices within serious games enhance children's feelings of control in their

* Corresponding author. Behavioural Science Institute, Radboud University Nijmegen, Montessorilaan 3, Room A5.17, P.O. Box 9104, 6500 HE Nijmegen, The Netherlands. Tel.: +31 24 36 15 823.

E-mail address: E.vandeSande@pwo.ru.nl (E. van de Sande).

http://dx.doi.org/10.1016/j.compedu.2014.12.004
0360-1315/

learning, enlarging motivation and engagement (Girard, Ecalle, & Magnat, 2012; Granic et al., 2014). However, little of what is claimed to be educationally effective is rooted in empirical theory (Bavelier et al., 2011; Ennemoser, 2009; Kiili & Ketamo, 2007).

A multimodal gaming environment requires executive control capacities such as working memory and inhibition (Karle, 2011; Mayer, 2001; Moons & De Backer, 2013). Young children with low working memory have shown difficulty in complex activities like storytelling and understanding visual representations (Gathercole, Lamont, & Alloway, 2006). Moreover, playing serious games requires a great deal of independent learning which calls on substantial cognitive load to overcome off-task fidgeting and irrelevant mouse actions (Plass, Moreno, & Brucken, 2010). It is thus likely that executive control is strongly demanded for both the monitoring of information and sustaining effective gaming behavior (Bavelier, Green, Schrater, & Pouget, 2012). However, the role of executive control in serious gaming is far from clear. Although one study has shown associations between the attentional level of executive control and serious gaming, that study highlights the endpoint of computer attainment but no insights into executive control requirements while playing (Dye, Green, & Bavelier, 2009).

Unfortunately, the online demands of young children's executive control while playing serious games have also hardly been investigated (Granic et al., 2014; Watt, 2009). A few studies on another type of educational software, drill-and-practice games, have shown that children low in executive control have difficulties with planning and choosing the right steps with fewer to no learning gains as a result. These children made more mistakes, took more time to succeed, and showed more irrelevant mouse clicking (De Koning-Veenstra, Timmerman, Van Geert, & Van der Meulen, 2014; Kegel, Van der Kooij-Hofland, & Bus, 2009). Given that drill-and-practice games provide more guidance than serious games, it is easy to assume that demands to children's executive control in serious games are even higher. Moreover, multiple levels of executive control may simultaneously be required to support in-game behaviors, given the internal task demands as well as the urge to inhibit external inclinations that lead to off-task behavior (Cartwright, 2012). Executive control both on the attentional level and action level is needed to monitor the information in a multimodal learning environment and to simultaneously sustain goal-directed behavior (Cartwright, 2012; Diamond, 2013). *Attentional control* (also referred to as *cognitive inhibition*) enhances the formation of problem-solving strategies, formulating strategies through private speech, and efficient filtering of irrelevant information (Fernyhough & Fradley, 2005; Shaw, Grayson, & Lewis, 2005; Tran & Subrahmanyam, 2013). Veenstra, Van Geert, and Van der Meulen (2012), for example, showed that young children with attentional deficits made more errors and had more difficulty in switching strategies after instructive feedback when playing with learning-to-learn computer games. And *action control* (also called *behavioral inhibition*) helps children to inhibit random motor behaviors and to overcome off-task fidgeting (Kegel, van der Kooy-Hofland, & Bus, 2009). Young children with higher levels of action control show more adaptive behaviors and engaged work habits (Rimm-Kaufman, Curby, Grimm, Nathanson, & Brock, 2009). They are also more self-directed and better able to stay in their seats during (endured) task performance (Diamond, 2013; Ponitz, McClelland, Matthews, & Morrison, 2009). In a study by Kegel et al. (2009) on kindergartners' mouse behavior, the researchers found that less action control resulted in more errors and irrelevant mouse clickings, resulting in less learning gains.

Executive control is also demanded to stay engaged when repeating the game, which is necessary to learn from the game. When children master games, they likely know where to put their attention in the game (see Karle, Watter, & Sheddon (2010) for a study with students). This might diminish the challenge with likely less engagement and game flow (Kiili, 2007). Kiili and Ketamo (2007) found that 40% of a group of kindergartners stopped reflecting upon the game strategies soon after they started playing. Such metacognitive activities are likely to be strongly influenced by attentional control.

Contrarily, the role of action control might increase during repeated gameplay to overcome distractive behavior caused by the diminished challenge (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Booren, Downer, & Vitiello, 2012). De Koning-Veenstra et al. (2014) showed that 34% of a group of preschoolers had decreased effectiveness in their learning behaviors over the course of two to three sessions of games that targeted cognitive skills, as shown by more uninhibited mouse clicks. However, no direct action control assessments were included in the study.

Detailed explanations of the role of attentional and action control in serious games can only be found in the online interactions while playing. Unfortunately, studies on this topic either have focused on interactions of executive control with outcome measures or have examined mouse behaviors of drill-and-practice games with no direct assessments of attentional and action control. Moreover, very little is known about how game behaviors develop over time. Studies on this topic generally involve the presence of behaviors in single games that are new to the children (Booren et al., 2012; Saine, Lerkkanen, Ahone, Tolvanen, & Lyytinen, 2011). To date, to our knowledge, no empirical insight exists into how attentional and action control foster sustained learning behavior during lengthy and familiar game settings.

The present study is the first to examine how attentional and action control benefit the in-game behaviors of young children while playing a serious game. Moreover, we investigated whether the demands of both levels of executive control in in-game behaviors differed when the game was new versus familiar. We let 106 children play a serious game twice and tracked their in-game behaviors during those gameplays. We registered the scaffolds that children needed to solve the tasks, the time to succeed, and the number of mistakes. Vocal expressions, such as reasoning and engaged sounds, were also counted. Furthermore, off-task behaviors and questions were registered, as well as irrelevant extra mouse actions. For all these behaviors, we investigated their relationship with attentional and action control. Specifically, we addressed three research questions:

(1) What are the unique contributions of attentional and action control to in-game behaviors while working with a new serious game?

We expected attentional control to enable the monitoring of new task demands, as shown by a relationship with fewer scaffolds, less game time (i.e., more efficient gameplay), fewer mistakes and questions, and more vocal expressiveness. In addition, we expected action control to help in overcoming random mouse clicking and off-screen fidgeting, as shown by less extra irrelevant drawings and fewer off-task behaviors.

(2) What are the unique contributions of attentional and action control to the in-game behaviors when the game is more familiar?

Given the single-level nature of the game we selected, we expected that challenges in the second game round would be monitored more easily, resulting in lower demands to attentional control. Contrarily, the diminished challenges were expected to be at the expense of