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Scaffolding Executive Function Capabilities via Play-&-Learn Software for Preschoolers

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Abstract

Educational software in the form of games or so called "computer assisted intervention" for young children has become increasingly common receiving a growing interest and support. Currently there are, for instance, more than 1000 iPad apps tagged for preschool. Thus it has become increasingly important to empirically investigate whether these kinds of software actually provide educational benefits for such young children. The study presented in the present paper investigated whether preschoolers have the cognitive capabilities necessary to benefit from a teachable-agent-based game of which pedagogical benefits have been shown for older children. The role of executive functions in children's attention was explored by letting 36 preschoolers (3;9 – 6;3 years) play a teachable-agent-based educational game and measure their capabilities to maintain focus on pedagogically relevant screen events in the presence of competing visual stimuli. Even though the participants did not succeed very well in an inhibition pre-test, results showed that they nonetheless managed to inhibit distractions during game-play. It is suggested that the game context acts as a motivator that scaffolds more mature cognitive capabilities in young children than they exhibit during a non-contextual standardised test. The results further indicate gender differences in the development of these capabilities.

Keywords: inhibition, attention, teachable agents, eye tracking, learning by teaching

Through the introduction of technology in preschools, new avenues for facilitating interventions in preschool have opened up (Clements, 2002; Huffstetter, King, Onwuegbuzie, Schneider, & Powell-Smith, 2010). One important potential is the facilitation of school readiness for children who otherwise would be at risk of falling behind once they start school due to weak preparatory skills, particularly in early numeracy and literacy (Clements, Sarama, Spitler, Lange, & Wolfe, 2011; Kendeou, van den Broek, White, & Lynch, 2007; Morgan, Farkas, & Wu, 2009). In the present study, we investigate the possibilities of introducing computer games in a revamped approach of the *learning by teaching* (LBT) paradigm with the use of so called *teachable agents* in preschool. The LBT paradigm reverses the role of the student and lets students become teachers. However, the question is whether this kind of educational software, that has been proven pedagogically valuable for school children, is suitable for children of preschool age. In order to be able to teach, focus and attention on your tutee is crucial and this requires a sufficient development of executive control. Furthermore, the preschool is at times a distracting environment with high levels of noise and other perturbations. Thus, before investing resources in developing a full-fledged LBT-game for preschoolers and launching a longitudinal study to investigate learning effects, there are some crucial and more basic questions that need to be answered. With this study we have used a scaled down version of an LBT-game in order to investigate preschoolers' ability to inhibit visual distractions.

Need for Empirically Informed Educational Software Development

The impact of computer usage throughout today's society has also affected preschool curricula in which teaching of basic technological interaction and use of computers in education is nowadays encouraged (The Swedish National Agency for Education, 2011; UNESCO, 2008). Research on technology's impact on children's health over the past 30 years has produced divergent results. It is suggested that children in the midst of their cognitive development should have minimum technological exposure (Council on Communications and Media, 2010). In a review of neuroscientific and psychological studies related to children's exposure to digital media, Howard-Jones (2011) emphasise that we must acknowledge the factors which lead to detrimental effects on the developing brain. He concludes these factors to be (a) violent media content, (b) excessive use, and (c) late night use. Studies have shown that these factors can, for some individuals, result in attention disorders, disturbed sleep patterns, visual strain, and even seizures (Landhuis, Poulton, Welch, & Hancox, 2007; Page, Cooper, Griew, & Jago, 2010).

However, results pertaining to research on moderate use of computers and its impact on young children's learning and educational development present a more pleasant side. Children with access to computers at home during preschool age have been found to perform better on school readiness as well as motor and cognitive development tasks even when socioeconomic status is controlled for (Fish, et al., 2008; Li & Atkins, 2004). Computer use in early age has also shown positive effects on language acquisition (Chera & Wood, 2003; Din & Calao, 2001), social, collaborative problem-solving (Cardelle-Elawar & Wetzel, 1995; Muller & Perlmutter, 1985), and learning motivation (Bergin, Ford, & Hess, 1993; Liu, 1996; for a review on the effects of media use on young children's learning and reasoning, see Lieberman, Bates, & So, 2009).

These mixed results leave both preschool teachers and parents struggling with how to approach the issue of letting young children interact with technology. Ljung-Djärf (2008), in a study of attitudes towards computers in three preschools in Sweden, found that there were three overall attitudes towards computer activities: (a) threatening other activities, (b) one of many alternative activities, (c) an essential activity. Preschool personnel tried their best to implement computer use in lines with the preschool curriculum. However, the choice of computer use was largely left to the child and it was mostly utilised through play separate from scheduled and structured activities.

The widespread use of computer-based technology with young children necessitates that any educational software delivers what it promises. However, the Center on Media and Child Health, USA, claims most educational video games have not been scientifically tested and thus advises parents to use their best judgement (CMCH, 2008). It is firmly believed that computers can be a valuable asset in preschool education, especially as a tool to help children who otherwise would be at risk falling behind once they start school. In order for computers to become powerful educational tools, software development must be informed by educational and developmental research on young children, and the resulting products must be subjected to empirical investigation.

Advantages of Intervention in Preschool

Studies of school readiness have reported large individual differences among children with regard to both literacy and numeracy skills (Aunio, Hautamäki, Sajaniemi, & Van Luit, 2009; Jordan, Kaplan, Ramineni, & Locuniak, 2009). To ensure preschool children do not lag behind, it is important to consider ways to support children and help them overcome potential risks of starting school with an initial disadvantage (Denton & West, 2002; Griffin & Case, 1997; Locuniak & Jordan, 2008; Räsänen, Salminen, Wilson, Aunio, & Dehaene, 2009; Wilson, Dehaene, Dubois, & Fayol, 2009). The majority of children who enters school with early language and math difficulties are low-performers whose deficiencies stem from external factors, such as low socio-economic status (SES) and low exposure and training at home and at preschool (Denton & West, 2002; Jordan, Kaplan, Nabors Oláh, & Locuniak, 2006). Without intervention, these children are likely to remain low-performers throughout school (Jordan, Kaplan, Ramineni, & Locuniak, 2009; Kendeou, van den Broek, White, & Lynch, 2007; Mononen, Aunio, Koponen, & Aro, 2014). However, preschools are understaffed in many countries and preschool teachers often feel overloaded by what is already required from them in their everyday activities (Bullough, Hall-Kenyon, MacKay, & Marshall, 2014).

Here educational software harbours a potential with respect both to scaling-up and enabling intervention with reasonable time investment by teachers. Indeed some educational software can be used with little instruction, and teachers may be allowed to focus on one group of children while simultaneously being sure that another group of children is engaged in fun, meaningful activities whilst learning (Praet & Desoete, 2014). However, returning to a previous point, the pedagogic quality of much educational software is low. In order to benefit young children at preschool the educational software that is used must be of high quality as well as be proven pedagogically valuable for the age group in question. The study presented in this article involves a kind of educational software game proven educationally valuable for school children and investigates whether it can also be suitable for younger children.

Computer-Based Learning-by-Teaching

Educational benefits from LBT have been known since the early eighties through the seminal work of Bargh and Schul (1980). This paradigm reverses the roles by letting students become tutors in order to teach their peers. In the present paper, an explorative study is presented which investigates cognitive prerequisites in preschoolers with respect to a digital LBT game developed for this age group. The reason for this venture is that the LBT paradigm has demonstrated great pedagogical advantages for school children. Children who take the role as tutors show an increase in effort compared to when they learn for themselves. The effort is evidenced through the children spending more time on learning materials and also by them analysing the material more thoroughly (Bargh & Schul, 1980; Martin & Schwartz, 2009). This increased effort seems to arise from motivational mechanisms (Benware & Deci, 1984). Working with learning material in order to teach others seem to bring about feelings of responsibility and meaningfulness of the task (Bargh & Schul, 1980) leading to positive effects on self-efficacy beliefs (Moores, Chang, & Smith, 2006), that is, the belief in one's own competence within a given domain. Self-efficacy beliefs in fact turn out to positively correlate with actual accomplishments (Pajares & Graham, 1999). A proposed major factor of the benefits of the LBT approach is that it stimulates metacognition (Flavell, 1979), in other words, reflective thinking about problem-solving and one's own learning (Schwartz, et al., 2009).

In recent years, digital implementations of the LBT paradigm have seen light in the form of educational games involving teachable agents (TA; Brophy, Biswas, Katzlberger, Bransford, & Schwartz, 1999). A TA is in essence an artificial intelligence algorithm that ensures that the behaviour of this digital representation of a tutee over time reflects how it is being taught by the human student so that the digital tutee indeed appears to learn. This form of pedagogical software, in line with research on the traditional form of LBT, has proven powerful for school children aged 8 years and upwards, both in terms of learning outcomes and motivational effects (Biswas, Leelawong, Schwartz, Vye, & The Teachable Agents Group at Vanderbilt, 2005; Ogan, et al., 2012; Pareto, Haake, Lindström, Sjödén, & Gulz, 2012).

This human-to-digital-tutee version of LBT has three unique advantages over non-digital LBT: (a) all children can be teachers, this includes those that are not naturally inclined to take such a role because they either feel less knowledgeable than their peers, or due to feelings of low self-efficacy; (b) the child who teaches can automatically be matched with the digital tutee to ensure an adequate challenge for each child tutor. To obtain this kind of match in human-to-human peer learning is often difficult due to that a large difference in competence between tutee and tutor results in non-optimal learning benefits; lastly, (c) no human tutee will suffer from a poor tutor, which can occur and be experienced as an injustice problem when LBT-inspired pedagogies are used in a group of students. The body of research that provides evidence for the educational benefits of the digital LBT approach has had a focus on pupils aged between 8 and 14 (Biswas, et al., 2005; Gulz, Haake, & Silvervarg, 2011; Kim, et al., 2006; Wagster, Tan, Wu, Biswas, & Schwartz, 2007). Whether the benefits of a digital LBT-game can be generalised to preschoolers is an open question. In particular, the less developed *executive functions* in preschool children bring about doubt.

The term "executive functions" is an umbrella term for a multitude of different cognitive processes which facilitates top-down control in individuals (Diamond, 2013) and is a vital component of school readiness and academic achievement (Blair & Razza, 2007; Borella, Carretti, & Pelegrina, 2010; Zaitchik, Iqbal, & Carey, 2014). The focus of the present study was on top-down guidance or control of attention, more specifically sustained attention and inhibition. Sustained attention refers to the ability to remain alert and maintain attention on the designated task. In order to enable such focus of attention, one has to be able to suppress elements that are competing for attention; this is handled by inhibitory processes. Several researchers consider inhibition to be a primary executive control function (Burgess, Alderman, Evans, Emslie, & Wilson, 1998; Garavan, 2002; Norman & Shallice, 2000).

In order to fully benefit from LBT software that includes a digital tutee, children, in their role as teachers, must be able to pay sufficient attention to their tutee’s actions and learning (Okita & Schwartz, 2013). An adequate level of attention and focus retention requires a certain developmental level with respect to executive functions, such as attentional and inhibitory capabilities. There is an intense developmental period of executive functions during preschool age (Perner & Lang, 1999) and this suggests that executive functions will not be as well developed in 3- to 6-year-olds as compared to 8-year-olds. Consequently, an educational game based upon the idea that preschool children should teach and instruct – and pay close attention to – a digital tutee may not necessarily work out well.

Although, a study by Gelman and Meck (1983) showed that children aged 3-5 were able to detect errors when a puppet performed a counting task, even when the numbers exceeded the children's explicit counting range. The study suggested that the children have implicit knowledge of numbers exceeding their apparent count limit, but due to performance demands they cannot explicate this. By observing someone else counting, the children can free up cognitive resources and therefore more easily reflect upon errors. Thus, this provides good reason for tailoring LBT-based games to preschoolers in order to alleviate cognitive strains. It is also important to emphasise that executive abilities are gradually developed (Levin, Culhane, Hartmann, Evankovich, & Mattson, 1991; Wellman & Liu, 2004).

The scientific opinion of young children's cognitive capabilities has repeatedly been revised throughout history. This is usually mediated through the introduction of novel methods and techniques, and more often than not, children turn out to be more cognitively able than previously assumed. Surprising results have been found in preschoolers' moral reasoning (Hong, 2004); infants appeal to mental states (Baillargeon & Onishi, 2005; Southgate, Chavallier, & Csibra, 2010); and young children's selective attention and memory encoding efficacy (Blumberg & Torenberg, 2003; Markant & Amso, 2014). These results elucidate the fact that cognition does not exist in a vacuum. Especially in educational environments, skills and abilities emerge through contextual framing which acts as a scaffold for enhancing cognitive behaviour.

Digital learning games can provide this type of contextual scaffold as recently shown by Chin, Dohmen, and Schwartz (2013). Departing from Piaget's prevalent claim that 9- to 10-year-olds are not developmentally mature to reason about hierarchical relations and inheritance in taxonomies, results of their study showed that this was only true for traditional learning environments. The 9- to 10-year-olds in the study who had an opportunity to learn the same content by means of a digital game based on the LBT-pedagogy were able to reason about inheritance in taxonomies. A rich and complex digital game targets different levels of difficulty as well as different learning goals therefore it is impossible to know before empirical investigation what aspects of a game can be learnt and mastered given different developmental levels. This makes it relevant to empirically investigate to what extent 3- to 6-year-olds can have the cognitive prerequisites to pedagogically profit from LBT software.

Distractions in Preschools

The preschool environment is known to be lively with a plethora of visual and auditory distractions. In conjunction with less developed executive control in preschoolers, this might become a hindrance in introducing computer-based interventions in preschools. Visual distractions have long been known to be detrimental to preschoolers' performance on simple motor tasks (Poyntz, 1933; Somervill, Hill, White, York, & Hayes, 1978). Computers at preschools are normally situated in shared spaces where other activities are taking place; game playing might be a shared activity or other playing activities might occur around or near the child who is interacting with the computer. This implies that distractions might be of great concern especially in relation to the use of LBT-based games in preschool since players of these games need to focus on their digital tutee in order to be able to reap the benefits these games potentially have in store in terms of intervention programs in preschool.

Aim and Research Questions

Our aim in the present study was to closer examine preschoolers' distractibility by bringing an LBT-based educational game to a preschool. The following two explorative research questions were formulated

- Are there preschoolers who can sufficiently focus on their digital tutee's actions to inhibit distractions? and if so
- How do their test scores of executive control differ from preschoolers who cannot?

Pre-tests to determine the preschoolers' sustained attention and inhibition abilities were administered. Subsequently we studied the preschoolers' inclination to be distracted and lose focus on what was central in an LBT-based game from a pedagogical design perspective. For this study, distractibility is defined as time spent gazing at pedagogically irrelevant elements within a time-limited window when focus is needed on parts relevant to the digital tutee's display of problem-solving and learning. Visual distractions were incorporated into the game in the form of animations in order to measure the effects it might have on the participants' attention. The rationale for using a game to investigate the preschoolers' level of distractibility is an ecological one with the aim to get the experiment design as representative as possible to the actual context of preschoolers interacting with a teachable agent.

Method

Participants

65 children (34 girls, 31 boys) aged 3;1 to 6;3 from a preschool in Southern Sweden

were given permission through written consent forms by their guardians to participate in the experiment (70 % guardian consent rate). The particular preschool was selected because it is situated in a rural area which is representative of Sweden with regard to level of education and income among its population. In this municipality, 41 % of the inhabitants have completed higher education compared to 39 % of the population of Sweden. The average income is 298k SEK compared to 274k SEK for the average working Swede. We did not investigate any variables that might differ between families whose children were allowed to participate and families whose children were not. Although we cannot exclude the possibility that there were differences between the groups, it is thought that it may be attenuated by the nationally very small differences of SES in Sweden. The preschool houses children from ages 1 to 6 years old and the only criteria for children to participate were that they had turned 3 years of age. The study was approved by the Regional Ethical Review Board of Lund (ref. 2013/111).

Procedures and Measures

Each child participated alone in two separate data collection sessions; one pre-test session about 25 minutes long and a main test session about 15 minutes long. Data collection was carried out over a period of four weeks in April 2013; two weeks of pre-test data collection and two weeks of main test data collection. Thus there was a gap of two weeks between the two sessions for each participant. Both sessions took place in a room at the child's department of the preschool to which the door could be closed in order to minimise uncontrollable distractions. During the pre-test sessions, the participants performed one inhibition and one sustained attention pre-test task and also played the digital LBT-game without any distractive animations in order to familiarise themselves with the game. The rationale for letting participants get familiar with the game before data collection of the main task was to make sure that we did not measure novelty effects. That is, we wanted to make sure that distractive or attentional behaviour was not induced from curiosity of the game components themselves. In the main task session, the participants played the digital LBT-game with the distracting visual stimuli.

Data collection was carried out by one experimenter who was present all through the sessions; no teachers were present during the sessions. The experimenter spent one day at the preschool prior to start of the study and was introduced to the children in order for them to feel familiar with the experimenter. The preschool served lunch at 11:30 am followed by group reading and relaxation time. All data collection sessions thus took place sometime between 10:00-11:30 and 13:00-15:00 and teachers were given the task of asking a child, who had been given parental consent, whether she or he would like to participate. Thus, no control was exerted upon time spacing between the two data collection sessions in favour for the children's individual availability and autonomy.

First pre-test: Inhibition. To measure the ability to inhibit irrelevant visual stimuli, an anti-saccade task (Hallet, 1978) embedded in a narrative to appeal to younger participants was used. The anti-saccade task is an established method of measuring inhibition of reflexive motor movements (Antoniades, et al., 2013; Hutton & Ettinger, 2006; Munoz & Everling, 2004). In this study, a narrative for the task was created in order for it to be more easily explained to the target participants; otherwise the procedure mimicked those of established tests. The task consisted of 24 trials where two apples were shown on either side of a centred diagonal cross on the screen. The participant was instructed to imagine that the apples belonged to him or her. A cartoon monster was shown to the participant and it was explained that this monster would appear and eat one of the apples, and that the only way to save the other apple was to look at it and avoid looking at the monster. Participants were asked to try and save as many apples as they could.

This task was a test of the participants' inhibitory skills of reflexive motor movement when presented with visual stimuli, and is a way to measure the development of executive control with regard to inhibition. The task was presented on a computer screen and the children's eye-movements were tracked using an SMI RED remote eye tracker sampling at 250 Hz.

Children under the age of 8 have trouble suppressing reflexive saccades towards moving stimuli (Munoz & Everling, 2004). As most of the children were unlikely to pass most of the trials, it was not deemed meaningful to measure this task in terms of correct and incorrect trials. Instead the measure was calculated by using time spent avoiding looking at the monster as a fraction of the monster's display time.

Second pre-test: Sustained Attention. A traditional go-no-go paradigm task (Groot, de Sonneville, Stins, & Boomsma, 2004; Robertson, Manly, Andrade, Baddeley, & Yiend, 1997) was adopted in order to measure sustained attention. The stimulus was presented on a computer screen and an external keyboard was used to capture the participant's response. Five colours were quasi-randomly displayed 15 times each. Each colour was displayed for 500 ms and separated by a 100 ms mask. The participant was asked to press the spacebar of the keyboard each time a new colour was shown on the screen (60 go-trials) except for when the colour was blue (15 no-go- trials). Before beginning the task, all colours one at a time were displayed to the participants and they were asked to name them in order to make sure that participants were familiar with the colours and that they did not have any colour vision deficiencies that could disrupt performance. All participants correctly identified the colours. The participants were also given a test run of 15 trials after which the task began.

From the total 75 trials, each participant's final score was recorded as (a) hits, i.e., the number of times a participant withheld pressing the space bar key when the colour blue was presented; (b) misses, i.e., the number of times a participant pressed the space bar key when the colour blue was presented; (c) correct rejections, i.e., the number of times a participant pressed the space bar key when any other colour than blue was presented; and (d) false alarms, i.e., the number of times a participant withheld pressing the space bar key when any other colour than blue was presented. With these scores, a signal-detection sensitivity index – $\log d$[1] – was calculated (Davison & Tustin, 1978). Participants will have an innate tendency towards being either response prone or response aversive which will lead to a biased measure if only hits are used. The calculated measure of $\log d$ is a means to handle this response bias, and was used as the value for Sustained Attention during the analyses. Generally, d'[2] is calculated in order to handle response bias. However, $\log d$ is recommended to use with tests of less than 100 trials (Brown & White, 2005), this since d' has a tendency to be positively biased for tests with a low number of trials (Kadlec, 1999). In order to handle extreme discriminability (i.e., a participant managing to score 100 % on either go or no-go trials), Brown and White's (2005) recommendations of adding a constant – .5 in this case – to hits, misses, correct rejections, and false alarms was adopted.

Main test: LBT-game with visually distracting stimuli. The main task consisted of the participants playing the digital LBT-game Bird Hero – developed in JavaScript and HTML5 by Anderberg, Axelsson, Bengtsson, Håkansson, and Lindberg (2013). The game narrative revolves around a flock of chicks that are blown out of their nests and need help to get back. The child helps the chicks return home via a lift by pushing lift buttons (see screen shots in Figure 1). When a chick presents the number of feathers representing the floor it lives on, the child's task is

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[1] $\log d = \frac{1}{2} \times \log 10 \left(\frac{Hits}{Misses} \times \frac{Correct\ Rejections}{False\ Alarms}\right)$

[2] $d' = Z\left(\frac{Hits}{Hits+Misses}\right) - Z\left(\frac{False\ Alarms}{False\ Alarms+Correct\ Rejections}\right)$

to match this number with one of eight lift buttons presented at the bottom of the computer screen. The game consists of four game modes: (a) child plays, (b) TA watches whilst child plays, (c) child guides TA who tries to play, and (d) child watches TA play on his own. The four game modes are depicted in the bottom part of Figure 1. First, in Game Mode 1, the child alone helped the chicks to the correct branch by manoeuvring the lift panel. In Game Mode 2, the TA in the form of a panda introduced himself and asked whether he could watch in order to later on be able to help some birds himself. In Game Mode 3, the TA suggested which lift button should be pressed by presenting his choice in a thought bubble. The participant decided whether the suggestion was correct or incorrect through a binary choice by pressing a green tick or a red cross respectively. These binary buttons were presented centred at the bottom of the computer screen and the TA’s thought bubble did not disappear until the participant pressed one of these binary buttons. In Game Mode 4, the TA played without any help from the participant. Participants wore headphones during game play in order to be able to listen to the TA and the birds.

It is important to emphasise that these game modes are not an experimental manipulation but a concept crucial to LBT-based games. The Bird Hero game was developed to simulate a fully working LBT-game but in a "Wizard-of-Oz"-type implementation, that is, without any advanced artificial intelligence incorporated, since we are not investigating learning effects in this particular study but instead how young children behave with a TA. This is thus, as has been expressed above, an ecological rationale.

Distractibility manipulation. Throughout the game, three different distracting visual stimuli were used in the form of animations that were irrelevant to game play (Figure 2): (a) a football rolling across the grass in front of the TA and the bird, (b) an aeroplane passing by in the background, and (c) a flickering square, symbolising a program glitch. These animations were introduced experimentally to approximate the effects of a noisy environment with task-irrelevant stimuli under controlled circumstances in order to measure their influence on children's attention. Since the task-irrelevant animations were condensed into an eye-trackable area, they provided a possibility for measuring distractibility. The aim was to investigate which participants were able to inhibit these stimuli and focus their visual attention on the task at hand. The distractive animations were played in Game Mode 3 and 4 at crucial parts of game play when the child – in order to pedagogically profit from the game – would have to concentrate on the TA.

In Game Mode 3, where the TA suggests which button to press and the child accepts or rejects the suggestion, the football rolled passed once on the lower part of the screen as the TA presented his suggestion in the thought bubble in one of the game rounds. This animation played for 3 seconds. The animation was played back when the TA made an action which the participant should attend to. Importantly, in Game Mode 3 the participant is in control of the game and can look at the thought bubble any time after the distracting animation has finished. The distraction in Game Mode 3 serves the purpose of giving a more general view of how distractions affect the participants by means of comparing two game rounds where the distracting animation is either present or absent.

In Game Mode 4, in which the child only observed the TA playing but was not able to act herself, the glitch flickered in the top left corner of the screen just as the TA made his choice on the first round (out of two). After the TA had made his choice, the aeroplane flew past diagonally, entering the top left corner of the screen. For the second round, the same two animations were played but in reversed order (i.e. aeroplane during the TA's choice and glitch after the TA's choice). These animations played for 2 seconds each.

The way the TA made his choice was by moving his hand horizontally, from left to right, along the eight lift buttons at the bottom of the computer screen. Once he reached the end of the screen, he moved his hand back from right to left and made his selection. His hand then continued all the way to the left and the hand moved horizontally once more from left to right and back again and exited the screen on the far left. The TA's hand movement across the screen took 2 seconds. The reason why the TA moves his hand along the lift buttons twice is so that when the two counterbalanced animations are played – during and after the TA's choice – the TA's hand is situated at the same spot in order to make the two conditions as visually similar as possible with the only difference that a lift button is up or down depending on whether it has been pressed by the TA or not. The animations were played 1 second before the TA reached the button he was meant to press (during the TA's choice) or had recently pressed (after the TA's choice). This is a time limited situation where the TA is in charge of the game and the child can either attend to the TA's actions or to the distracting animations – but not both. An SMI RED remote eye tracker sampling at 250 Hz was used throughout game play.

Because the game holds many moving elements – which triggers smooth-pursuit eye movements – fixations could not be reliably detected. Instead, we used gaze proportions of, or accumulated gaze time on, areas of interest (AOIs) calculated from the raw sample data. The AOIs were defined as Bird, Lift Buttons or Binary Buttons, Distraction, and TA or TA Hand. The gaze time spent on the distractive animations was used as a measure of distractibility. Comparison between animations before and after the TA's choice in Game Mode 4 gave an indication of whether children are less inclined to be distracted when the TA displays his learnt ability compared to when nothing interesting from a pedagogical perspective is happening on the screen (Research Question 1). The distractibility measure during the TA choice was used in analysis together with the pre-test measures in order to answer whether measures of executive function can predict distractibility behaviour (Research Question 2).

Results

Of the original 65 participants, 36 were part of the analysis (20 girls, 16 boys; M_{age}= 5;2; *SD* = 9 months). The large attrition was due to three reasons: (a) for natural reasons, a large part of the participants were not at all familiar with numbers and could therefore not participate in the main task (18 participants; M_{age}= 4;1); (b) a few participants were reluctant to complete all pre-tests (7 participants); and (c) the eye tracking data were too poor for some participants in the main or pre-tests (4 participants). Statistical analysis was performed using the statistical programming language R (v.2.15.1).

Pre-Tests Analyses

The means, standard errors, maximum and minimum values of the two pre-tests measures as well as age and Distractibility measures are summarised in Table 1. As expected, the participating preschoolers did not perform well on the inhibition task which is in line with previous research (Fukushima, Hatta, & Fukushima, 2000). On average the participants managed to completely inhibit the distraction 9 times in this task out of the 24 trials. However, using the described inhibition time fraction measure there were differences revealed across the age variable. A statistically significant positive correlation was found between age and the Inhibition measure ($r = 0.45$) whilst the correlation between age and the Sustained Attention measure, though positive, was weak ($r = 0.28$). This analysis suggests that the older a participant was, the better she or he performed on the pre-test tasks. A weak positive correlation was also found between the two pre-tests ($r = 0.29$). Student's *t*-tests were carried out and did not reveal any statistically significant difference between genders with regards to Sustained Attention (t = 0.02; df = 34; p = 0.98) and Inhibition (t = -0.35; df = 34; p = 0.73).

Distractibility Analysis

The graphs of Figure 3 show two similar time windows of the game – just when the TA presents his choice in a thought bubble of Game Mode 3 – where the difference is that the football animation was played as a distraction in the second time window (Figure 3B). In both time windows, gaze proportions are averaged over the 36 participants. Figure 3C represents a difference graph between the two time windows. On average, the participants spent 994 ms (*SE* = 125 ms) of the total 3 seconds animation playback time looking at the distraction (33 %).

The graphs of Figure 4 show the two time windows during (4A) and after (4B) the TA's choice in Game Mode 4. Gaze proportions are averaged over the 36 participants and consist of the TA helping two birds. The majority of the participants did not attend to the distracting animations at all during the TA's choice (20 out of the 36) and only 2 participants attended to both of the animations played during the TA's choice. In Game Mode 4, the average time of which the participants gazed at the distractions during and after the TA's choice was 198 ms (*SE* = 43 ms; 9.9 % of screen time) and 581 ms (*SE* = 82 ms; 29 % of screen time) respectively. Having many participants that were not distracted lead to the data being skewed and the Distractibility measure had thus a zero-inflated distribution. To handle this, the Distractibility measure was converted to a dichotomous variable where those who were distracted (Distractibility > 0 ms) were assigned a 1 and those who were not distracted (Distractibility = 0 ms) were assigned a 0. A Yates' chi-squared test revealed a statistically significant difference in attention to the distractions during the two time windows before (16 distracted, 20 non-distracted) and after (30 distracted, 6 non-distracted) the TA choice

($X^2 = 10.17$; $df = 1$; $p < 0.01$).

Student's *t*-tests were carried out to investigate whether there were differences between those who were distracted during the TA choice from those who were not. This revealed no statistically significant differences between these two groups with regard to age or performance on the Inhibition and Sustained Attention pre-tests. However, the majority (15 of 20) of the non-distracted participants during the TA choice were female which resulted in a statistically significant Yates' chi-squared test between genders ($X^2 = 5.23$; $df = 1$; $p < 0.05$).

We used a logistic regression to analyse what pretest and participant variables could predict whether a child was distracted or not by our manipulation. The dichotomous Distractibility measure was used in the analysis against the two pre-test measures. Age and gender was also included in the analysis since age seemed to correlate with the pre-tests, and also, gender was revealed to have an impact on gaze behaviour. This analysis revealed statistically significant main effects of Sustained Attention and gender on Distractibility (Table 2). The results suggested that approximately one girl for every nine boys were distracted by our manipulations ($\beta_{\text{female}} = -2.194$; $odds = 0.111$; $p < .01$). The Sustained Attention main effect indicated that for every increase in the signal detection sensitivity index (log *d*), the odds of being distracted increased almost a hundred-fold ($\beta_{\text{SA log d}} = 4.525$; $odds = 92$; $p < 0.05$). The pseudo R^2 (McFadden, 1973) for the model was 0.254. A second logistic regression analysis was carried out including interactions between all predictor variables of the first model. No significant interaction effects were found.

Discussion

The pedagogical power of teachable agents (TAs) in learning environments, as a digital version of a learning-by-teaching (LBT) approach, has repeatedly been shown for students aged

8 to 14. In this study we explored the possibility of initiating the use of this kind of pedagogical software also in preschool. Due to developmental stages of executive functions it may be argued that children this young are not cognitively able to benefit from such educational games. Furthermore, a preschool is a lively environment which would further add to the doubt of whether these proposed intervention games would be suitable there. This study addressed two questions: (a) whether there are preschoolers who can inhibit distractions in order to pay attention to a TA, and (b) whether experimental measures of inhibition and sustained attention can predict the distractibility in these preschoolers.

As can be noted by the graphs in Figure 3, the distractive football animation takes quite a lot of the participants' visual attention in general when the participants are in charge of the game. Looking at the difference graph (Figure 3C) it is evident that the distraction steals equal amounts of attention from the more relevant areas of interest. This can then be contrasted with the graphs in Figure 4 which represents gaze proportions on AOIs during (4A) and after (4B) the TA makes his choice in Game Mode 4. During the TA's choice the gaze proportions of the distractive animations drop dramatically.

These results along with the presented distractibility analysis show that this group of preschoolers seem very able to inhibit distractions in order to focus their attention on their digital tutee. The participants in this study were in fact so good at this that the majority did not look at the visual distractions at all when the TA was choosing between numbers. However, after the TA made his choice the participants were once again visually occupied by the distractions as indicated by the graph in Figure 4B.

The results thus suggest that, although everything is kept constant between the two conditions, the children were more distracted after the TA had made his choice than they were during his choice selection. Interestingly, the participants in this study did not succeed well in the inhibition pre-test but nonetheless managed to inhibit during the main task performance. This shows the relevance of context and motivation in empirical investigations of cognitive capabilities. We suggest that the children's attentional behaviour is scaffolded by the context (i.e., engagement in a play-&learn software) thus they performed better in terms of inhibiting distractions than in the context of a standard inhibition test.

By inhibiting distractions, participating preschoolers could increase their attention on more important features of the game. As is shown in Graph A of Figure 4, the preschoolers does focus more of their visual attention on the TA's hand and the lift buttons, one of which their tutee is about to press, and less on the bird and the distraction which are of less importance to benefit from the game. It is particularly interesting that the preschoolers keep such focus even though they cannot themselves be active in the game in this mode (Game Mode 4), they can only observe their tutee's actions. This result corroborates the findings of a pilot study carried out by Axelsson, Anderberg, and Haake (2013) where they found that preschoolers seem to pay attention to their TA. It also places preschoolers together with primary school children in this respect. Lindström et al. (2011) showed that primary school children paid close attention to their digital tutee whilst the tutee was acting on its own. In contrast to the preschoolers, however, the primary school children also often showed high engagement in this situation.

The present study also found similar results to those of Roderer, Krebs, Schmid, and Roebers (2012) with regard to distractibility and engagement. In their study of selective encoding for learning, they found that preschoolers were able to increase attention towards relevant stimuli and inhibit task-irrelevant stimuli thus showing engagement in task-oriented behaviour. Roderer et al. (2012) used fairly simple and mainly static information in their study and concluded that their results were potentially dependent upon their operationalisation. However, with the results of the present study, preschoolers seem able to increase attention towards relevant stimuli also in TA-based learning environments which are more visually complex and narratively elaborated. Hence, these studies together show that preschool children are not as susceptive to visual distractions as one might believe, which further suggests that children are able to filter out distractions when their interest and focus lay elsewhere.

In regard to the second research question, the results showed that the measure of sustained attention appears to be a predictor of distractibility. Although, the results are reversed as to what one would expect. Participants that performed well on the sustained attention task were more distracted during the TA's choice. This result was surprising. One possible explanation could be related to the lack of inhibition. The children who participated in this study were shown to have poor inhibitory skills as suggested by the results of the anti-saccade task. Thus, it seems that the Sustained Attention measure captured some other aspect of attention in these participants – in relation to the distractibility measure – since motor inhibition is required also for the go-no-go paradigm task used. Our interpretation of the result is that the measure seems to have been related to the children's more general attentional abilities, that is, their tendency to notice changes in their environment. That would mean that a child who is well able to detect whenever the screen colour is blue in the sustained attention task will also be more likely to notice the visual distractions. This could suggest that overall attention to changes in the environment also leads to being more distracted unless inhibitory capabilities have matured. Thus, when it comes to the participants that were not distracted at all, another factor must account for them being able to inhibit – or more likely filter out – the distractions.

An unanticipated result was that the female participants were less likely to attend to the distracting visual stimuli. Similar results have however been found in previous studies where boys have been found to score higher on distractibility measures (Bridges, 1929; Victor & Halverson, 1975). Poyntz (1933) found that even though boys responded to distractions more frequently, they did not spend more time being distracted than girls. Although results in the present study conversely showed that boys were on average more distracted, it is important to emphasise that the overall mean time for attention to the distracting visual stimuli during the TA choice was less than 200 ms (10 % of distraction screen time). Thus, even if a participant was distracted, regardless of gender, he or she was not distracted for long and quickly retained his or her attention to the TA. The results of a recent study of metacognitive reasoning in preschoolers showed that girls were more inclined to play another round with a TA when asked than were boys (Haake, Axelsson, Clausen-Bruun, & Gulz, 2015. A previous study (Robertson, Cross, Macleod, & Wiemer-Hastings, 2004) – including 60 somewhat older children (10-12 years old) who got to use an educational software support in either a TA or a non-TA version – showed that girls tended to interact more in the TA version than the non-TA version, whereas the pattern was reversed for the boys. Thus, there might be some motivational aspects to the digital LBT concept in general which allows girls to be slightly more focused and engaged than the boys.

Results from the present study suggest that the preschool age is the point where important cognitive capabilities for benefitting from the use of LBT games are forming. These capabilities are fairly heterogeneous in this young age group. However, the LBT game context has through this study been shown to be of practical use for scaffolding mature behaviour for some preschoolers compared to what abstract behavioural tests would suggest. Theoretically, this implies that children with underdeveloped inhibitory skills might still be able to attend to LBT-based software.

Study Limitations

Sample size. The large participant attrition in this study was not anticipated. Working with a young target population is difficult and requires a large participant marginal and so does working with eye-tracking due to difficulties in retrieving reliable data because of calibration difficulties and tracking loss. Another problem with sample size of this study was that list-wise deletion of participants unfamiliar with numbers had to be employed. Executive functions have been shown to be an important factor in the development of early numeracy (Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009) and a strong predictor for future mathematics achievements (Hassinger-Das, Jordan, Glutting, Irwin, & Dyson, 2014). This leaves the results of the present study vulnerable to only being relevant to children at the higher end of the skill spectrum of executive control. In future LBT studies with this age group, the number of participants needs to be increased. Furthermore, if a familiarisation for numbers is required, the attrition of participants has to be estimated and accounted for in order to ensure strong statistical power. For smaller studies, the minimum age could be considered to be increased in order to handle attrition but this will limit the generalisability of results.

Learning effects. Our research in the present study has been guided by the question whether preschoolers *can* profit from LBT-based games rather than *do* they profit. This limits us in terms of being able to say anything about learning effects with regards to preschoolers playing LBT-based games – in this case with respect to number sense and early math. However, preliminary results from a follow-up study show evidence that the LBT-based play-and-learn-game used in this study seems to have a positive impact in terms of early math learning gains (Gulz, Londos, & Haake, 2015).

Limited SES range. Since the Swedish population deviates very little in terms of SES levels, and the fact that SES levels in Sweden are fairly high, our study will have little to say about whether the cognitive prerequisites needed for LBT-based games are sufficient for children brought up in lower SES circumstances. Replications of this study of children in low SES areas as well as cross-cultural studies would be needed to draw any such conclusions.

Future Research

From the results of the present study, it seems reasonable to pursue research and development with respect to educational LBT-based software for preschoolers. The results of the study open up several future research lines. The results indicated that girls might benefit more from this pedagogical form and whether this is true must be further investigated. In any case, the display of mature cognitive behaviour of some of the preschoolers in this study shows great potential for the development of educational tools for exercising and training of preschoolers' metacognitive reasoning.

The software developed in the work of this study will be utilised as a research instrument in combination with other methods in future investigations. One objective is to find out to what extent 3- to 5-year-olds feel responsible for their tutee and at what stage the ego-protective buffer – that is, the sharing of responsibility for mistakes and errors by attributing them partly to the tutee and partly to oneself – comes into play (Chase, Chin, Oppezzo, & Schwartz, 2009). Another future objective is to investigate whether it is possible to further the development of theory of mind and metacognition in preschoolers through the use of emotional display in TAs.

Conclusions

The present study shows that the paradigm of learning by teaching implemented with teachable agent based educational games could possibly be used with much younger children than one would have thought since some of the participants in the present study possessed the prerequisites to be able to benefit from LBT-based games. Three to six year old children who do not have mature skills at inhibiting attention to distractions can nonetheless do so when paying attention to a digital tutee they are responsible for helping. This shows that the context or task (the latter always partly defined by context or nature of the activity) influences the attentional skills of these young learners.

In conclusion, though the study suffers from some obvious limitations which affect its generalisability with regard to the results, it does show that there at least are young children that have the cognitive prerequisites to be able to play learning-by-teaching-based games. Even if not all children are able to play these games, they can be made available as soon as the child is ready. Furthermore, software games have the great potential of being individually customisable to a broader audience compared to conventional teaching methods.

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Tables and Figures

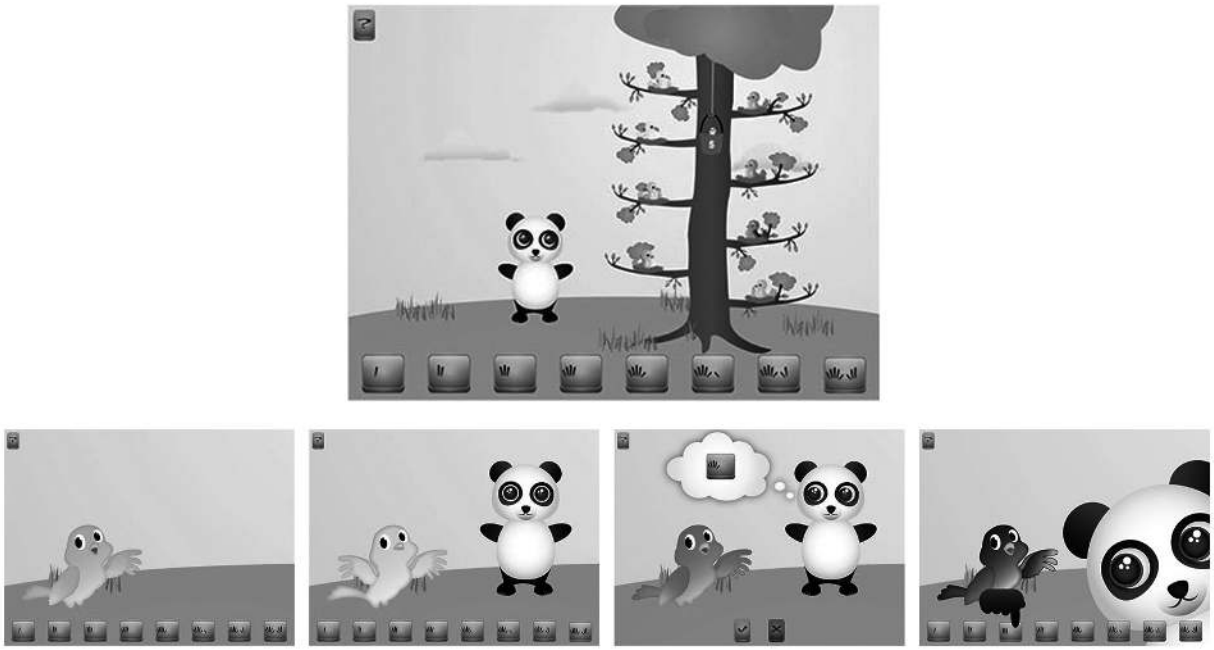

Figure 1. Screen shots of the LBT-game Bird Hero. Top: a picture of the tree with the elevator going up to the bird's nest. Bottom: the four Game Modes of the game.

Figure 2. Screen shots of the three visually distracting animations: football animation during Game Mode 3 (left); glitch (middle) and aeroplane (right) animations during Game Mode 4.

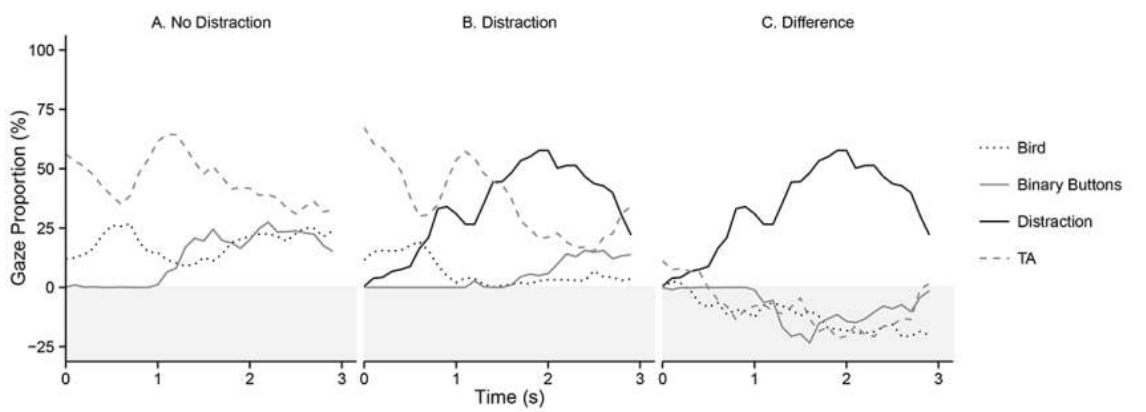

Figure 3. Gaze proportion in two similar time windows of four areas of interest over time with (A) and without (B) the football distraction in Game Mode 3. Graph C shows the resulting difference from gaze proportions of Graph A subtracted from those of Graph B. Duration is the length of the football animation distraction, and 0 on the x-axis denotes distraction onset.

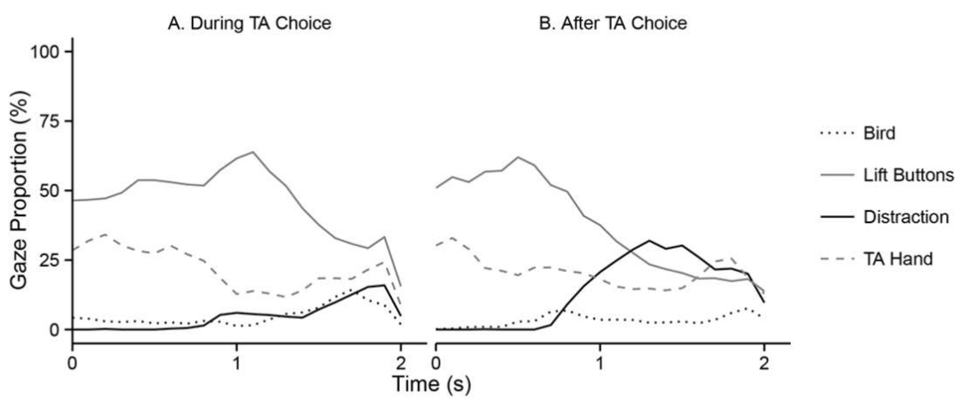

Figure 4. Gaze proportion of four areas of interest over time during (A) and after (B) TA choice in Game Mode 4. The time duration is the length of the glitch/aeroplane animation distractions, and 0 on the x-axis denotes distraction onset.

Table 1

Means, standard errors, minimum values, and maximum values of the study variables

	M	*SD*	*Min*	*Max*
Age (years)	5.15	0.74	3.76	6.25
Distractibility (ms)	198.44	260.92	0	844
Inhibition (%)	60.15	16.43	19.04	89.59
Sustained Attention ($\log d$)	0.46	0.22	0.09	0.97
Hits	8.89	3.02	1	13
Misses	6.11	3.02	2	14
Correct Rejections	48.94	8.15	22	60
False Alarms	11.06	8.15	0	38

Table 2

Logistic regression analysis with Distractibility as dependent variable and the pre-test measures, age, and gender as independent variables

	b	*SE*	*p*	*Odds*
Intercept	-1.260	1.736	0.468	-
Age (centred at $M = 5.15$)	-0.460	0.636	0.470	0.632
Gender (F)	-2.194*	0.855	0.010	0.111
Inhibition	0.158	2.821	0.955	1.171
Sustained Attention ($\log d$)	4.525*	2.248	0.044	92.248

Note: $^{*}p < 0.05$