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Eight-year-olds, but not six-year-olds, perform just as well as adults when playing Concentration: Resolving the enigma?

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Abstract

Anecdotal reports suggest that children often outperform adults when playing Concentration. This is surprising as cognitive processes tend to develop progressively throughout childhood. To date, very few studies have examined this apparent paradox, and with mixed results. In the present study, the ability of 6-year-olds (n=34), 8-year-olds (n=48), and adults (n=38) to play Concentration was examined in a controlled computer-based setup involving eye tracking. The main dependent variables were the number of moves and time in seconds to finish the first nine (out of 12) matching pairs. The results revealed that while 6-year-olds were outperformed by older children and adults, 8-year-olds performed just as well as adults. It is suggested that Concentration may represent a cognitive challenge rarely encountered in the real world, and when playing Concentration, adults seem to use strategies that are effective in real life situations, but may be less appropriate when playing the game.

Key words: cognitive development, working memory, strategy, fuzzy trace theory, eye tracking.

Highlights

- Anecdotal reports suggest that children outperform adults when playing Concentration/Memory
- This is intriguing, as cognitive processes tend to develop progressively throughout childhood
- Very few studies exist, and none of these were well-controlled and involved eye tracking
- We report a comprehensive examination of 6-, 8-year olds, and adults playing Concentration
- While 6-year-olds were generally outperformed, 8-year-olds performed just as well as adults

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Eight-year-olds, but not six-year-olds, perform just as well as adults when playing Concentration: Resolving the enigma?

1. Introduction

The widely popular game *Concentration* (or *Memory*) is a game where players are presented with a number of identical pairs of cards typically representing everyday objects (e.g., 'car', 'chair', or 'ball') placed face down. The players are instructed to turn two cards. If the two cards are identical, they represent a match, and the cards are removed after which the player proceeds. If the two cards are dissimilar, they are turned face down again, and the turn is handed to the next player. The player who ends up with the largest number of matches has won. Parents typically report losing to their children when playing Concentration (Crovitz, 1970; Gellatly, Jones, & Best, 1988; Jansen-Osmann & Heil, 2007; Meacham, 1972).[1] This is quite intriguing for a number of reasons. First, Concentration is both a 'where' and a 'what' task (e.g., Milner & Goodale, 1995; Ungerleider & Mishkin, 1982) and in order to play Concentration efficiently, the player not only has to remember the specific icons turned (the 'what' component), but also the specific location of each icon (the 'where' component). However, few studies have actually examined which cognitive functions underlie game performance, and the functions that have been examined (e.g., visuo-spatial memory, Schumann-Hengsteler, 1996) are typically considered to improve with age (e.g., see Burggraaf, Frens, Hooge, & van der Geest, 2018; Gathercole, Pickering, Ambridge, & Wearing, 2004; Vasilyeva & Lourenco, 2012)—findings, that are clearly at odds with the anecdotal reports (i.e., if functions underlying game performance are less developed in children compared to adults, they should not be able to 'beat' their parents at the game).

[1] We are not aware of similar anecdotal reports regarding any other games.

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Second, there is no reason to believe that any of the skills required to play Concentration efficiently should be characterized as 'expert knowledge' (as is known to be the case when for instance young but skilled chess players outperform adult non-chess players in remembering chess positions; cf. Chi, 1978). Consequently, if the anecdotal reports hold and children indeed outperform adults when playing Concentration, it cannot be explained by reference to any expert knowledge possessed exclusively by the children. Instead, the skills required to play Concentration efficiently appear to be related to rather general cognitive developmental achievements that are supposed to improve throughout childhood, making children's potential superiority, relative to adults, thought-provoking.

Surprisingly few studies have attempted to systematically examine how children fare relative to adults when playing Concentration. Instead, Concentration has been used as a task to examine for instance gender differences in spatial memory (Tottenham, Saucier, Elias, & Gutwin, 2003), or working memory in bilinguals with or without reading difficulties (Jalali-Moghadam & Kormi-Nouri, 2015). In addition, Concentration has been used as a proxy for examining a range of parameters including the effect of allocentric vs. egocentric coordinates (Lavenex et al., 2011), whether note taking facilitates memory (Eskritt & Ma, 2014), or the development of explicit memory (Gulya, Rossi-George, Hartshorn, Vieira, & Rovee-Collier, 2002). To date, only five studies have explicitly examined how children compare to adults when playing Concentration, and the results are mixed.

Baker-Ward and Ornstein (1988) compared a group of children (5- to 9-year-olds) and adults when playing Concentration. They found that overall, the two groups did not differ with respect to game efficiency (number of moves to finish the game), but that children obtained a higher number of 'perfect hits' (i.e., turning a matching pair as soon as the necessary information is available) than adults, lending at least partial support to anecdotal parental reports. However, the remaining four studies have failed to replicate this pattern of

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results. Chagnon and McKelvie (1992) examined participants aged 5-65 years playing Concentration and found no difference in game efficiency between children and adults. A similar result was obtained by Jansen-Osmann and Heil (2007) who tested 7-8-, and 11-12-year-old children as well as adults with a modified version of Concentration in which the participants first had to learn the locations of matching cards according to a certain criterion after which their memory for the location of the icons was tested (although adults were superior in a version of the task using spelled words as icons). In contrast, the results from the two remaining studies showed that (some) children were less efficient than adults. Gellatly, Jones, and Best (1988) tested 5-, 7-, and 9-year-old children and found that the 5-year-olds needed more moves to finish the game than the other groups, whereas Schumann-Hengsteler (1996) found that 5- to 10-year-olds required more moves than adults to finish the game (there was no difference between children of different ages). In the study by Schumann-Hengsteler, differences in the strategies used by children and adults respectively, were also found as (a) children displayed more 'redundant moves' (turning an already known card, but without knowing the location of the matching card) than adults, (b) adults produced more opportunities for potential matches than children, and (c) the youngest children produced fewer 'location errors' (henceforth: 'almost hits', that is, knowing the approximate location of a matching card, but making the error of turning an either horizontally, vertically, or diagonally adjacent card) compared to the other participants. Thus, leaving anecdotal reports aside, evidence for age related differences in Concentration game efficiency is sparse and inconclusive.

Let us for a moment consider the possibility that children, at least to some extent, *are* superior to adults when playing Concentration. Could this make sense from a developmental perspective? Although progression is indeed the general trend as the child develops, there appear to be a few exceptions. For instance, the ability to discriminate between phonemes has

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been shown to *decrease* from early infancy to childhood (Werker, Gilbert, Humphrey, & Tees, 1981; Werker & Tees, 1983, 1984). Another example concerns implanted false memories. Ross and colleagues (2006) showed that after having seen a video of a theft in a cafeteria, older children were *more* likely than younger peers to post-hoc (erroneously) identify on a photo an innocent bystander of same age/ethnicity/gender as the 'thief', provided that subjects were misinformed that the culprit was among the people on the photo. Such exceptions in which the expected progress in development as the child grows older is reversed, at least temporarily, has been dubbed *developmental reversals* by Brainerd and Reyna (2007, 2012).

Thus, if children outperform adults when playing Concentration, it may be seen as an example of a developmental reversal. As pointed out by Schumann-Hengsteler (1996), the finding that children, relative to adults, produced fewer so-called 'almost hits' (see above) may be explained by the fuzzy trace theory from the memory literature (Reyna & Brainerd, 1995). According to fuzzy trace theory, people have separate stores of so-called verbatim and gist representations of what they have experienced. *Verbatim* traces contain information about surface features of the events, that is, shape, color, size, and texture of objects, as well as features of the context in which the objects are located. *Gist* traces, in contrast, contain the meaning or the semantic information of the objects and the context. And because semantic memory, for instance in terms of vocabulary, increases substantially throughout childhood (Anglin, 1993; Bloom, 1998), the risk of such semantic interference should be disproportionally larger for adults relative to children. The argument is, that possessing more semantic knowledge of the icon objects may induce more associations related to these items, but that such additional processing may actually decrease game efficiency, because the primary task is to remember the exact location of the object—not to elaborate on the semantic content of the object. Based on fuzzy trace theory we may therefore expect that superior

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semantic knowledge of the icons involved could potentially have *detrimental* effects on game efficiency when playing Concentration (Schumann-Hengsteler, 1996). One way to address this possibility would be to compare children and adults on different sets of icons for which their semantic knowledge varied. With a single exception where spelled words were used as icons (Jansen-Osmann & Heil, 2007), this has, however, not been examined systematically.

1.1 The present study

In the present study, we set out to conduct a comprehensive investigation of how 6- and 8-year-old children played Concentration relative to adults, hoping to shed new light on the enigma. The three age groups were chosen in order to relate our findings to the few existing studies. The sample sizes were based on the few existing studies while attempting to avoid Type-II errors. Relative to previous research, we sought to improve the design in four distinct areas. First, whereas four of the five previous studies used cardboard cards for the games, we used a computerized version administered on a touch pad. In the computerized version a number of important game parameters were equalized across moves, icon sets, and participants (i.e., the positioning of the cards, and the spatiotemporal aspects of how the cards turned and eventually disappeared). Hence, a considerable amount of potential noise in the test procedure could be removed. Further, by standardizing temporal game parameters, 'time to complete' could be calculated as a second measure of game efficiency in addition to 'moves to complete'.

Second, three different sets of icons were employed: (1) a conventional set of everyday icons allowing for comparison with the existing studies, (2) a set of *numbers* as icons, and (3) a set of custom-made *abstract symbols*. These additional sets of icons were included to examine the hypothesis based on fuzzy trace theory that semantic knowledge may affect game efficiency. Thus, numbers were chosen as a domain in which adults were expected to have some more knowledge than children, whereas abstract symbols were chosen to compare

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children and adults in a domain for which none of the groups had concrete experience prior to playing.

Third, eye tracking was used to elucidate the participants' looking behavior just prior to turning a card. As mentioned above, at least one study found that children made fewer 'almost hits' than adults (Schumann-Hengsteler, 1996). We reasoned that eye tracking would be an ideal tool to examine this possibility more in depth. Note, that whereas instances of 'almost hits' can be identified without using eye tracking, only eye tracking (or equivalent) can provide information about the visual behavior (e.g., number of cards fixated upon) prior to actually choosing a given card.

Finally, the ability of working memory and inhibition to predict game efficiency in the two child subsamples (6- and 8-year-olds respectively) was explored. We examined visuospatial working memory, because the game requires the player to store visually presented information (such as card locations or details) and process this information as the game progresses (with new cards being revealed, matched cards removed etc.). Inhibition was examined because game efficiency may to some degree depend on the ability to suppress conflicting irrelevant information (e.g., previously turned cards). To determine the presence of age-related differences in these core cognitive processes, we also compared the two child subsamples.

Because previous results are mixed, the following hypotheses are at best tentative: With regards to overall game efficiency (i.e., number of moves and time used) we had two contrasting hypotheses. Based on cognitive development theory as well as the results from the majority of the existing studies on Concentration, we expected the adults to outperform the children. For the sake of simplicity we dub this the *Common Sense Hypothesis.* Based on anecdotal reports as well as existing examples of developmental reversals, we also had an alternative hypothesis stating that the children would outperform the adults. We dub this

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alternative hypothesis the *Developmental Reversals Hypothesis*. Based on Schumann-Hengsteler's (1996) analysis originating from the fuzzy trace theory, we expected adults to fare relatively *worse* on icons such as numbers and especially concrete objects than on icons demanding little semantic knowledge (i.e., abstract icons). Regarding game strategy we had two hypotheses based on existing evidence: We expected the children to make more 'redundant moves' than adults. However, we also expected the children to produce fewer 'almost hits' than adults (see above). Eye tracking analyses were exploratory. Due to the scarcity of previous studies, no *a priori* hypotheses were made with regard to the ability of working memory and inhibition to predict game efficiency. However, based on ample research (Davidson, Amso, Anderson, & Diamond, 2006; Gathercole, Pickering, Ambridge, & Wearing, 2004; Huizinga, Dolan, & van der Molen, 2006; Williams, Ponesse, Schachar, Logan, & Tannock, 1999) we did expect 8-year-olds to outperform 6-year-olds in all cognitive domains.

2. Method

2.1 Participants

Participants in this study were 34 six-year-olds (M_{age}= 6.3, range = 6.1-6.5; 15 girls), 48 eight-year-olds (M_{age} = 8.0, range = 7.8-8.9; 27 girls), and 38 adults (M_{age} = 27.1, range = 17.6-55.5; 28 females). Children were recruited from birth registries from The National Board of Health. The study was approved by the local ethics committee at [BLINDED] (project title: Memory_Concentration_2015). Adults had signed up using a participant database with a self-booking system. Participants were predominantly Scandinavian Caucasian from middle to higher SES families living in the East Jutland area. An additional 17 participants (7 children and 10 adults) were tested but excluded from the analyses due to technical error or insufficient eye-tracking (tracking less than 50%). Children were compensated with a small LEGO® gift and adults with a gift certificate (app. 7 USD).

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2.2 Equipment and materials

A custom-made Concentration game was run on a PC. The game was displayed on a 29.5cm (width) x 16.5cm (height) touch sensitive tablet placed in front of the participants, approximately 35cm from their eyes. A Tobii Pro X2-60 eye tracker was tracking the participants' eye movements at a rate of 60 hertz with 0.5° accuracy. The total visual angle of the screen was 45.7° (width) x 27.3° (height). The distance between the participants' eyes and the eye-tracker was approximately 50 cm. An external scene camera recorded the tablet and participants' screen touches during the test (see Fig. 1d). The Tobii Fixation Filter (default) was used. This filter detects quick changes in the gaze point signal using sliding averaging and can thus distinguish between fixations and saccades. Interpolation of samples was used when data samples were missing (e.g., during an eye blink). Before the actual data collection, a 5-point calibration was conducted using Tobii Studio calibration. Luminance was held constant in the room for all participants.

Three different sets of icons were employed (concrete, numbers, abstract; each with 24 cards [12 pairs], see Fig. 1). The version with concrete icons was a subset of a commercially available Concentration game from ELC®, whereas the icon sets with numbers and abstract symbols were custom-made for the task.

The storage component of visuospatial working memory was measured with the Finger Windows forward condition from the Wide Range Assessment of Memory and Learning 2 (Sheslow & Adams, 2003). In this condition, the child had to reproduce location sequences previously presented by the examiner. The backward condition (Bedard & Tannock, 2004) measured the storage plus processing components of visuospatial working memory and required the child to reproduce the sequences in the reverse order of presentation. The primary outcome for each condition was number of correctly recalled sequences.

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Inhibition was examined with a traditional (child) version of the Flanker task (Jäger, Schmidt, Conzelmann, & Roebers, 2014) presented on a laptop. The task consisted of a pure block with 16 congruent trials, and a mixed block with 32 (16 congruent and 16 incongruent) trials. The conflict score (mean reaction time [RT] on incongruent mixed block trials minus RT on pure block congruent trials) served as the primary outcome variable.

2.3 Design and Procedure

2.3.1 Concentration. Each participant played as single-player (no opponent) with all three sets of icons in a pseudo balanced order, that is, half of the participants in each age group played the three versions in the sequence: concrete – numbers – abstract, whereas the other half played in the sequence: abstract – numbers – concrete. Before the first test game all participants played a practice game consisting of a reduced version (12 cards, 6 pairs) of the first set of icons they would play in the test phase (but with different icon locations). As all participants were familiar with Concentration, instructions were kept simple, and after the practice phase participants were simply asked to do their best. The location of the cards was identical for all participants but varied across the three game variations. Aside from the fact that the player had no opponent, the game proceeded just as in the traditional versions: The participant turned two cards at a time. A card turned in 0.3 sec., and after the second card had been turned, both cards were visible for 1.0 sec. If the two cards were identical, they represented a match and disappeared (faded over 1 sec.). If the two cards were dissimilar, they were turned face down again. The game proceeded until all matches were found.

2.3.2 Flanker Task and Finger Windows. The Finger Windows test and the Flanker Task were administered after the Concentration Game, always in the same sequence (Finger Windows – Flanker Task) and only to the participating children (6 and 8 years of age).

2.4 Data coding and reduction

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2.4.1 Concentration. Two types of data were collected from the Concentration game: game data (i.e., data on which cards were turned and when) and eye tracking data (i.e., data on number of cards fixated upon before turning a card). A number of game measures were central in order to qualify how participants played the games: *number of moves used*, *time in seconds used, almost hits, cards fixated upon, perfect hits, redundant moves,* and *success ratio* (see Table 1 for definitions of these game measures in alphabetical order).

Game data and eye tracking data were coded manually. Game data coding was conducted offline by means of move-by-move registration based on the scene camera recordings. With regards to the eye tracking data, each card was configured as an area of interest (AOI), and based on the Tobii Studio red-dot visualization, a coder assessed which cards the participants fixated upon prior to tuning a card.

Only data from the first nine pairs (out of 12) were analyzed, since exclusion of late-game performance provides a cleaner measure of the decision-based actions in the game (cf. Schumann-Hengsteler, 1996). An independent coder re-coded a representative 20% of all codings and interrater agreement was very high: Mean 98.9% (range: 90.9-99.9%).

3. Results

3.1 Overview of results

Table 2 displays the *M*s and *SD*s of the primary variables across age groups and icon sets.

With a few exceptions, the analyses followed the same strategy: We conducted a series of mixed-model ANOVAs, with Age Group (6-year-olds vs. 8-year-olds vs. adults) as between-subjects variable and Icon Set (concrete vs. number vs. abstract) as within-subjects variable, with different dependent variables. The ANOVAs were accompanied by post-hoc Bonferroni corrected comparisons to allow for follow-up pairwise comparisons (with three comparisons, the α-level for all post-hoc comparisons was set at $0.05/3 = 0.017$). Since all *M*s

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and *SD*s are specified in Table 2, they are not reported below. The analyses were divided into four sections. First, we looked at analyses related to what we called 'game efficiency'. Second, we looked at the ability to create opportunities for hits, and whether these were utilized. Third, we looked at game strategy and errors. Finally, we analyzed the potential predictors of game efficiency in the child subsamples.

3.2 Game efficiency

First, we looked at the number of moves required to complete the first nine matches of the game. A mixed-model ANOVA with Age Group (6-year-olds vs. 8-year-olds vs. adults) as between-subjects variable and Icon Set (concrete vs. number vs. abstract) as within-subjects variable and with *number of moves* as the dependent variable revealed a main effect of Age Group, $F(2, 117) = 5.75$, $p = .004$, $\eta_p^2 = .089$ (see Fig. 2A). Pairwise post-hoc analyses showed that only the difference between the performance of the 8-year-olds and the 6-year-olds was significant ($p = .001$).

The analysis also revealed a main effect of Icon Set, $F(2, 234) = 19.58$, $p < .001$, $\eta_p^2 = .143$. Across age groups, the participants fared best with the concrete icons, worst with the numbers and with the abstract icons somewhere in between. Pairwise post-hoc analyses showed that the participants, regardless of age, performed better with the concrete icons relative to both numbers and abstract icons (both comparisons: $p < .001$). In contrast, the difference between numbers and abstract icons was not significant. Age groups and icon sets did not interact.

Game efficiency was also assessed with respect to time required to finish. Thus, the mixed-model ANOVA was re-run with *time in seconds* required to finish the first nine matches of the game as the dependent variable. Again, the analysis revealed a main effect of Age Group, $F(2, 117) = 4.79$, $p = .01$, $\eta_p^2 = .076$ (see Fig. 2B). As indicated by the graphical presentation, pairwise post-hoc analyses showed that whereas adults and the 8-year-olds were

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equally efficient time-wise, both adults ($p = .008$), and the 8-year-olds ($p = .007$) were reliably faster than the 6-year-olds.

This analysis also yielded a main effect of Icon Set, $F(2, 234) = 15.63$, $p < .001$, $\eta_p^2 = .118$. The results from the pairwise post-hoc analyses replicated the previous pattern of results as the concrete icons were finished faster than both the icons with numbers ($p < .001$) and the icons with abstract symbols ($p < .001$). There was no difference in time required to finish the number icons and the abstract icons. Again, age group and icon set did not interact, indicating that different age groups were not differentially affected by different icon sets.

To summarize, the analyses of game efficiency revealed that the 6-year-olds performed significantly worse than both their older peers (with respect to both moves and time) and the adults (with respect to time). The 8-year-olds were slightly more efficient (i.e., requiring fewer moves) than the adults, but the difference was not statistically significant. Thus, when considering the 6-year-olds, the results were in accordance with the Common Sense Hypothesis. However, when focusing on the 8-year-olds, the results are at odds with the Common Sense Hypothesis – although not directly consistent with the Developmental Reversals Hypothesis either. Based on the fuzzy trace theory, we expected adults to fare relatively *worse* on the set of icons for which they should possess substantially more knowledge than children (i.e., numbers and concrete objects). The results were inconsistent with this hypothesis, because there were no interactions between age groups and icon sets in any of the analyses concerning game efficiency.

3.3 Creating and seizing opportunities

In order to make matches, without having to rely on sheer luck, you have to create opportunities. We analyzed three aspects related to creating opportunities: (1) The ability to create opportunities, (2) the ability to seize opportunities, and (3) the extent to which the

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participants were able to make so-called 'perfect hits' (i.e., immediately turning a matching pair, as soon as the necessary information becomes available).

The ability to create opportunities was analyzed by means of the mixed-model ANOVA mentioned above, but here with the *number of opportunities created* as the dependent variable. This analysis revealed a main effect of Age Group, $F(2, 117) = 4.19$, $p = .018$, $\eta_p^2 = .067$ (see Fig. 3A). Pairwise post-hoc analyses showed that adults created reliably more opportunities than 8-year-olds ($p = .005$), whereas the 6-year-olds did not differ from the other age groups. The analyses also revealed a main effect of Icon Set, $F(2, 234) = 17.95$, $p < .001$, $\eta_p^2 = .133$, indicating that across age groups, it was easier to create opportunities with some icons sets than others (see Fig. 3A). Pairwise post-hoc analyses revealed that across age groups it was reliably easier to create opportunities with both numbers ($p < .001$) and abstract icons ($p < .001$) relative to the concrete icons, whereas there was no difference between numbers and abstract icons. There was no interaction between Age Group and Icon Set.

Creating opportunities is, however, not the same as utilizing them. Thus, in order to assess success in this regard, we computed 'success ratio' operationalized as the mean number of hits per opportunity created. The success ratio was analyzed by means of the standard ANOVA, but this time with *success ratio* (hits per opportunity created) as the dependent variable. In contrast to the previous analyses, this analysis did not reveal a main effect of Age Group ($F = 2.42$), whereas there was a main effect of Icon Set, $F(2, 234) = 21.85$, $p < .001$, $\eta_p^2 = .157$. Pairwise post-hoc analyses revealed that across age groups the success ratio was reliably higher with the concrete icons relative to both the number ($p < .001$) and the abstract icons ($p < .001$), whereas numbers and abstract symbols did not differ.

In all previous analyses, there were no interactions between Age Group and Icon Set, but here we saw a marginally significant interaction, $F(4, 234) = 2.34$, $p = .066$, $\eta_p^2 = .037$. This result and visual inspection of Fig. 3B inspired an additional ANOVA with Age Group as between-subjects factor and with *success ratio* (hits per opportunities created) for the *concrete icons* exclusively as the dependent variable. This analysis resulted in a main effect of Age Group, $F(2, 117) = 6.47$, $p = .002$, $\eta_p^2 = .100$. Follow-up pairwise post-hoc analyses showed that the 8-year-olds had a higher success ratio, than both adults ($p = .009$) and 6-year-olds ($p = .001$), whereas the success ratio did not differ reliably between adults and 6-year-olds.

Finally, by means of an ANOVA with the number of 'perfect hits' as the dependent variable, we analyzed whether the children in the present study would produce more 'perfect hits'. Although there was a trend (see Fig. 3C), there was no main effect of Age Group ($F < 1$), and no interaction between icon set and age. The analysis resulted in a main effect of Icon Set, $F(2, 234) = 10.24$, $p < .001$, $\eta_p^2 = .080$. Pairwise post-hoc analyses revealed that in general, the participants obtained more perfect hits with the concrete icons relative to both the number icons ($p < .001$) and the abstract icons ($p < .001$), whereas there was no difference between numbers and abstract symbols.

To summarize the results concerning creating and utilizing opportunities, we found that the adults were reliably better at creating opportunities than the 8-year-olds. However, as already indicated, creating opportunities is no guarantee of using them. When looking at the success ratio, there was no main effect of Age Group. In contrast to the previous analyses, we here obtained a marginally significant interaction between Age Groups and Icon Set, and follow-up analyses revealed that when looking exclusively at the performance of the concrete set of icons, the pattern was reversed, that is, the 8-year-olds reliably outperformed the adults. Finally, age had no influence on the number of perfect hits achieved.

3.4 Game strategies and errors

To test the stated hypotheses related to game strategy and errors, we analyzed both the number of 'redundant moves' and the number of 'almost hits' by means of the same strategy of analysis employed above, but this time with redundant moves and almost hits as the dependent variables. Finally, we looked into the number of cards fixated upon before turning a card when having an opportunity to make a match. We begin by analyzing redundant moves.

An ANOVA with Age Group as between-subjects variable and Icon Set as within-subjects variable and with *number of redundant moves* (first and second card turned, combined) as the dependent variable, revealed a main effect of Age Group, $F(2, 117) = 7.72$, $p = .001$, $\eta_p^2 = .117$ (see Fig. 4A). Pairwise post-hoc analyses showed that the 6-year-olds produced reliably more redundant moves than both their older peers ($p < .001$) and the adults ($p = .002$), whereas there was no difference between these two groups.

The analyses also revealed a main effect of Icon Set, $F(2, 234) = 11.81$, $p < .001$, $\eta_p^2 = .092$. Pairwise post-hoc analyses showed that fewer redundant moves were produced with concrete icons than with both numbers ($p < .001$) and abstract icons ($p < .001$), while there was no difference between the latter two. Age groups and icons did not interact with regards to their involvement in redundant moves.

We also analyzed the frequency of 'almost hits' per game (i.e., knowing the approximate location of a matching card, but making the error of turning an either horizontally, vertically, or diagonally adjacent card) by means of the same ANOVA as before, but this time with *almost hits* as the dependent variable. This analyses revealed a main effect of Age Group, $F(2, 117) = 5.83$, $p = .004$, $\eta_p^2 = .091$ (see Fig 4B). Pairwise post-hoc analyses revealed that adults were reliably more inclined to produce this kind of error than both the 6-years-olds ($p = .016$) and the 8-year-olds ($p = .001$), whereas the children did not differ. The tendency to produce almost hits was not affected by the icon sets. However, there was an interaction between Age Group and Icon Set, $F(4, 234) = 3.76$, $p = .006$, $\eta_p^2 = .060$, indicating that this error type was more prominent when adults played with the abstract

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symbols, whereas the pattern was more or less the same across icon sets with children (see Fig. 4B). An additional ANOVA with Age Groups as the between-subjects factor and with almost hits exclusively for the abstract icon sets as the dependent variable revealed a main effect of Age Group, $F(2, 117) = 8.58$, $p < .001$, $\eta_p^2 = .128$. Pairwise post-hoc analyses confirmed that adults did indeed produce reliably more almost hits with the abstract icons compared to both 6-year-olds ($p < .001$) and 8-year-olds ($p < .002$), whereas there was no difference between the children.

Thus, as hypothesized, 6-year-olds were much more inclined to produce redundant moves than the older age groups. However, in contrast to our expectations, the 8-year-olds and the adults were indistinguishable with regard to redundant moves. Regarding almost hits, the hypothesis was confirmed, as adults did indeed produce reliably more almost hits relative to the children.

The use of eye tracking allowed us to examine aspects of the participant's looking behavior hitherto unexplored in studies on Concentration. As we had no specific hypothesis regarding the participant's visual behavior prior to conducting the present study, this additional analysis was exploratory. Van Orden, Limbert, and Makeig (2001) have previously shown that several eye tracking outcomes are associated with cognitive load in adults. For instance, the number of fixations has been shown to be positively correlated with cognitive load. In order to examine whether this was also the case in the present study, we repeated the ANOVA, but this time with *number of cards fixated upon* before turning a card when having an opportunity to make a match (already turned cards and repeated fixations on same card excluded) as the dependent variable. This analyses resulted in a main effect of Age Group, $F(2, 117) = 7.83$, $p = .001$, $\eta_p^2 = .118$ (see Fig. 4C). Pairwise post-hoc analyses revealed that adults had a reliably higher number of cards fixated upon before actually turning a card than the 6-years-olds ($p = .002$), and 8-year-olds ($p < .001$), whereas the two groups of children

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did not differ. In addition, the analyses showed a main effect of Icon Set, $F(2, 234) = 10.92$, $p < .001$, $\eta_p^2 = .085$. Follow-up pairwise post-hoc analyses revealed that fewer cards were fixated upon with the concrete icons than number icons ($p < .001$) or abstract icons ($p < .001$), whereas numbers and abstract icons did not differ.

Interestingly, when considering the adults alone, the distribution of cards fixated upon across icon sets followed the same pattern as the outcomes of game efficiency; that is, the more difficult the icon set (cf. 'game efficiency'), the higher the cognitive load, and hence, more cards were fixated upon (compare Fig. 4C to Fig. 2A and 2B). Thus, among adults more fixations were related to higher cognitive load, which is in accordance with the finding by Van Orden et al., (2001). However, among children the distribution of number of cards fixated upon was somewhat different. First, adults simply fixated on many more cards before actually turning a card when having an opportunity to make a match, than children. Second, whereas the distribution of number of cards fixated upon across icon sets among the 8-year-olds seemed to follow the same overall pattern, as we saw in adults (although at a much higher magnitude) in which the most difficult icon sets systematically resulted in more cards fixated upon, this pattern was less prominent among the 6-year-olds (compare Fig. 4C, to Fig. 2A and B for 6-year olds).

3.5 Working memory and inhibition

Finally, we examined age-related differences in visuospatial working memory and inhibition, as well as the ability of these cognitive processes to predict game efficiency (operationalized as number of moves). The ANOVAs of the Finger Windows and the Flanker task data resulted in main effects of Age Group (6-year-olds vs. 8-year olds): Finger Windows forward number correct, $F(1, 80) = 40.67$, $p < .001$, $\eta_p^2 = .337$, Finger Windows backward number correct, $F(1, 80) = 19.68$, $p < .001$, $\eta_p^2 = .197$, and Flanker task conflict RT, $F(1, 79) = 10.31$, $p = .002$, $\eta_p^2 = .115$. Group differences were in the expected direction

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with a higher number of correctly recalled sequences and shorter conflict RTs in the older age group.

In the younger age group, there was a moderate, negative correlation between number of correctly recalled sequences on the forward condition of the Finger Windows task and number of moves in the Concentration game: r = -.42, n = 34, p = .015, with higher number of correctly recalled sequences associated with lower number of moves (i.e., greater game efficiency). Number of correctly recalled sequences on the forward condition was not significantly correlated with number of moves in the older age group, r = -.22, n = 48, p = .137, and number of moves did not correlate significantly with any other cognitive outcome in any of the age groups.

The linear regression analysis revealed that in the younger group, forward number correct, backward number correct, and conflict RT (all three factors entered simultaneously) explained 18.80% of the variance in game efficiency (number of moves), $F(3,29) = 2.24$, p = .105. Only forward number correct made a significant contribution to the prediction of game efficiency (β = -.39, p = .031). In the older group, the same variables explained only 4.75% of the variance in game efficiency, $F(3,44) = .73$, p = .539, and none of the variables made a significant contribution.

The results suggest that while 8-year-olds clearly outperformed 6-year-olds on tasks measuring visuospatial working memory and inhibition, these cognitive processes (at least when measured with the current tasks) contributed relatively modestly to game efficiency in each of the two age groups.

4. Discussion

We conducted a comprehensive and systematic examination of the ability of 6- and 8-year-old children and adults to play Concentration. Compared to previous studies on Concentration, we employed a design with enhanced experimental control in four distinct

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areas: (a) distance between locations and movements of cards were harmonized across trials, (b) three different sets of icons with different levels of familiar semantic content were used, (c) eye tracking was employed, and (d) the role of working memory and inhibition was examined in the child subsamples—factors which, all things equal, should help shed new light on the enigma.

With regard to game efficiency (number of moves and time required to finish nine pairs), the 8-year-olds performed just as well as the adults, and with a trend towards outperforming the adults with respect to moves required to finish nine pairs. By comparison, the 6-year-olds generally performed worse than both their older peers and the adults. How do these results relate to the Common Sense Hypothesis and the Developmental Reversals Hypothesis? First, the results indicate, that the children should *not* be treated as one homogeneous group. Thus, when considering the 6-year-olds, the results seem to be in accordance with the Common Sense Hypothesis as the 6-year-olds were clearly less efficient than the older participants. However, when considering the 8-year-olds, the results are at odds with the Common Sense hypothesis, because the 8-year-olds performed (at least) as well as the adults.

Gellatly et al. (1988) also found age differences in game efficiency, as the 5-year-olds in their study were reliably inferior to the older children and adults. Although the remaining four studies on Concentration (Baker-Ward & Ornstein, 1988; Chagnon & McKelvie, 1992; Jansen-Osmann & Heil, 2007; Schumann-Hengsteler, 1996) did not find significant differences with regard to game efficiency between children of different age groups, the results from both Baker-Ward and Ornstein (1998) and Schumann-Hengsteler (1996) revealed trends in this direction, and the study by Chagnon and McKelvie (1992) was probably underpowered as only 24 subjects across the 5-65 year age range participated.

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In our view, the really intriguing part is not that 8-year-olds fared better than the 6-year-olds, but rather that the 8-year-olds performed just as well as the adults. In principle, similar results on game efficiency can be achieved by different means, and in the following we discuss how adults and 8-year-olds may have achieved their results.

4.1 Differences in strategy when playing in Concentration – and in the real world

Adults succeeded in creating reliably more opportunities than the 8-year-olds, but the adults were no better at seizing these opportunities; in fact they were reliably less effective than the 8-year-olds when considering the concrete icons sets alone. As concrete icons are probably the most frequently encountered icon types in commercially available Concentration games, this result may help explaining the prominence of anecdotal reports of parents losing to their children. Both adults and 8-year-olds made substantially fewer redundant moves than the 6-year-olds. As we predicted that adults would make fewer redundant moves than children, these results were only partially in accordance with our initial hypothesis. However, the results followed the same pattern as the game efficiency results, as the performance of the 8-year-olds was similar to the adults', and superior to the 6-year-olds'.

As predicted, adults systematically produced more almost hits than both groups of children. In our view this recurrent pattern of results may be central to disentangle the enigma. Recall that Schumann-Hengsteler (1996) found that 5-year-olds had fewer almost hits. She explained this result with reference to fuzzy trace theory, suggesting that, in contrast to children, adults may be more inclined to remember the gist of the memory (i.e., the semantic information of the cards), alternatively assisted by 'vague verbal labels' in their attempt to remember card locations (e.g., "right corner, upper row"; Schumann-Hengsteler, 1996). In our view, adults may indeed have been more prone to remember the gist relative to children, but in the present study the gist seems to refer mostly to the 'alternative' suggestion by Schumann-Hengsteler (1996), that is, to the *approximate location* of the card's position (evidenced by the higher number of almost hits in adults)—not the semantic content of the card (recall that there was no interaction between age group and icon set, indicating that semantic content was *not* differentially affected by age; we return to a discussion of the results regarding semantic content of the icons in the section below).

Possibly, adults' tendency to produce more almost hits may reflect an important, but hitherto neglected, difference between real world tasks and the specific problems related to playing Concentration. Consider a typical real world task where one is required to remember an exact location. For instance, one may return to a city after several years, looking for a friend's apartment, a specific shop, or restaurant, without having the exact address. When attempting to solve such a problem in the real world, remembering the approximate (but not the specific) location and consequently producing 'almost hits', is probably an effective step to success. That is, almost hits are valuable, because they help us 'home in' on the target location through important cues in the surroundings (a memorable statue close by, etc.), that may elicit further memories and ultimately help us get where we need to be. Studies of such real world tasks reveal that relative to children, (a) adults select more reference points in the real world, and are better at making distance judgments (Allen, Kirasic, Siegel, & Herman, 1979), (b) adults and older children are better at recognizing landmarks (Kirasic, Siegel, & Allen, 1980), and (c) older participants are better at place recognition when being 'off' a learned route (Cornell, Heth, & Alberts, 1994). Thus, in real world tasks, almost hits are beneficial, and adults outperform children in such tasks.

When playing Concentration, the situation is, however, somewhat different. Here, the potential advantage of having almost hits is reduced. One crucial difference is, that whereas distinct landmarks are perceptually available in real world tasks, the icon on the target card (or its neighbor) is always placed face down when playing Concentration and therefore unavailable when the decision to turn a card is made. Consequently, cuing from the

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'environment' is far less salient and effective when playing Concentration than in equivalent real world situations.

But why should adults apply such a relatively ineffective strategy when playing Concentration? We propose that being required to search among a relatively large number of identical 'landmarks' while the target is concealed, as is required when playing Concentration, may be a special case only rarely encountered in the real world. The closest real world equivalent to Concentration may be something like a wall of lockers at a train station. However, in the real world equivalent, each locker is typically—and for good reasons—uniquely identified by a number or a code, specifically aimed at avoiding the problem present in Concentration in which all back sides of the cards are identical. As a result, when playing Concentration adults probably have no obvious and well-rehearsed strategy at hand and may simply rely on the strategies that are effective in what may *appear* to be similar (albeit actually rather different) real world tasks. In other words, when cognitive overload becomes prominent (adults created more opportunities than 8-year-olds), adults remember the gist (the approximate location) which lead them to produce almost hits.

We propose that when 8-year-olds perform just as well as adults when playing Concentration, it is not because children possess a certain skill regarding, for instance, 'spatial associative learning' that adults do not (as suggested by Baker-Ward & Ornstein, 1988). Note that none of the data obtained here suggest that children should possess any cognitive skills at a level superior to adults. Furthermore, that would also contradict evidence suggesting that for instance working memory increases throughout childhood (e.g., Gathercole et al., 2004). Thus, we do not think that the impressive performance of the 8-year-olds when playing Concentration should be interpreted as an example of developmental reversals. Instead, we suggest that adults and children tend to use different strategies when playing Concentration, and that the strategies favored by adults (creating many opportunities

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and remembering the approximate location of the cards)—although containing some merit—are simply less effective when playing Concentration due to the unique nature of the game, relative to real world tasks.

The finding that adults, relative to children, reliably fixated on more cards before actually turning a card when having an opportunity to make a match lends further support to this interpretation. Fixations are associated with cognitive effort (van Orden et al., 2001), and when playing Concentration adults seem to entertain a standard strategy: Adults scan the environment for information to help them 'solve' the task. However, no contextual cues are offered in Concentration as the cards are face down, and consequently, the strategy is not optimal. Note that this interesting result concerning number of cards fixated upon, could not have been obtained without the use of eye tracking or equivalent methodology. We are unaware of any other studies that have compared fixations in children and adults, so at the time of writing, we do not know whether this increase in employing fixations is a distinct feature of adult's visual behavior or not. It is of course also possible that the increased number of fixations among adults simply reflect that adults, relative to children, consider more choices before turning a given card. Future studies should examine differences in game strategies in children versus adults further.

4.2 The relevance of semantic knowledge – and visual features

Based on Schumann-Hengsteler (1996) we expected adults to fare relatively *worse* on numbers and especially concrete objects than on icons demanding little semantic knowledge (i.e., abstract icons). However, as age and icon sets did not interact on any of the two game efficiency measures (moves and time), this hypothesis was not confirmed. In fact, and *regardless* of age, there was a clear and stable pattern concerning the relationship between icon sets and game efficiency: Concrete icons were consistently easier than abstract icons, which again were easier than numbers (see Fig. 2). Note that this pattern of results cannot

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easily be explained with reference to the participant's semantic knowledge of the three icon sets as the participants, all things equal, should possess *least* knowledge about the abstract icons, which invariably ended up as the second easiest (or second most difficult) of the icon sets. Thus, other explanations are warranted.

Perhaps the most straightforward way to explain the stable order in which game efficiency differs across icon sets would be by considering how different (or similar) the different pairs were from a visual feature perspective. In the infant literature, the typical way to assess visual feature differences between objects is to consider the dimensions shape, size, color, and texture/material (e.g., Kingo & Krøjgaard, 2011; Krøjgaard, 2004; Wilcox, 1999). From this perspective, the order of 'easiness' manifested in the present study seems to make sense: The number icons were the most 'difficult' icons, because these icons were, from a visual feature perspective, most alike (all number cards consisted of black numbers on a white background, whereas the two remaining icon sets contained substantially more feature diversity; see Fig. 1). Differences in feature diversity *within* each icon set may also, at least partially, explain the finding that the concrete icons were consistently easier than the abstract icons. Although we acknowledge that we have no data to support this, visual inspection of the icon sets suggest that this may indeed have been the case. First, the *shapes* of the motives in the concrete icon set seem to contain more variability compared to the shapes of the cards in the abstract icon set. Second, the *textures/materials* of objects displayed on the cards in the concrete icon set seem to contain more diversity than the cards in the abstract icon set. In contrast, when considering the visual features of the cards, we see no obvious features by which the abstract icons should be easier to distinguish, relative to the concrete icons. Thus, differences in basic visual features are likely to be the main reason why icon sets consistently were solved in a stable order of easiness (i.e., concrete > abstract > numbers).

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4.3 Working memory and Concentration

The results from the working memory task showed that the 6-year-olds were clearly inferior to the 8-year-olds, which is consistent with the common finding that working memory in general (Gathercole et al., 2004) and visuospatial working memory specifically (Pickering, 2001) improves as children get older.

However, when considering the associations between working memory and game efficiency, only working memory storage was reliably associated with game efficiency, and only for the 6-year-olds. In addition, the linear regression model was not statistically significant, and the three potential predictors (working memory storage, working memory processing, and inhibitory control) contributed only modestly to game efficiency. Taken together, these results suggest that there was substantial additional variance to be explained, and that the Concentration game may be measuring more and somewhat different processes than those targeted by working memory tasks such as Finger Windows.

Why was working memory not a stronger predictor of game efficiency? While certain skills are indeed relevant for performing well in both tasks (i.e., remembering the spatial location of items), they also *differ* in at least two respects: First, whereas Finger Windows concern the memory of identical and meaningless items (i.e., 'holes'), Concentration requires the participant to remember and distinguish between many different and semantically loaded items (typically everyday objects), as well as their respective locations. In other words, and as already pointed out in the introduction, whereas the Finger Windows task is a "where"-tasks, Concentration is a combined "where"- and "what"-task. Second, whereas the subject has no influence on the pace or order in which the items-to-be-remembered are presented in Finger Windows (Sheslow & Adams, 2003), Concentration is self-paced as the subject has to decide which cards to turn and which not to, implying the involvement of strategic considerations. Thus, although playing Concentration involves working memory, the task also differs from

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traditional span tasks, and the results from the present study suggest that these differences are central when attempting to understand the enigma.

4.4 Broader implications

First, besides providing empirical evidence in support of the anecdotal claim, that children are surprisingly proficient at playing Concentration, we offer what may be the first elaborated attempt to *explain* this intriguing enigma. Based on the findings showing that adults relative to children have more almost hits as well as fixate on more cards before actually turning a card, we propose that when playing Concentration, adults (but not children) are inclined to entertain strategies regarding remembering gists in the form of approximate locations of the cards; a strategy that is beneficial in real world tasks, but less effective when playing Concentration. Thus, performance on Concentration does indeed seem to represent an exception to the core Piagetian claim that adults should be superior to children in *any* cognitive task (e.g., Piaget & Inhelder, 1969). Meanwhile, Concentration may represent a quite unique cognitive task only rarely encountered in the real world.

Second, the results from the present study seem to question whether Concentration should be used as a proxy for (visuospatial) working memory. Some studies have employed Concentration as means to examine working memory (e.g., Jalali-Moghadam & Kormi-Nouri, 2015; Lavanex et al., 2011), but to the best of our knowledge, no one has analyzed to what extent this is actually justified. Visuospatial working memory is obviously associated with the ability to play Concentration, and the associations between working memory storage and game efficiency, and to some extent the results from regression analysis from the present study, is in accordance with this assumption. However, there is more variance to be explained, and tasks such as Finger Windows appear to differ from Concentration on a number of crucial respects, including content of the to-be-remembered items, and the locus of

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pace of the tasks. Thus, the results and analyses from the present study question whether Concentration can be used as a proxy for visuospatial working memory.

Whereas the results obtained here provide answers to some questions, other questions emerged. In the version of the Concentration presented here, differences in the visual features between icon sets seemed to have had more impact on game efficiency than the semantic content of each set. However, in order to assess the *relative* impact of visual features and semantic content with higher accuracy, further studies in which these dimensions are meticulously controlled for would be necessary. Another interesting question pertaining to the results obtained here, is whether adult's inclination to fixate on more cards than children is a general characteristic of adult's visual behavior when solving cognitively demanding tasks, or whether it is a more domain specific characteristic related only to playing Concentration or equivalent.

Analyzing how children and adults play Concentration seems to be a double edged sword: On the one hand the self-paced nature of the game clearly complicates the analyses considerably and may be one of the reasons why so relatively few have set out to investigate the enigma systematically. Some of the interesting questions related to the task may be examined more directly using non-game-like subtasks (e.g., Jansen-Osmann & Heil, 2007). On the other hand, anecdotal reports of children's ability to outperform adults in for instance Concentration constitute an interesting puzzle, that, as proposed here, may direct researcher's attention to hitherto neglected aspects of cognition and its development, helping us to disentangle and understand the relevant and necessary strategies used to comply with memory tasks in games as well as in the real world.

5. References

Allen, G. L., Kiracic, K. C., Siegel, A W., & Herman, J. F. (1979). Developmental issues in cognitive mapping: The selection and utilization of environmental landmarks. *Child Development*, *50,* 1062-1070. DOI: 10.1111/1467-8624.ep7251716

Anglin, J. M. (1993). Vocabulary development: A morphological analysis. *Monographs of the Society for Research in Child Development, 58*, Serial No. 238). DOI: 10.1111/1540-5834.ep9410280902

Baker-Ward, L., & Ornstein, P. (1988). Age differences in visual-spatial memory performance: do children really out-perform adults when playing *Concentration*? *Bulletin of the Psychonomic Society*, *26,* 331-332. DOI: 10.3758/BF03337672

Bedard, A. C., Martinussen, R., Ickowicz, A., & Tannock, R. (2004). Methylphenidate improves visual-spatial memory in children with attention-deficit/hyperactivity disorder. *Journal of American Academy of Child and Adolescent Psychiatry*, *43,* 260-268. DOI: 10.1097/00004583-200403000-00006

Brainerd, C. J., & Reyna, V. F. (2007). Explaining developmental reversals in false memory. *Psychological Science, 18,* 442-448. DOI: 10.1111/j.1467-9280.2007.01919.x

Brainerd, C. J., & Reyna, V. F. (2012). Reliability of children's testimony in the era of developmental reversals. *Developmental Review*, *32,* 224-267. DOI: 10.1016/j.dr.2012.06.008

Burggraaf, R., Frens, M. A., Hooge, I. T. C., & van der Geest, J. N. (2018). Performance on tasks of visuoaptial memory and ability: a cross-sectional study in 330 adolescents aged 11-20. *Applied Neuropsychology: Child*, *7,* 129-142. DOI: 10.1080/21622965.2016.1268960

Chagnon, J., & McKelvie, S. T. (1992). Age differences in performance at Concentration: A pilot study. *Perceptual and Motor Skills, 74*, 412-414. DOI: 10.2466/pms.1992.74.2.412

Chi, M.T.H. (1978). Knowledge structures and memory development. In R.S. Siegler (Ed.), *Children's thinking: What develops?* (pp. 73-96). Hillsdale, NJ: Erlbaum.

Cornell, E. H., Heth, C. D., & Alberts, D. M. (1994). Place recognition and way finding by children and adults. *Memory & Cognition, 22,* 633-643. DOI: 10.3758/BF03209249

Crovitz, H. F. (1970). *Galton's walk: Methods for the analysis of thinking, intelligence, and creativity.* New York: Harper & Row.

Davidson, M. C., Amso, D., Anderson, L. C. & Diamond, A. (2006). Development of cognitive control and executive functions from 4 to 13 years: Evidence from manipulations of memory, inhibition, and task switching. *Neuropsychologia*, *44*, 2037–2078. DOI: 10.1016/j.neuropsychologia.2006.02.006

Eskritt, M., & Ma, S. (2014). Intentional forgetting: Note-taking as a naturalistic example. *Memory and Cognition, 42*, 237-246. DOI: 10.3758/s13421-013-0362-1

Gathercole, S. E., Pickering, S. J., Ambridge, B., & Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology, 40,* 177-190. DOI: 10.1037/0012-1649.40.2.177

Gellatly, A., Jones, S., Best, A. (1988). The development of skill at Concentration. *Australian Journal of Psychology, 47,* 1-10. DOI: 10.1080/00049538808259064

Gulya, M., Rossi-George, A., Hartshorn, K., Vieira, A., & Rovee-Collier, C. (2002). The development of explicit memory for basic perceptual features. *Journal of Experimental Child Psychology, 81,* 276-297. DOI: 10.1006/jecp.2001.2654

Huizinga, M., Dolan, C. V. & van der Molen, M. W. (2006). Age-related change in executive function: Developmental trends and a latent variables analysis. *Neuropsychologia, 44,* 2017–2036. DOI: 10.1016/j.neuropsychologia.2006.01.010

Jalali-Moghadam, N., & Kormi-Nouri, R. (2015). The role of executive functions in bilingual children with reading difficulties. *Scandinavian Journal of Psychology, 56,* 297-305. DOI: 10.1111/sjop.12198

Jansen-Osmann, P. & Heil, M. (2007). Are primary-school-aged children experts in spatial associative learning? *Experimental Psychology, 54,* 236-242. DOI: 10.1027/1618-3169.54.3.236

Jäger, K., Schmidt, M., Conzelmann, A., & Roebers, C. M. (2014). Cognitive and physiological effects of an acute physical activity intervention in elementary school children. *Frontiers in Psychology*, *5*, 1473. DOI: 10.3389/fpsyg.2014.01473

Kingo, O.S., & Krøjgaard, P. (2011). Object manipulation facilitates kind-based object individuation of shape-similar objects. *Cognitive Development, 26,* 87-103. DOI: 10.1080/15248372.2011.575424

Kirasic, K. C., Siegel, A. W., & Allen, G. L. (1980). Developmental changes in recognition-in-context memory. *Child Development, 51,* 302-305. DOI: 10.2307/1129630

Krøjgaard, P. (2004). A review of object individuation in infancy. *British Journal of Developmental Psychology*, 22, 159-183. DOI: 10.1348/026151004323044555

Lavanex, P. B., Lecci, S., Prêtre, V., Brandner, C., Mazza, C., Pasquier, J., & Lavanex, P. (2011). As the world turns: Short-term human spatial memory in egocentric and allocentric coordinates. *Behavioral Brain Research, 219,* 132-141. DOI: dx.doi.org/10.1016/j.bbr.2010.12.035

Meacham, J. A. (1972). The development of memory abilities in the individual and society. *Human Development, 15*, 205-228. DOI: 10.1159/000271244

Milner, A.D., & Goodale, M.A. (1995). *The visual brain in action*. Oxford, UK: Oxford University Press.

Piaget, J., & Inhelder, B. (1969). *The psychology of the child.* New York: Basic Books.

Pickering, S. J. (2001). The development of visuo-spatial working memory. *Memory, 9,* 423-432. DOI: 10.1080/09658210143000182

Reyna, V. F., & Brainerd, C. J. (1995). Fuzzy-trace theory: An interim synthesis. *Learning and Individual Differences, 7,* 1-75. DOI: 10.1016/1041-6080(95)90031-4

Ross, D. F., Marsil, D. F., Benton, T. R., Hoffman, R., Warren A. R., Lindsay, C. L. R., & Metzger, R. (2006). Children's susceptibility to misidentifying a familiar bystander from a lineup: When younger is better. *Law and Human Behavior, 30,* 249-257. DOI: 10.1007/s10979-006-9034-z

Schumann-Hengsteler, R. (1996). Children's and adults' visuospatial memory: The game Concentration. *The Journal of Genetic Psychology, 157,* 77-92. DOI: 10.1080/00221325.1996.9914847

Tottenham, L. S., Saucier, D., Elias, L., & Gutwin, C. (2003). Female advantage for spatial location memory in both static and dynamic environments. *Brain and Cognition, 53,* 381-383. DOI: 10.1016/j.bandc.2008.06.006

Sheslow, D., & Adams, W. (2003). *Wide range assessment of memory and learning* (2nd edn). Wilmington, DE: Wide Range.

Van Orden, K. F., Limbert, W., & Makeig, S. (2001). Eye activity correlates of workload during a visuospatial memory task. *Human Factors, 43,* 111-121. DOI: 10.1518/001872001775992570

Ungerleider, L.G., & Mishkin, M. (1982). Two cortical visual systems. In D.J. Ingle, M.A. Goodale, & R.J.W. Mansfield (Eds.), *Analysis of visual behavior* (pp. 549-586). Cambridge, MA: MIT Press.

Vasilyeva, M., & Lourenco, S. F. (2012). Development of spatial cognition. *WIRES Cognitive Science, 3,* 349-362. DOI: 10.1002/wcs.1171

Werker, J.F., Gilbert, J.H.V., Humphrey, K., & Tees, R.C. (1981). Developmental aspects of cross-language speech perception. *Child Development, 52,* 349-355. DOI: 10.2307/1129249

Werker, J.F., & Tees, R.C. (1983). Developmental changes across childhood in the perception of non-native speech sounds. *Canadian Journal of Psychology, 37,* 278-286. DOI: 10.1037/h0080725

Werker, J.F., & Tees, R.C. (1984). Cross-language speech perception: Evidence for perceptual reorganization during the first year of life. *Infant Behavior and Development, 7,* 49-63. DOI: 10.1016/S0163-6383(84)80022-3

Wilcox, T. (1999). Object individuation: infants' use of shape, size, pattern, and color. *Cognition, 72,* 125-166. DOI: 10.1016/S0010-0277(99)00035-9

Williams, B. R., Ponesse, J. S., Schachar, R. J., Logan, G. D. & Tannock, R. (1999). Development of inhibitory control across the life span. *Developmental Psychology, 35,* 205–213. DOI: 10.1037//0012-1649.35.1.205

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Table 1. *Definitions of key measures regarding game efficiency, game strategy, errors and visual behavior (in alphabetical order):*

Measure:	Definition:
Almost hits	Knowing the approximate location of a matching card, but making the error of turning an either horizontally, vertically, or diagonally adjacent card.
Cards fixated upon	Number of cards fixated upon before turning a card when having an opportunity to make a match (already turned cards and repeated fixations on same card excluded).
Number of moves	Number of moves used to finish the first nine matching pairs
Opportunities	When a card is turned, and the matching card had already been turned in a previous round.
Perfect hits	Immediately turning a matching pair, as soon as the necessary information is available.
Redundant moves	Turning an already known card, but without knowing the location of the matching card.
Success ratio	Number of hits attained divided by number of opportunities created.
Time	Time in seconds used to finish the first nine matching pairs

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Table 2. *Displays the Ms and SDs of the main Concentration game results across the three age groups.*

	Icon set	Moves M (SD)	Time (s) M (SD)	Opportunities created: M (SD)	Success ratio (hits/opportunity) M (SD)	Perfect hits M (SD)	Redundant moves M (SD)	Almost hits M (SD)	Cards fixated upon M (SD)
6-year-olds (N = 34)									
	Concrete	24.6 (4.6)	104.5 (23.5)	12.7 (4.0)	0.70 (0.16)	5.7 (1.8)	11.5 (5.9)	0.65 (0.98)	6.8 (5.1)
	Number	27.6 (7.4)	113.1 (29.7)	14.6 (5.1)	0.63 (0.17)	5.1 (1.9)	14.4 (8.5)	0.44 (0.56)	7.1 (5.5)
	Abstract	26.4 (6.1)	108.3 (23.0)	14.5 (4.8)	0.65 (0.20)	5.1 (2.0)	12.8 (7.2)	0.35 (0.60)	7.7 (6.3)
	All combined	26.2 (4.5)	108.6 (19.2)	13.9 (3.5)	0.66 (0.13)	5.3 (1.3)	12.9 (5.2)	0.48 (0.45)	7.2 (4.1)
8-year-olds (N = 48)									
	Concrete	20.9 (3.4)	87.2 (19.2)	10.7 (2.3)	0.80 (0.13)	6.2 (1.4)	7.0 (5.2)	0.23 (0.52)	5.0 (3.5)
	Number	24.8 (4.8)	103.8 (23.9)	13.9 (4.3)	0.66 (0.16)	5.3 (1.6)	10.6 (5.4)	0.56 (0.77)	8.5 (7.7)
	Abstract	24.1 (4.0)	98.9 (18.8)	13.5 (3.1)	0.65 (0.14)	5.0 (1.6)	10.0 (5.3)	0.46 (0.71)	7.2 (4.9)
	All combined	23.3 (2.9)	96.6 (15.2)	12.7 (2.5)	0.70 (0.11)	5.5 (1.1)	9.2 (3.7)	0.42 (0.34)	6.9 (3.1)
Adults (N = 38)									
	Concrete	21.7 (3.6)	85.6 (21.5)	12.4 (2.7)	0.72 (0.14)	5.8 (1.5)	7.1 (4.4)	0.42 (0.68)	6.8 (4.3)
	Number	26.7 (7.7)	106.4 (41.2)	16.9 (7.2)	0.58 (0.19)	4.6 (2.2)	11.1 (7.9)	0.74 (0.98)	12.1 (8.7)
	Abstract	25.0 (7.4)	97.1 (28.9)	14.6 (6.7)	0.66 (0.18)	5.2 (1.9)	10.5 (7.9)	1.05 (1.01)	11.4 (8.2)
	All combined	24.5 (4.2)	96.4 (23.7)	14.6 (3.7)	0.65 (0.11)	5.2 (1.2)	9.5 (4.6)	0.74 (0.55)	10.1 (4.8)

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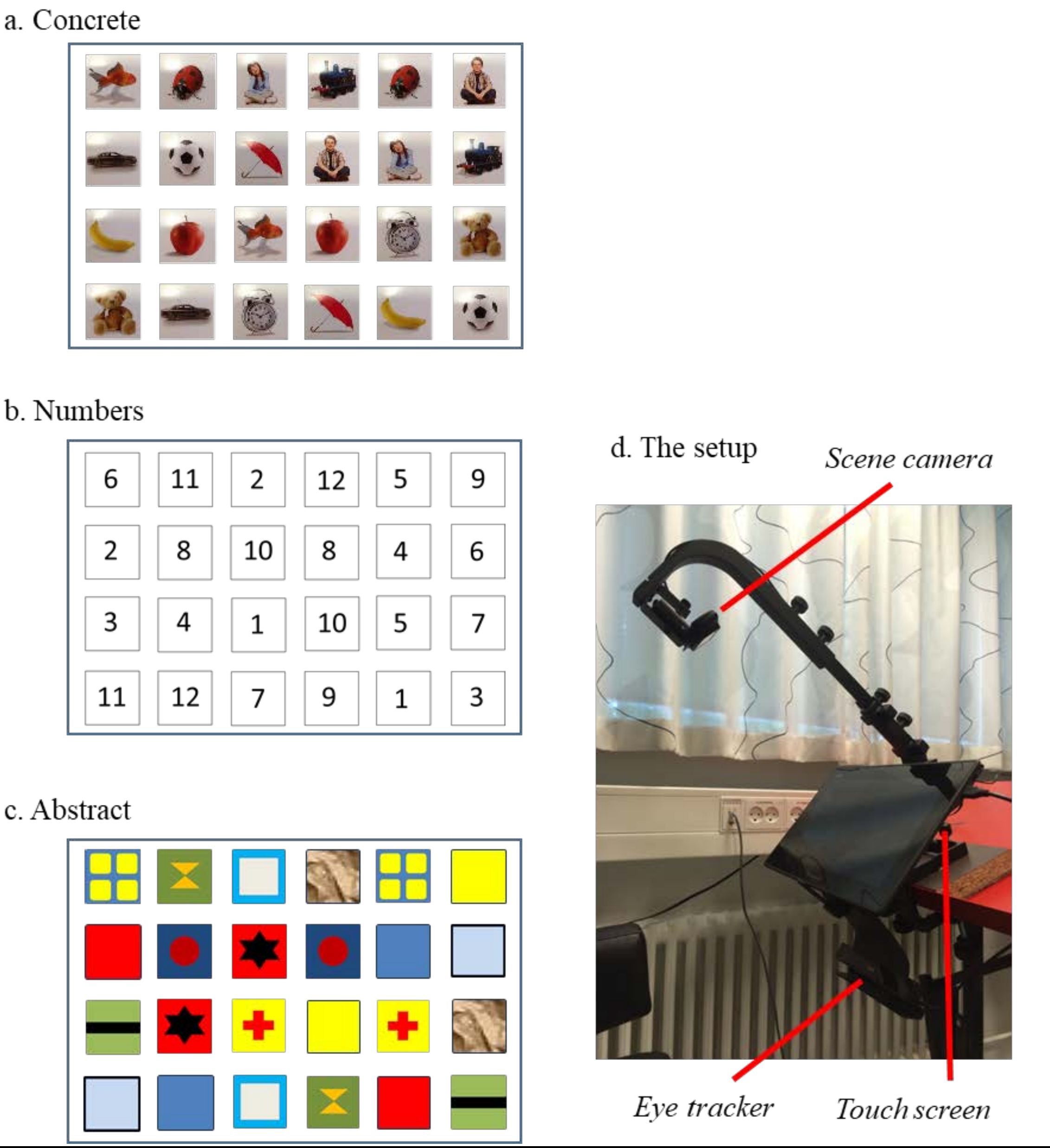
Fig. 1. Displays the three icon sets used (a-c), as well as the setup (d)



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<u>Fig. 2. Displays game efficiency across age groups and icon sets measured as (A) mean number of moves required, and (B) mean number of seconds required to collect 9 matching pairs.</u>

A: Moves required to collect 9 pairs (lower is better)

B: Seconds required to collect 9 pairs (lower is better)

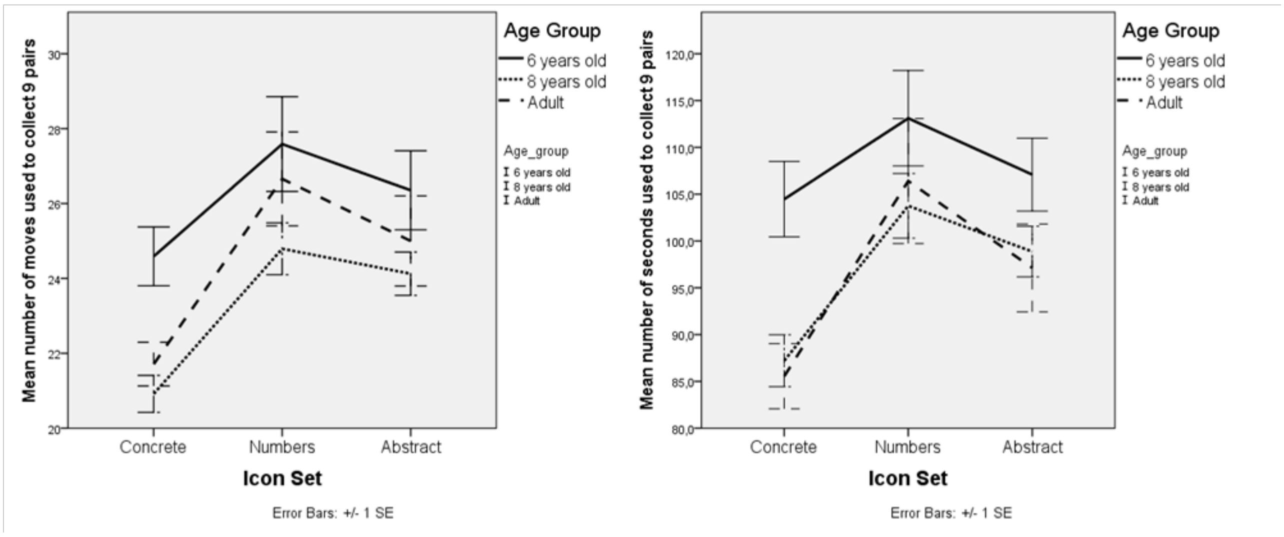

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Fig. 3. Displays the ability to create and seizing opportunities across age groups and icon sets measured as (A) mean number opportunities created, (B) success ratio (hits per opportunities), and (C) mean number of perfects hits. For all three, higher is better.

A: Number of opportunities created

B: Success ratio (hits per opportunity)

C: Perfect hits (producing a match at the first informed opportunity) to collect 9 pairs

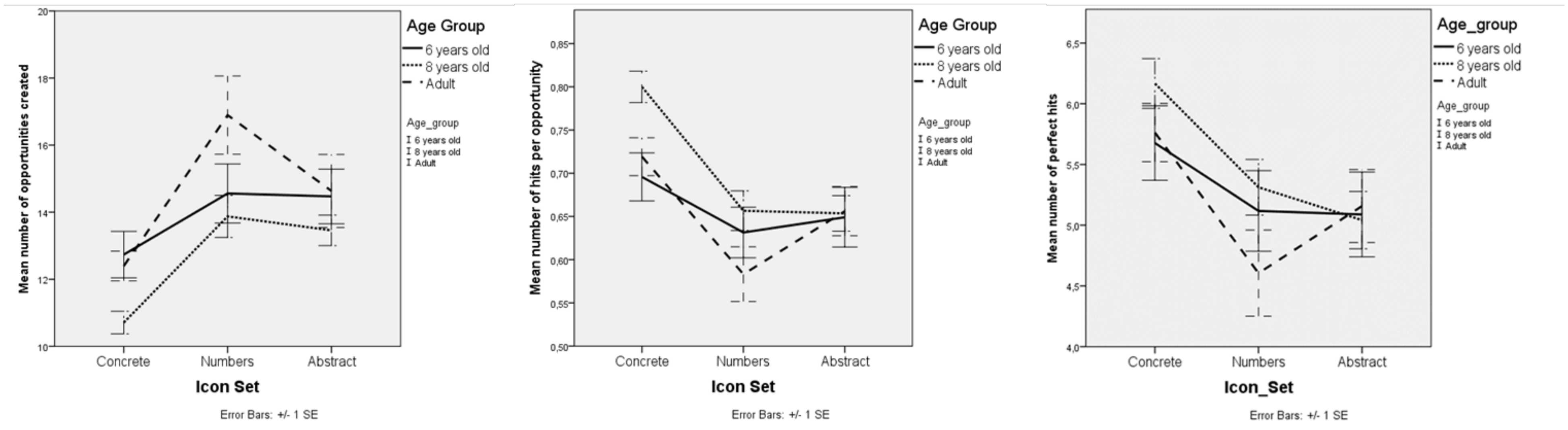

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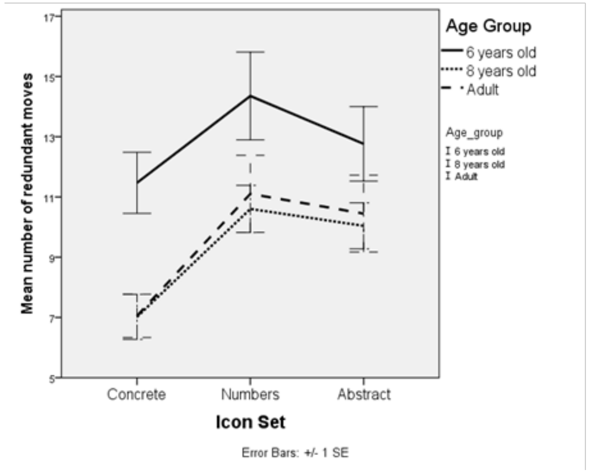
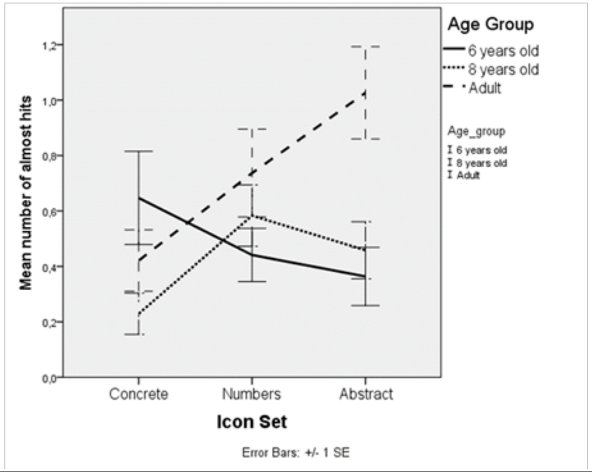
Fig. 4. Displays strategy and errors across age groups and icon sets measured by (A) number of redundant moves, (B) number of almost hits, and (C) cards fixated upon before actually turning a card.

A: Mean number of redundant moves (lower is better)



B: Mean number of almost hits (knowing the approximate location of a matching card, but making the error of turning an either horizontally, vertically, or diagonally adjacent card).



C: Mean number of cards fixated upon before turning over a card when having an opportunity to make a match [already turned cards and repeated fixations on same card excluded])