Evaluating Analogical Reasoning in Elementary School Children Using an Executive Functions Framework

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S1138855

March 2013, Enschede

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Abstract

Introduction The research question was: what is the relation between the level of the executive functions inhibition, working memory and fluency and analogical reasoning performance in children between the age of 8 and 11? It was hypothesized that older children would be better problem solvers than younger children and that older children would have higher analogical reasoning performance and perceive more relational similarities than younger children. Changes in analogical reasoning performance were expected to be explained by differences in the executive functions inhibition, working memory and fluency. This study tried to find support for this explanation.

Method Sixty children in the age of 8 to 11 participated in this study. The study is explorative. Children were given a test for verbal fluency and design fluency, for verbal and visual working memory and a task for analogical reasoning performance. Last, the Color-Word Interference Test was administered to measure inhibition.

Results Children in fifth grade could not solve more problems than children in third grade ($t=.366$, $p=.716$). They did not have higher analogical reasoning performance, but the number of relational similarities perceived was significantly higher in fifth grade than in third grade on the near-transfer task ($t=2.877$, $p=.006$). Inhibition, visual working memory and verbal fluency were significantly related to the number of superficial similarities on the near-transfer task. On the far-transfer task, verbal fluency was significantly related to the number of superficial similarities. The number of relational similarities was only positively related to verbal working memory on both tasks, but this was not significant.

Conclusions and Discussion The hypotheses were partially supported by the data. More older children could solve the far-transfer task than younger children and older children perceived more relational similarities. The executive functions inhibition, working memory and fluency were positively related to analogical reasoning, especially to the number of superficial similarities, which gives support to the expectation that changes in analogical reasoning would be explained by the executive functions inhibition, working memory and fluency. The results do not completely correspond to earlier studies, probably due to differences in procedures and tests used. The analogical reasoning task appeared to be too difficult for the children and there was too much noise to focus on the tasks. Also, the score-range for analogical reasoning was too narrow and the sample was too small to obtain significant results. A more diverse and larger sample should be used in the future.

Samenvatting

Introductie De onderzoeksvraag was: wat is de relatie tussen het niveau van de executieve functies inhibitie, werkgeheugen en *fluency* en prestatie op analoog redeneren in kinderen tussen 8 en 11 jaar? Hypotheses waren dat oudere kinderen betere probleemoplossers zouden zijn dan jongere kinderen en dat oudere kinderen hoger zouden presteren op analoog redeneren en meer relationele overeenkomsten zouden zien dan jongere kinderen. Verwacht werd dat verschillen in analoog redeneren verklaard zouden kunnen worden door verschillen in de executieve functies inhibitie, werkgeheugen en *fluency*, waar in dit onderzoek ondersteuning voor werd gezocht.

Methode Zestig kinderen in de leeftijd van 8 tot 11 jaar namen deel aan dit onderzoek. Kinderen kregen een test voor verbale *fluency* en design *fluency*, voor verbaal en visueel werkgeheugen en een taak voor analoog redeneren. Tenslotte werd de Color-Word Interference Test afgenomen om inhibitie te meten.

Resultaten Kinderen in groep 7 konden niet meer problemen oplossen dan kinderen in groep 5 ($t=.366$, $p=.716$). Ook hadden ze geen hogere scores op analoog redeneren, maar zij zagen wel meer relationele overeenkomsten dan kinderen in groep 5 op de *near-transfer* taak ($t=2.877$, $p=.006$). Inhibitie, verbaal werkgeheugen en verbale *fluency* waren sterk gerelateerd aan het aantal oppervlakkige overeenkomsten die ze zagen op de *near-transfer* taak. Op de *far-transfer* taak was verbale *fluency* sterk gerelateerd aan het aantal oppervlakkige overeenkomsten. Het aantal relationele overeenkomsten was alleen positief gerelateerd aan verbaal werkgeheugen op beide taken, maar dit was niet significant.

Conclusies en Discussie De hypotheses worden deels ondersteund door de data. Meer oudere kinderen konden de *far*-transfer taak oplossen dan jongere kinderen en oudere kinderen zagen meer relationele overeenkomsten. De executieve functies waren positief gerelateerd aan analoog redeneren, vooral aan het aantal oppervlakkige overeenkomsten dat kinderen zagen. Dit ondersteunt de verwachting dat verschillen in analoog redeneren verklaard zouden kunnen worden door verschillen in de executieve functies inhibitie, werkgeheugen en *fluency*. De resultaten komen niet helemaal overeen met andere onderzoeken, waarschijnlijk door verschillen in de gebruikte procedures en tests. De taak voor analoog redeneren leek te moeilijk te zijn voor de kinderen en er was te veel lawaai om goed te kunnen focussen op de taken. Ook was de score-range voor de analoog redeneer-taak erg klein en was de sample klein, waardoor resultaten vaak niet significant waren. In toekomstig onderzoek zou een meer diverse en grotere sample gebruikt moeten worden.

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Introduction

Problem solving plays an important role in daily life. People encounter many problems that need to be solved every day. People often use a solution to an old problem to find a solution to a new problem. They therefore use the knowledge they have about a past situation and use this to make inferences about a new situation (Dunbar & Blanchette, 2001; Holyoak, Junn, & Billman, 1984). Because older children probably have faced more problems in their lives than younger children and therefore have more experience solving these problems, the first hypothesis is that older children are better problem solvers than younger children.

Applying knowledge about a situation to a new situation is called transfer (Goldstone & Day, 2012). Transfer is an important aspect of learning and of education, which are the focus of this study. It enables children to apply what they learned in school to other settings (Goldstone & Day, 2012). There are two levels of transfer: near transfer and far transfer. In a near-transfer task the problems have the same underlying structure (content) and the same type of cover story (context) (Kneppers, Elshout-Mohr, Boxtel, & Hout-Wolters, 2007). In a far-transfer task the problems have the same underlying structure, but a different type of cover story (Kneppers et al., 2007). For transfer to take place it is important to see that situations are related to each other.

Relating different situations to each other is called analogical reasoning (AR). People can use analogical reasoning spontaneously in some situations, but need to be prompted to do so in other situations (Dunbar & Blanchette, 2001). Preschool children at the age of three and four years old already develop a capacity for analogical thinking (Goswami & Brown, 1990; Holyoak et al., 1984). This study is aimed at analogical reasoning in the context of complex problem solving. Holyoak and Thagard (1997) provide a theoretical framework to explain how analogical reasoning takes place. They developed a multi-constraint theory that proposes different ways to relate situations to each other: similarity, structure and purpose. In the current study the similarity constraint is emphasized. The similarity constraint is about seeing direct similarities between situations, which can be similarities between the superficial object features or between relations in each of the situations (Holyoak & Thagard, 1997). People can use analogical reasoning if the similarities between the situations are perceived (Dunbar & Blanchette, 2001; Holyoak et al., 1984; Holyoak & Thagard, 1997). Superficial similarities are mostly not problem-related, but can help in relating problems to each other. In problems that are mostly related to each other by superficial similarities (near-transfer tasks) this can help in finding a solution to the problem (Kneppers et al., 2007). However, problems can also

have superficial similarities, without being further related to each other. When encountering such problems, analogical reasoning does not help in finding a solution. Superficial similarities work as a distraction in such problems. Problems that are further related to each other, have underlying similarities (relational similarities). The relational similarities are therefore most important in analogical reasoning (Krawczyk, Hanten, et al., 2010; Krawczyk, McClelland, Donovan, Tillman, & Maguire, 2010; Morrison et al., 2004; Richland, Chan, Morrison, & Au, 2010; Richland, Morrison, & Holyoak, 2006; Thibaut, French, & Vezneva, 2010). Problems with relational similarities and little superficial similarities are far-transfer tasks (Kneppers et al., 2007). In these tasks the relational similarities can help in relating problems to each other and the superficial similarities mostly work as a distraction. Especially in far-transfer tasks therefore, the relational similarities are most important in analogical reasoning.

Young children mostly use superficial similarities for analogical reasoning, while older children use more relational similarities (Rattermann & Gentner, 1998; Sternberg & Nigro, 1980). There is much disagreement about the age at which children use superficial or relational similarities. For example, according to Sternberg and Nigro (1980) children from third to sixth grade use superficial similarities and children from ninth grade and older use relational similarities. According to Piaget the shift occurs at the age of 11 years old when children come into a formal operational stage (Rattermann & Gentner, 1998). Because older children use more relational similarities for analogical reasoning, the second hypothesis is that older children perceive more relational similarities between problems than younger children and that older children therefore have higher analogical reasoning performance, especially on far-transfer tasks where there are fewer superficial similarities and more relational similarities.

An important explanation for the shift from superficial similarities to relational similarities comes from Rattermann and Gentner (1998). Their research suggests that the focus on superficial or relational similarities is related to knowledge about the domain. Their research shows that children mostly shift from object features to relational similarities (relational shift) as they gain more knowledge about a domain (Rattermann & Gentner, 1998), so prior knowledge plays an important role in analogical reasoning. As older children have gained more experience in life and probably have more knowledge than younger children, they are more likely to see the relational similarities.

An alternative explanation for the shift from superficial similarities to relational similarities is that the executive functions develop strongly during this school-age period

(Goswami, 2011) and that these executive functions cause the shift. Executive functions are processes involved in the control of action and thought, like planning, decision making and judgment (Reynolds & MacNeill Horton, 2008). Analogical reasoning requires the maintenance, manipulation and selective activation of mental representations to identify correspondences, map correspondences, and draw inferences about higher-order similarity relationships (Green, Fugelsang, Kraemer, Shamosh, & Dunbar, 2006; Morrison et al., 2004; Waltz, Lau, Grewal, & Holyoak, 2000). Solving a problem can be easier by using an analogy, because a solution to an old problem can also be the solution to a new problem or can help in finding a comparable solution to a new problem (Dunbar & Blanchette, 2001). However, analogical reasoning can also impair effective problem solving. Analogical reasoning makes it easier to think of a previously used solution, while a new solution might be more effective. In this case, a person is stuck in a certain thinking pattern and finds it difficult to think "outside-the-box". This might be related to the executive function fluency, because a person with high fluency skills can shift to another thinking pattern more easily (Ionescu, 2012). In this study, we examined the relation between fluency and analogical reasoning performance and also the relation between the executive functions inhibition and working memory and analogical reasoning performance, because inhibition might be related to the selective activation needed for analogical reasoning and working memory might be related to the maintenance and manipulation of mental representations. These three executive functions are further explained below.

The focus of this research lies on this alternative explanation that explains analogical reasoning in terms of executive functions and tests if this explanation is supported by research. Earlier research found some relations between executive functions and analogical reasoning. For example, people with traumatic brain injury and with degeneration in the frontotemporal lobes show reduced analogical performance when they have to integrate multiple relations or have to inhibit superficial distractors in favor of relational similarities (Krawczyk, Hanten, et al., 2010; Morrison et al., 2004). Because the subjects involved in these studies all had brain damage, the results obtained in these studies cannot easily be generalized to healthy subjects. The current study therefore focuses on healthy subjects to see if the same results can be found. Other research found that when executive functioning increases with age, analogical reasoning improves, because the capacity to integrate multiple relations and inhibitory control increased (Richland et al., 2006; Thibaut et al., 2010), but this might also be due to increases in knowledge. Many studies focus on analogical performance of students and adults (Dreistadt, 1969; Gick & Holyoak, 1980; Krawczyk, Hanten, et al.,

2010). The current study focuses on analogical reasoning performance in school-age children to test whether the same results can be obtained in children. The studies that do focus on school-age children, mostly use analogical reasoning in the form of A:B::C:D (Goswami & Brown, 1990; Krawczyk, McClelland, et al., 2010), which are well-defined problems. The current study uses analogies in the context of complex problem solving, using pictures, because more superficial and relational similarities can be included and the problems can be solved in multiple ways, not just by using analogical reasoning. Some children are better at analogical reasoning than others and can better transfer what they learned to other situations. This study has an explorative nature to find out what differences there are between children that are good at analogical reasoning and children that are not. The study examines whether executive functioning is positively related to analogical reasoning performance and whether some executive functions are more important than others. If analogical reasoning indeed depends on the executive functions this can form a basis for more specific instruction to children. This can then lead to improvements in analogical reasoning and transfer, which can lead to improvements in learning.

The executive functions addressed in this study are inhibition, working memory, and fluency. The first executive function, inhibition, is a process that controls attention. Through inhibition relevant information receives attention and irrelevant information is ignored (Marton, Kelmenson, & Pinkhasova, 2007). Inhibition therefore probably plays a role in the selective activation needed for analogical reasoning. In analogical reasoning the relational similarities between situations are most important and superficial similarities can work as a distraction (Krawczyk, Hanten, et al., 2010; Krawczyk, McClelland, et al., 2010; Morrison et al., 2004; Richland et al., 2010; Richland et al., 2006; Thibaut et al., 2010) and should be inhibited. People with poor inhibitory control get distracted easily and cannot focus on the important information. In near-transfer tasks there are multiple superficial similarities that can help solve the problem (Kneppers et al., 2007). In far-transfer tasks however, the superficial similarities work more as a distraction and the relational similarities are important for solving the problem (Kneppers et al., 2007). People with poor inhibitory control will probably be distracted by the superficial similarities and are less able to see the relational similarities that are so important for solving the problem. Therefore, analogical reasoning performance will be impaired, especially performance on the far-transfer task. People with high inhibitory control will be less distracted by the superficial similarities. This leads to the expectation that inhibition is positively related to analogical reasoning-performance and to the number of relational similarities perceived.

The second executive function, working memory, is involved in the maintenance and manipulation of mental representations. Working memory is a function of the brain that is involved in keeping information active. This means that the information can be kept in memory longer, so it can be linked to other information in memory or to manipulate the information (Baddeley, 1998). Research by Morrison et al. (2004) shows that an increase in working memory capacity leads to expansion of relational reasoning ability. Low working memory capacity also lowers the ability to map elements of analogous situations together (Hummel & Holyoak, 2003). In far-transfer tasks the relational similarities are most important. This leads to the expectation that because increases in working memory capacity lead to expansion of relational reasoning ability, working memory is positively related to performance in far-transfer tasks and to the number of relational similarities perceived.

The last executive function addressed in this study is fluency. Fluency is related to creativity and flexibility. Creativity is the ability to come up with new and original ideas and is positively related to the number of ideas a person comes up with, flexibility is the ability to shift from one aspect of a situation or feature to another (Ionescu, 2012). Because high creativity is related to a higher number of ideas a person comes up with, the expectation is that fluency is positively related to the number of similarities perceived. Also, without creativity it will be difficult to see correspondences between situations or aspects of those situations that are not obviously related to each other (Green, Kraemer, Fugelsang, Gray, & Dunbar, 2012). This is especially the case in far-transfer tasks where most correspondences are underlying similarities (Kneppers et al., 2007). Without flexibility it is harder to shift from surface features to relational features or to look further to more useful similarities between situations. This is especially the case in far-transfer tasks as well, where the relational features are most important (Kneppers et al., 2007). In all, this leads to the expectation that fluency is positively related to analogical reasoning-performance on far-transfer tasks and to the number of similarities perceived, especially relational similarities.

The research question of this study is: what is the relation between the level of the executive functions inhibition, working memory and fluency and analogical reasoning performance in near-transfer and far-transfer tasks in children between the age of 8 and 11? Analogical reasoning performance is perceiving superficial and relational similarities between problems and being able to use these similarities to solve a problem. The hypotheses are: 1) Older children are better problem solvers than younger children; 2) older children have higher analogical reasoning-performance and perceive more relational similarities than younger children. The second hypothesis is expected to be explained by increases in executive

functioning with age, so executive functioning would be positively related to analogical reasoning. Inhibition is expected to be positively related to the number of relational similarities perceived, working memory is expected to be positively related to the number of relational similarities perceived, and fluency is expected to be positively related to the number of (superficial and relational) similarities perceived.

Method

Participants

Participants in this study were recruited from a local elementary school in the eastern part of the Netherlands, selected through convenience sampling. All children from third and fifth grade were selected. The total sample consisted of 60 participants. Of these respondents one was not able to participate due to illness. Data of two respondents were excluded, because part of the data was missing. One of these respondents was absent during a test-session and the other did not want to participate in a test-session. Data of one respondent was excluded, because she was an outlier on one of the tests and an extreme outlier on another. Data of 56 respondents remained to be analyzed. In third grade data of 25 respondents remained for analyses and in fifth grade 31 respondents remained. The age varied from 8 to 9 years in third grade (M = 8.16 years, SD = .374), and 15 were male. The age varied from 10 to 11 years of age in fifth grade (M = 10.23 years, SD = .425), and 14 were male.

Instruments

Analogical reasoning task. The first task administered was an analogical reasoning task. This task was developed for the current study. The task measured problem solving ability and analogical reasoning performance. The task consisted of three problems, based on the Radiation problem, developed by Duncker in 1945 and applied by Gick and Holyoak (Gick & Holyoak, 1980). Children had to solve these problems. The three problems had superficial and relational similarities that related the problems to each other, so children could use analogical reasoning to solve the problems. However, the problems could also be solved by other means than analogical reasoning. The problems were each complemented with a picture, which was a graphical representation of the problem.

In the first problem the children read a story about a princess locked up in a castle by the king. The princess was guarded by a dragon. A group of knights wanted to save her. To do that, they had to reach the dragon simultaneously. The problem was that the castle was surrounded by water with a few bridges. When the knights would try to cross the bridge as a

group, the bridge would collapse. The children were asked to give a solution to this problem. After this, the solution to the problem was given (the knights had to divide into small groups and each cross a different bridge).

In the second problem there was a treasure buried on an island. A group of pirates wanted to get the treasure. To do this, they had to reach the treasure simultaneously. The problem was that the island was surrounded by water and could only be crossed by boat. When all the pirates would use one boat, the boat would sink. This was a near-transfer task, because the problem had the same underlying structure and the same type of cover story as the first problem (Kneppers et al., 2007). The children were instructed to give a solution to the problem. When they gave a solution or could not solve the problem, they were asked to turn to the next page and write down the similarities between problem one and two. This question was asked because people often do not spontaneously use analogical reasoning, so as to prompt the children to use analogical reasoning and also to see if children perceived similarities between the problems. Then the children were asked again to give a solution to the problem, because they were now prompted to use analogical reasoning and might give a different solution than before.

In the third problem there was a virus. The virus could be killed by a laser. The problem was that the virus was surrounded by blood and tissue. When using a small radiation beam the tissue would be saved, but the virus would not be killed. When using a large radiation beam both the virus and the surrounding tissue would be killed. This was a far-transfer task, because the problems had the same underlying structure, but a different type of cover story (Kneppers et al., 2007). The children were instructed to give a solution to the problem. When they gave a solution or could not solve the problem, they were asked to turn to the next page and write down the similarities between problem one and two, and problem three as a prompt to use analogical reasoning. Then the children were asked again to give a solution to the problem, because they were now prompted to use analogical reasoning and might give a different solution than before.

Inhibition test. The second test administered was an inhibition test. Inhibition was measured by the Color-Word Interference Test. This is a subtest of the test battery Delis-Kaplan Executive Function System (Delis, Kaplan, & Kramer, 2001) and is validated by Delis, Kramer, Kaplan, and Holdnack (2004) and Homack, Lee, and Riccio (2005). This test is used by many researchers as a measure of inhibition. This test was administered individually. Condition one, two and three were administered. Condition one and two were

administered because these subtests measured reading/naming speed of the children and this speed could influence the speed at condition three, which measured inhibition.

In condition one the children got a sheet with colored squares on it. This subtest measured the time in seconds needed to name all the colors on the sheet. In condition two children got a sheet with color-names on it. This subtest measured the time in seconds needed to name all the color-names on the sheet. Condition three measured inhibition. The aim was to name the ink-color and to inhibit the color-name. Inhibition was the time in second needed to name all the colors. More information on this test can be found in the test-manual (Delis, Kaplan, & Kramer, 2001).

Working memory tests. Working memory was measured by two subtests, measuring the phonological loop and the visuospatial sketchpad. Some children tend to think in words and others in pictures (Kirby, Moore, & Schofield, 1988; Richardson, 1977). This was accounted for by a verbal and a visual test. The phonological loop is responsible for holding verbal information for a short time (Baddeley, 1998) and this can be measured by a word-recall test (Pickering & Gathercole, 2004) in which words should be hold in memory for a short time. The word-recall test was designed by the researcher, because no word-recall test was available. The test was administered classically. In this test the children were shown sixteen words on the digital board. They got two minutes to memorize the words. After two minutes the words were removed from the screen and the children had to write down all the words they remembered.

The visuospatial sketchpad is responsible for holding visual information for a short period (Baddeley, 1998), such as information about the visual appearance and the location of an object and this can be measured by a picture-recall test (Tubi & Calev, 1989). The picture-recall test was designed by the researcher, because no picture-recall test was available. In this test the children got two minutes to memorize sixteen different images, shown on the digital board. After the two minutes they had to write down what images they remembered.

Fluency tests. Fluency was divided into verbal and design (visual) fluency. Verbal fluency was measured by the Animal Verbal Fluency (AVF) test. This test is used in many studies as a measure of verbal fluency (Tombaugh, Kozak, & Rees, 1999; Van der Elst, Hurks, Wassenberg, Meijs, & Jolles, 2011; Van der Elst, Van Boxtel, Van Breukelen, & Jolles, 2006). In the AVF-test the children had to write down as many animals as they could think of in three minutes.

Design fluency was measured by a test in which children were given a sheet of paper with 25 small circles. This test is part of the Torrance Tests of Creative Thinking developed

by Torrance in 1966 and used (Anderson & Stoffer, 1979; Baker, 1978; Kaltsounis, 1976; Oliveira et al., 2009) and validated (Baker, 1978; Oliveira et al., 2009) by many researchers. The purpose of the test was to make drawings using the circles. The children were instructed to make as many drawings as they could using the circles. For example, they could make a flower using a circle or they could use two circles to make glasses. It was emphasized that the number of drawings was important and not the complexity. Appendices 1 and 2 show filled in examples of the Design Fluency test.

Design

This study was an explorative study. The children were naturally divided into two age-groups. These were children in third and fifth grade. The grade of the children was an independent variable, used to measure age differences in analogical reasoning skills. The most important independent variables were the scores for inhibition, working memory and fluency. The dependent variables in this research were problem solving, analogical reasoning performance and the number of superficial and relational similarities perceived by the children.

Procedure

The children took a consent form home, explaining the goal of the study and the tests that would be administered to the children. Parents had to fill this in if they refused their child to participate. None of the parents refused.

Each grade was tested separately, with the same procedure used. In the first session the researcher explained to the children what the goal of the study was and what tests the children could expect. Sequentially, the design fluency test, verbal fluency test, visual working memory test, verbal working memory test, and the analogical reasoning task were administered. These tests were classically administered and took place in a quiet classroom. The design fluency test and the verbal fluency test took three minutes each. For the visual working memory test and the verbal working memory test the children got two minutes to memorize the pictures/words and the tests were finished if all children wrote down what they remembered. The maximum time needed for the analogical reasoning task was about half an hour, although many children finished in ten minutes.

In the second session the inhibition test was administered individually in a quiet room. The maximum time for the first condition was 90 seconds. The maximum time for the second condition was 90 seconds. The maximum time for the third condition was 180 seconds.

After all children had taken the tests, the researcher gave a debriefing, thanked the children for participating and answered any questions the children had.

Scoring and Analyses

Problem solving. The analogical reasoning task was used to measure problem solving ability and to measure analogical reasoning. The score for problem solving indicated whether a child could solve the problems or not. Children could solve the problems by using analogical reasoning, but also by other means. The problem solving score did not differentiate between this. Problem solving could be scored as 0 or 1 for each of the problems. The score was 0 if children could not solve the problem or gave a solution that did not meet the requirements. The score was 1 if children gave a solution to the problem that met the requirements. The requirements for the near-transfer task were that the pirates got to the island simultaneously and that the boat would not sink. The requirements for the far-transfer task were that the virus would be killed and that the surrounding organs would be saved. An example of a good solution was taking the organs out, then use a large radiation beam and then put the organs back in. The three problem solving scores were added to each other to find the average number of problems children could solve.

Analogical reasoning. The analogical reasoning score did differentiate between different means for solving a problem. This score indicated whether a child used analogical reasoning or not. Analogical reasoning was separated for the near-transfer and the far-transfer task. There were three scores per task: analogical reasoning performance, number of superficial similarities, and number of relational similarities.

Analogical reasoning performance could be scored as 0 or 1. The score was 0 if children gave no solution or gave a wrong solution. The score was 1 if children gave a correct solution and named elements from the previous problems/solutions, because this indicated use of analogical reasoning, although this was not a guarantee that the child used analogical reasoning. To obtain a score of 1 to the near-transfer task, children had to name that the pirates had to divide into groups and use multiple boats. To obtain a score of 1 to the far-transfer task, children had to name that multiple small radiation beams would be used from different directions/simultaneously. Analogical reasoning performance was divided into spontaneous use of analogical reasoning and prompted use. Analogical reasoning performance was used spontaneously if children gave a correct solution before being asked to write down similarities. Prompted use was if children gave a correct solution after being asked to write down similarities, so also if they changed their solution between the first and second time asked

The score for the number of superficial similarities indicated how many superficial similarities children perceived. A similarity was counted as superficial if it was a

correspondence that was not problem-related. For example: the knights and pirates both wanted something or there was water in both stories. There was no maximum score for the number of superficial similarities.

The score for the number of relational similarities indicated how many relational similarities children perceived. A similarity was counted as relational if it was problem-related. For example: they were with too many people or they had to divide and work together. There was no maximum score for the number of relational similarities.

Executive functions. The inhibition score was the completion time (in seconds) of condition three of the Color-Word Interference Test. The maximum score was 180 seconds. Working memory had two scores: verbal working memory and visual working memory. Both scores were the number of correct items written down. The maximum for both was 16. Fluency had two scores: verbal fluency and design fluency. The verbal fluency score was the total number of different animals written down. When the same animal was written down twice, only one of the items was counted. The design fluency score was the total number of different drawings. When using multiple circles in one drawing, one circle was counted, because the number of different ideas was important and not the number of circles. When for example multiple different smileys were drawn, only one smiley was counted. The fluency tests had no maximum score. Children could draw/write more items below the answering format.

Analyses. Independent t-tests with 95% confidence intervals were used to compare children in fifth grade with children in third grade on measures of problem solving, analogical reasoning performance and the number of superficial and relational similarities. Correlation analyses were used to find correlations between executive functions and analogical reasoning.

Results

Complex Problem Solving

In this research, analogical reasoning was studied in the context of complex problem solving. The first hypothesis was that older children would be better problem solvers than younger children. The data showed that most children were able to solve the problems. It was found that 89.3% of the children were able to come up with a plausible solution to the first problem. After problem one the correct solution to this problem was given, so all children had a fair chance on the near- and far-transfer task. The near-transfer task appeared to be a little harder. Of the sample half of the children (50.0%) were able to come up with a plausible

solution that met the requirements. In the far-transfer task 80.4% of the children came up with a plausible solution that met the requirements, although some of the solutions would probably lead to death of the patient, like "take the organs out, then use the radiation beam and then put the organs back in". The minimum number of problems the children could solve was 1 and the maximum was 3 (third grade M = 2.16, SD = .746; fifth grade M = 2.23, SD = .560). Children in fifth grade could not significantly solve more problems than children in third grade (t=.366, p=.716). Many children could solve the far-transfer problem (third grade M = .68, SD = .476; fifth grade M = .90, SD = .301), but significantly more children in fifth grade than in third grade could solve this problem (t=2.039, p=.048).

Analogical Reasoning

The second hypothesis was about analogical reasoning. To test this hypothesis and the relation between executive functioning and analogical reasoning, a correlation analysis was performed for all relevant variables in the data. All correlations are shown in Table 1. This table consists of two parts. Table 1a shows the correlations for the near-transfer task and Table 1b shows the correlations for the far-transfer task. A distinction was made between spontaneous use of analogical reasoning and prompted use of analogical reasoning, which were analyzed separately.

Spontaneous use. The second hypothesis was that older children would have higher analogical reasoning-performance and would perceive more relational similarities than younger children. It was found that 37.5% of the children used analogical reasoning to solve the near-transfer task. These children gave a correct solution to the near-transfer task and named elements of problem one in the solution. Only 5.4% of the children used analogical reasoning to solve the far-transfer task. These children gave a correct solution to the far-transfer task an named elements of the previous problem(s). The children that did use analogical reasoning on the far-transfer task were all in fifth grade. The difference between fifth grade and third grade on the near-transfer task was not significant (t=.205, p=.839). The difference between fifth grade and third grade on the far-transfer task was also not significant (t=1.793, p=.083), but almost reached significance.

Other scores for analogical reasoning performance were the number of superficial and relational similarities the children perceived. The number of superficial similarities perceived ranged from 0 to 3 (third grade M = .64, SD = .638; fifth grade M = 1.29, SD = 1.039) on the near-transfer task and also from 0 to 3 on the far-transfer task (third grade M = .12, SD = .332; fifth grade M = .32, SD = .702). The number of relational similarities perceived ranged from 0 to 2 (third grade M = .52, SD = .586; fifth grade M = .48, SD = .724) on the near-

transfer task and from 0 to 1 (third grade M = .08, SD = .277; fifth grade M = .03, SD = .180) on the far-transfer task. The hypothesis was that older children would see more relational similarities between problems than younger children. The number of relational similarities was significantly higher in fifth grade than in third grade on the near-transfer task (t=2.877, p=.006), but not on the far-transfer task (t=1.422, p=.162). The number of superficial similarities was not significantly higher in fifth grade than in third grade, neither on the near-transfer task (t=-.206, p=.837), nor on the far-transfer task (t=-.745, p=.461).

Changes in analogical reasoning performance were expected to be explained by the executive functions inhibition, working memory and fluency. Inhibition scores ranged from 49 to 131 (M = 87.46, SD = 20.455). Working memory was divided into verbal working memory and visual working memory. Verbal working memory scores ranged from 3 to 16 (M = 8.84, SD = 2.742) and visual working memory scores ranged from 7 to 14 (M = 10.86, SD = 1.519). Fluency was divided into verbal fluency and design fluency. Verbal fluency scores ranged from 15 to 42 (M = 26.88, SD = 5.264) and design fluency scores ranged from 5 to 23 (M = 11.32, SD = 4.113).

The first executive function, inhibition, was expected to be positively related to the number of relational similarities perceived. As shown in Table 1, the Pearson correlation between inhibition scores and the number of superficial similarities was significant on the near-transfer task (ρ=-.301, $p<.05$), but not on the far-transfer task (ρ=-.183, $p>.05$). The Pearson correlation between inhibition scores and the number of relational similarities on the near-transfer task was not significant (ρ=.179, $p>.05$) and the Pearson correlation between inhibition scores and the number of relational similarities on the far-transfer task was also not significant (ρ=.100, $p>.05$). A negative correlation meant that a higher inhibition skill was related to a larger number of similarities perceived and a positive correlation that fewer similarities were perceived.

The second executive function, working memory, was also expected to be positively related to the number of relational similarities perceived. A distinction was made between verbal and visual working memory. As shown in Table 1, the correlation between verbal working memory scores and the number of superficial similarities was not significant on the near-transfer task (ρ=.043, $p>.05$), nor on the far-transfer task (ρ=.105, $p>.05$). The correlation between visual working memory scores and the number of superficial similarities was significant (ρ=.474, $p<.01$) on the near-transfer task, but not on the far-transfer task (ρ=-.083, $p>.05$). As shown in Table 1, the Pearson correlation between verbal working memory scores and the number of relational similarities perceived was not significant on the near-

transfer task (ρ=.065, p>.05), nor on the far-transfer task (ρ=.014, p>.05). The Pearson correlation between visual working memory scores and the number of relational similarities perceived was significant (ρ=-.362, p<.01) on the near-transfer task, but this correlation was negative. The correlation between visual working memory and the number of relational similarities perceived on the far-transfer task was not significant (ρ=-.108, p>.05).

The third executive function, fluency, was expected to be positively related to the number of (superficial and relational) similarities perceived. As shown in Table 1, the Pearson correlation between verbal fluency scores and the number of superficial similarities was significant on the near-transfer task (ρ=.285, p<.05) and on the far-transfer task (ρ=.342, p<.05). The correlation between verbal fluency scores and the number of relational similarities was not significant on the near-transfer task (ρ=-.165, p>.05), nor on the far-transfer task (ρ=-.177, p>.05). The Pearson correlation between design fluency and the number of superficial similarities was not significant on the near-transfer task (ρ=.260, p>.05), nor on the far-transfer task (ρ=.076, p>.05). The Pearson correlation between design fluency and the number of relational similarities was also not significant on the near-transfer task (ρ=-.154, p>.05), nor on the far-transfer task (ρ=-.097, p>.05).

Prompted use. The question about the similarities between the problems was used as a prompt for the children to use analogical reasoning. However, it was found that none of the children used prompted analogical reasoning. None of the children changed their solution between the first and second time asked and the children that could not solve the problem the first time, still could not solve it the second time. Prompted use of analogical reasoning therefore could not be further analyzed.

Table 1a. *Analogical Reasoning and Executive Functions in Near-Transfer Task: Correlations*

Variables	1	2	3	4	5	6	7	8	9
1. Problem solving	-								
2. Analogical reasoning	.775**	-							
3. Superficial similarities	-.039	.040	-						
4. Relational similarities	-.055	-.028	-.530**	-					
5. Inhibition	.009	-.021	-.301*	.179	-				
6. Verbal working memory	.125	.182	.043	.065	-.311*	-			
7. Visual working memory	-.024	.000	.474**	-.362**	-.370**	.178	-		
8. Verbal fluency	.024	.089	.285*	-.165	-.348**	.114	.405**	-	
9. Design fluency	-.018	-.034	.260	-.154	-.028	-.013	.285	.407**	-

Note. *p < .05 (2-tailed). **p < .01 (2-tailed).

Table 1b. *Analogical Reasoning and Executive Functions in Far-Transfer Task: Correlations*

Variables	1	2	3	4	5	6	7	8	9
1. Problem solving	-								
2. Analogical reasoning	.118	-							
3. Superficial similarities	-.035	-.097	-						
4. Relational similarities	.118	-.057	-.097	-					
5. Inhibition	-.261	.006	-.183	.100	-				
6. Verbal working memory	.103	.072	.105	.014	-.311*	-			
7. Visual working memory	.073	-.188	-.108	-.083	-.370**	.178	-		
8. Verbal fluency	.178	-.010	.342**	-.177	-.348**	.114	.405**	-	
9. Design fluency	.028	-.038	.076	-.097	-.028	-.013	.285	.407**	-

Note. *p < .05 (2-tailed). **p < .01 (2-tailed).

Conclusions and Discussion

In this study the aim was to find support for the idea that children shift from superficial similarities to relational similarities in analogical reasoning through the development of executive functions and to explore whether some executive functions are more important than others. The executive functions studied were inhibition, working memory and fluency. Analogical reasoning was examined in the context of complex problem solving and was measured according to the number of similarities the children perceived and if they could use this to correctly solve the problems. The research question was: what is the relation between the level of the executive functions inhibition, working memory and fluency and analogical reasoning performance in children between the age of 8 and 11? The hypotheses were: 1) older children are better problem solvers than younger children; 2) older children have higher analogical reasoning-performance and perceive more relational similarities than younger children. The second hypothesis was expected to be explained by increases in executive functioning with age, so executive functioning would be positively related to analogical reasoning.

The first hypothesis is not completely supported by the data. According to the data most children were able to solve the problems. Older children could not solve more problems than younger children. However, significantly more children in fifth grade than in third grade could solve the far-transfer task.

The second hypothesis is partially supported by the data, which showed that the difference in analogical reasoning performance between fifth grade and third grade was not significant, but that older children do perceive more relational similarities than younger children. This corresponds to research by Rattermann and Gentner (1998) that indicated that younger children use mostly superficial similarities and that older children use less superficial and more relational similarities. This difference between fifth grade and third grade could be partially explained by increases in the executive functions. The data showed a number of significant correlations. Inhibition, visual working memory and verbal fluency were strongly related to the number of superficial similarities on the near-transfer task. The correlation between design fluency and the number of superficial similarities almost reached significance. On the far-transfer task, verbal fluency was strongly related to the number of superficial similarities. The number of relational similarities was only positively related to verbal working memory on both tasks, but this was not significant. This does not support other studies that suggested that increases in working memory capacity lead to expansion of

relational reasoning ability (Hummel & Holyoak, 2003; Morrison et al., 2004) and that when inhibition improves, attention shifts from superficial similarities to relational similarities (Krawczyk, Hanten, et al., 2010; Krawczyk, McClelland, et al., 2010; Morrison et al., 2004; Richland et al., 2010).

Analogical reasoning is a very important concept in education. Analogical reasoning enables children to relate school-situations to other situations, so that they can apply what they learned in school to another setting and also to other school subjects (Goldstone & Day, 2012). The results from this study could form a basis for instruction to children. Knowing what differences there are between children that are good at analogical reasoning and children that are not, could help in developing better educational methods for teaching children. The data showed that all three executive functions inhibition, working memory, and fluency are important for good analogical reasoning. Knowing this could lead to more effective instruction that focuses more on the executive functions. Good analogical reasoning skills are important for learning, so training the executive functions could improve school results and could help children overcome their learning difficulties, which is a major problem in schools.

There are multiple explanations as to why the expected results were not completely found. The most important explanation is that the analogical reasoning test was too difficult. Only a few children were able to solve the far-transfer task by using analogical reasoning. This corresponds to earlier research by Kneppers et al. (2007) which indicates that accomplishment of far-transfer tasks is rare. Near-transfer tasks are usually solved more often, which also corresponds to the current research. However, the task could be changed in several ways, because many children did not understand the questions in the task completely. The children did not understand the word *overeenkomsten* (similarities) and the researcher had to explain this to the entire class. The last question in this task was confusing. The purpose was to compare problem one and two with problem three, but the children thought they had to compare problem one and two again. This question was very important, because the question was used as a prompt to use analogical reasoning. Even after explaining some concepts most children were not able to solve the problems correctly. Another problem with the analogical reasoning task was the scoring. The scoring range was very narrow, which could explain why correlations and age differences were not significant. The task could be scored differently, so that the range would be larger and more significant results could be found. For example, a point could be assigned to every element a child named.

Another explanation as to why the expected results were not found is that the other tests used in this research were not very appropriate. There is much disagreement about the

reliability and validity of the fluency-test. Also, the Animal Verbal Fluency could be influenced by language and by culture (Harrison, Buxton, Husain, & Wise, 2000). However, the children in this sample did not appear to have language problems and there was very little variation in culture. Also, word-recall and picture-recall would probably be more appropriate for testing short-term memory than for testing working memory. These tests could be replaced by the reading-span task or the operation-span task (Engle, 2002), but these tests are individually administered tests, because sentences or calculations must be read aloud. This would take much extra time to test all the children and the available time-schedule did not allow for this much extra time.

Furthermore, there are some environmental factors that might have influenced the results. The children in fifth grade were tested in a relatively quiet room, but there were some noises from the children in the classroom next-door. The children in third grade were tested in the hallway. Many children walked by for their break and they made a lot of noise. Also, the school was rebuilding at that time, with many construction noises as a result. All these noises could have distracted the children, which could have resulted in a different test-score than they would have normally obtained. The children themselves were pretty noisy and restless because of the holiday coming up, which affected their focus on the task. Some children mumbled what they were writing down, giving other children the chance to write down the same answers. The last explanation is that the sample was too small to get significant results. Some correlations almost reached significance. By testing a larger sample these correlations probably would have been significant and therefore would have changed the results. So future research should take this into account and test a much larger sample.

Future research should focus on a few aspects. Some of the tests used in this research could be replaced by more validated tests. Further, an incubation time could be inserted to see if this increases the analogical reasoning scores. Research from Dreistadt (1969) indicates that analogical reasoning improves after an incubation time in which the problem is put aside temporarily and later worked on again. People need more time to think about the problem to see the similarities between the different problems and to come up with a solution. In this study there was no incubation time used, because the children might ask someone else after school to solve the problem. Future research should keep this in mind and take into account the possibility to add an incubation time. Also, the test-setting should be more appropriate to reduce noise as much as possible. The culture of children could have an effect on the level of analogical reasoning (Chen, Mo, & Honomichl, 2004; Richland et al., 2010). Cultural differences can facilitate better knowledge representation by more efficient processing of

relationally complex problems and by differences in inhibitory control (Richland et al., 2010). Knowledge of cultural content may impact prerequisite knowledge of relations and therefore influence analogical reasoning on problem solving tasks (Chen et al., 2004). The current research was taken in a small rural school. In this sample the vast majority had the same culture and most children were from origin Dutch. It might be interesting to test if the same results are obtained in a sample with more cultural variation. Finally, the study should be administered in a much larger sample and with more age-groups included, to increase significance and to better test the development of analogical reasoning.

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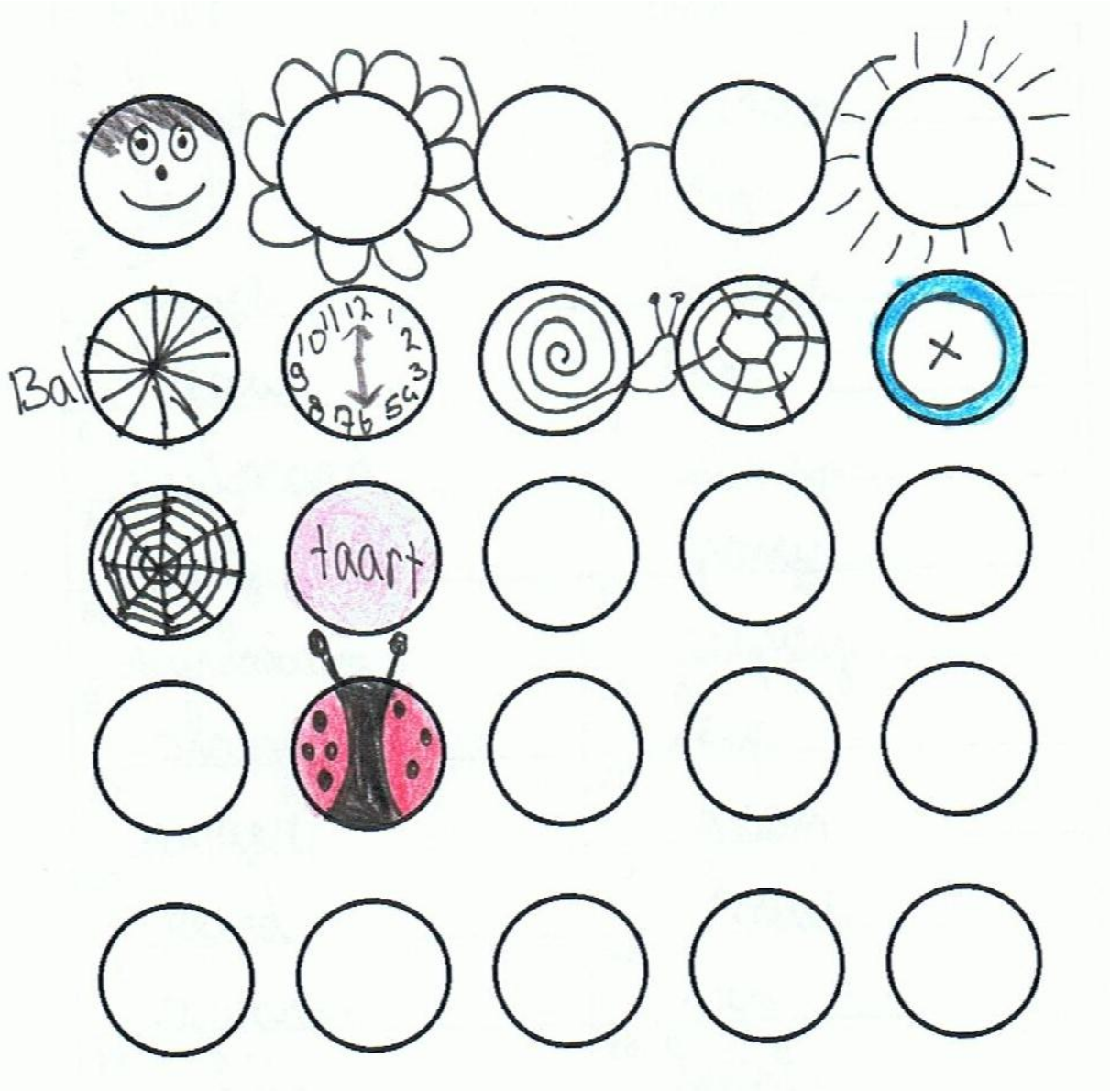
Appendices

Example 1 Design Fluency



Example 2 Design Fluency