Author: Chabani, Elaheh (Ellahe)
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Enhancing visuospatial processing skills in children

Ellahe Chabani

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Enhancing visuospatial processing skills in children

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Ellahe Chabani
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Promotor:

Prof. Dr. B. Hommel

Other Members:

Dr. G. Band

Prof. Dr. N. Schiller

Prof. Dr. P. van den Broek

Prof. Dr. T. van Gog ((Erasmus Universiteit)

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Chapter 1

General Introduction

Visual spatial processing skills (VSPS) or visual spatial intelligence as defined by Howard Gardner (in 'Frames of Mind') is "the ability to perceive the visual world accurately, to perform transformations and modifications upon ones initial perceptions, and to be able to re-create aspects of one's visual experience, even in the absence of relevant physical stimuli" and "while these images are typically seen as helpful aids to thinking, some commentators have gone much farther, deeming visual and spatial imagery as a primary source of thought" (p.173).

Some people have well developed visual spatial processing skills and visual reasoning, while others struggle. Nonetheless, VSPS is required for most daily living, activities, and as well for successful academic performance. More details are provided in the following chapters and sections below, however, in short reflections in the importance of VSPS's assessment and development at early ages include, but are not limited to:

a) *Visual spatial processing skills and malleability of these*

The importance of VSPS in learning at any age has been widely acknowledged (Lubinski, 2010; Miller & Halpern, 2013; Sorby, Casey, Veurink & Dulaney, 2013; Uttal, et al., 2012; Wai, Lubinski & Benbow, 2009; Assel, et al., 2003; Cheng & Mix 2012) and its development has been attributed to a number of variables, including the cognitive development, spatial experiences, aptitude, age, and gender (e.g., Hegarty & Waller 2006). Furthermore, recently, Uttal et al., (2012) found that even short training procedures could significantly improve VSPS. In line with the authors it is reasonable to suggest that adding spatially-challenging activities to standard courses can further improve spatial skills and can lead to transfer to other spatially-demanding tasks.

b) *Specific learning disabilities (SLD)*

Regardless of the on-going debate on the issue of definition and identification of specific learning disabilities many children are "in-need" and at-risk of failure resulting in early school dropping out (European Commission, 2012). In the same vein a very recent research published by the University College of London (2013), reports that "up to 10% of the population are affected by specific learning disabilities such as dyslexia, dyscalculia and/or group of neurological or brain-based problems (e.g., autism, ADHD), translating to 2 or 3 pupils in every classroom" (p.1). Among them, there are children with language-based learning disabilities that include Visual Perceptual Processing Disorders known as well as Nonverbal Learning Disability (National Center on Learning Disabilities (NCLD), 2003, 2009) that are less well-known and less understood. Individuals with language-based learning disabilities might have normal verbal abilities and average IQ but impaired VSPS in the absence of visual acuity. Some children with language-based learning disabilities demonstrate remarkable rote memory, attention to detail, but might have deficits or weak VSPS, poor organizational skills, difficulty with inference and abstract reasoning, problems with mathematical reasoning, difficulty reading nonverbal cues, impaired fine motor skills –i.e. children with ASD (e.g., Bhaumik et al., 2010). Bhaumik et al., have argued that delays in social and communicative development of children with ASD may also be explained by low levels of cognitive functioning related to VSPS. However, poor VSPS extends to the whole spectrum of learning i.e., symbols, letters, words, numbers, diagrams, maps, graphs, and charts that can affect academic literacy as much as everyday life (Frederickson & Cline, 2006; Groffman, 2006; Korkman, et al., 2007). According to Butterworth and Kovas (2013) “although the majority of learners can usually adapt to the one-size-fits-all approach of whole class teaching, those with SLDs will need specialised support tailored to their unique combination of disabilities."

While there is a need to teach VSPS at early ages, and to study the neural mechanisms that underlie these skills, the domain remains under-researched (National Council of Teachers of Mathematics, 2010; National Research Council 2006; Krakowski, Ratliff, Gomez & Levine, 2010).

c) Early assessments and interventions

There is an increasing recognition that early childhood is a particularly sensitive period in the process of development, cognitive functioning, behavioural, social and self-regulatory capacities (e.g., Dyson, et al., 2010; Murray, et al., 2010). The RAND Corporation (2012) has drawn attention to the fact that “Well-designed early childhood interventions have been found to generate a return to society ranging from $1.80 to $17.07 for each dollar spent on the program” (p.1). In short, an early identification of poor VSPS with appropriate intervention would: reduce long-term challenges in an ineffective acquisition of specific basic literacy and numeracy abilities, reduce the discrepancy between the learner’s actual achievement level and the learner real potential, and increase learns psychological and emotional wellbeing.

While, assessments and interventions of typical academic contents -the 3Rs (Reading, (w)riting and (a)rithmetic) have undergone considerable development over the last decades language-based learning disabilities has not received similar attention (National Council of Teachers of Mathematics [NCTM], 2010; National Research Council (NRC), 2006; Krakowski, Ratliff, Gomez & Levine, 2010). NCTM and NRC among others have called for the need of identifying and developing methods and procedures that support VSPS enhancement at earlier ages, to consider how to integrate VSPS-related performance into the curriculum in more general ways, and to think about how and when the use of new technologies with young children can lead to improvement.

d) Leaning in digital age

Technology is shaping the world we live in, and as a result, our students’ brains are rewiring and restructuring. Through wireless devices, visual messages, information are available at the touch of a button. Among the OECD, the European Commission, UNESCO and numerous other thinkers, The Partnership for 21st Century Skills (P21) has developed a “Framework for 21st Century Learning” - a vision for student success in the new global economy, increased migration and mobility. This framework asserts “As the 3Rs serve as an umbrella for other subjects and core content, the 4Cs (Critical thinking and problem solving, Communication, Collaboration, Creativity and innovation) are shorthand for all the skills needed for success in college, career, and life”.

Dave Gray (2008, May 23), “Our world is changing fast – faster than we can keep up with our historical modes of thinking and communicating. Visual literacy – the ability to both read and write visual information; the ability to learn visually; to think and solve problems in the visual domain – will, as the information revolution evolves, become a requirement for success in business and in life.” "We’re leaving an industrial age and entering an information age, yet we continue to teach, and operate our schools, as if they were factories. In an information age, visually literate societies will succeed and thrive. Shouldn’t we be one of them?"(p.1)

Where do we go from here?

If we are to help students succeed in a 21st-century, to meet the needs of struggling children that can have an average or gifted IQ but may also have SLD, we must find ways to diagnosis and to enhance VSPS as we do for the 3R’s. Indisputably, there is a need for both assessment and integration of Visual spatial processing skills - “the neglect of a needed skill” within curriculum at early ages.

Given the volume of studies and publications available that shown encouraging results in learning all kind of skills and in almost in any domain through games (e.g., Egenfeldt-Nielsen, 2005; Prensky, 2010), the aim of this research project was to move one step forward into this direction. Toward this end, the “TangSolver”, which is a variation of the tangram game, was developed as an optimal solution. However, TangSolver is just a means to an end in the process of promoting the assessment, and training of VSPS within standard courses. It is hoped that implementing such an application in school promotes teaching and training VSPS-related skills in young children and in particular inspires researcher to further develop assessment and training procedures.

In the interest of brevity and providing a general illustration, the following sections describe the analysis of problems and the rational in the development of the TangSolver. Thereafter, an overview of this research project is provided.

Visuospatial processing skills

Researchers and theorists in different areas have acknowledged that VSPS is not a unitary construct, but rather can be broken into a collection of sub-skills or components (Carroll, 1993; Eliot & Smith, 1983; Kaufman, 2007; Lohman, 1988; Sutton & Williams, 2007). Visual and spatial cognition emerge from a wide range of disciplines such as psychology, geography, art, science. Arguably, as consequence of diversity of approaches and related discipline, the definition, and terminology used for labelling this set of skills varies between authors and over time, and is often interchangeable (e.g., D’Oliveira, 2004; Hegary & Waller, 2005). Furthermore, the particular number of separable sub-skills is unclear (e.g., Carroll, 1993). This has resulted in a great deal of confusion regarding their definition, underlying factors, and their classification, which in turn has hindered assessment and integration of VSPS into the curriculum (NJCLD, 2010).

In response to the above issues and as well in an attempt to address SLD’s The NCLD, (2003, 2009) has identified seven key sub-skills. These sub-skills and as well the typical characteristics that children with poor VSPS may demonstrate are presented in table 1.

Table1

Visual Spatial Processing Sub Skills (NCLD, 2003)

Skill	Difficulties
Spatial visualization The ability to understand how objects are positioned in space & in relation to oneself. This involves the understanding of distance (near or far), the ability to visualize mentally rotated of objects, in 2D and 3D understanding.	With spatial relationships such as distance, size, shape and how things fit together to form a whole. Visual spatial orientation will influence the way a person reads and writes letters, words and numbers, as the orientation of the letters and numbers is specific to the position on the page and to the surrounding letters and numbers on the page.
Visual Discrimination Visually distinguishing the features of an object from another or of one item from another one.	With spacing letters and words such as reversal problem - "b," "d," "p," and "q," all look like the same symbol; reading maps - getting from one place to another. Difficulty in grouping of stimuli based on common characteristics in order to make sense of the written word or numbers. Difficulty toward abstract thinking.
Visual Figure/Ground Discrimination- The ability to see specified shapes, forms, symbols or objects when they are hidden in confusing, complex backgrounds.	In finding a specific bit of information on a printed page full of words and numbers. In perceiving whole/part relationships- to perceive letters that form a word and words that form a sentence. In seeing an image within a competing background.
Visual Sequencing Refers to the order in which forms, shapes, symbols or objects are produced visually such as in the printed word.	In staying in the right track while reading a paragraph- skipping lines, reading the same line over and over, reversing, or misreading letters, numbers, and words. Influence the way a person reads and writes words, sentences and numbers greater than nine or calculations, as the order of the letters and numbers is specific to the end result of the meaning represented by the letters in the words (such as saw and was), or numbers in the calculations (39-5=34 or 93-5=88).
Visual Closure Identifying an object when only parts of it are exposed.	In recognizing a picture of a familiar object from a partial image (A truck without its wheels). In identifying a word with a letter missing.
Visual Motor Processing Using information taken in by the eyes to coordinate body movements.	In copying from a board or book. In participating in sports that require well-timed and precise movements in space.
Visual Memory Recall of something seen some time ago, or immediate and delayed memory.	When the image is forgotten between taking it in and transposing it. These individuals have difficulty retaining spelling rules and unusually spelled words. Copying from the blackboard or any source for that matter is wrought with mistakes.

The role played by VSPS in learning

In today's classrooms, and in many fields, textbooks, instruction materials, graphs, flowcharts are designed to use VSPS mentioned in table 1 as a key to mastering academic's subjects matter (Kaufman, 2007; Lohman, 1988). Whereas the development of such materials continues to be an important concern, the increasing recent technological developments (Web 2.0, applications and concept maps) that rely heavily on VSPS have added further emphasis to the issue.

During the last decades, the relationship of separated visual spatial sub-skills and academic skills in young children has been widely investigated. To cite a few, for example in reading, even though both visual and auditory are fundamental, the initial cornerstone of reading is recognizing letter and wordsgraphs - orthographic knowledge. Orthographic knowledge involves visual perception, visual memory, visual discriminatory, spatial orientation, (see table 1) and analytical aspects (e.g., Edelsky, 2006; Retief & Heimburge 2006). Alternatively, in a resolution of multi-digit problem, keeping track of the order in which to write numbers, their presentation on the page and the recognition of separate columns are required. The inability to keep track of these numbers is not due to weakness in mathematical concept understanding or in vision acuity but rather to poor VSPS, which is refer as "Spatial Acalculia" (Forrest, 2004; Geary, 1993). In understanding diagrams, Mayer & Sims (1994) have argued that students with low VSPS need to allocate more cognitive resources to construct an imagery object in working memory. This cognitive load decreases the amount of resources that students allocate to connect verbal and visual information leading in low performance. There is as well evidence that not only poor VSPS can lead to difficulties with learning, but also in overall school performance and even sports (e.g., Groffman, 2006; Korkman, et al., 2007; Frederickson & Cline, 2006).

Undeniably, some individuals have more developed VSPS than others, and even individuals with SLD differ in severity of the problems they encounter, which means that we are not talking about homogenous groups. Good visuospatial learners with SLD blossom when their right hemisphere is activated through imagery and visualization, hands-on activities and examination (Golon, 2008; Silverman, 2002). These learners outcompete people with SLD and poor VSPS with respect to intuition, originality, and the ability to synthesize information from a variety of sources. They are able to see detail and appreciate graphs, charts, and representations to make sense of, and develop an understanding of concepts and ideas (Fliess, 2006; Gregory, 2005; Silverman, 2002). Despite their visual spatial strength, they are at a disadvantage with class and achievement tests that are timed. Silverman (2001) states, "Being required to show their work is nearly impossible for some visual-spatial children, because they see it all at once, rather than arriving at answers through traditional steps and are poor at rote memorization", "they just know. They don't know how they know and they can't explain to anyone else the route they took to the knowing—they just see it." Both the one with weaker or strengthened VSPS sometimes appears to others as "self-absorbed" or "out to lunch". These children need the most support in elementary school when the need to understand, manipulate, and build on visual symbols is most important (Davis, Rimm & Siegle, 2011; Golon, 2008; Subotnik, Olszewski-Kubilius & Worrell, 2011).

Given this, for learners who are experiencing VSPS challenges, learning becomes a tortuous task. These learners apply extensive effort on decoding visual instruction and manual output within the allocated timeframe, resulting in fatigue, stress, and lack of concentration on the content. More importantly, this stress can result in a cascade of emotions and behavioural problems (e.g., task avoidance or refusal within a classroom situation, irritable or aggressive behaviour) that interfere with everyday functioning in school, at home and in the community (Goldstein, 2005; Gordon & Browne, 2008; Kuhn & Siegler, 2006).

While there is limited amount of literature on assessment and interventions for school age children, there is evidence that VSPS can improve through practice and training of adolescents and adults (e.g., Uttal, et al., 2012). Among others, Butterworth and Kovas (2013) have stressed the attention to the specificity of the child's cognitive profile and the fact that if we are to support our children there is a need to monitor and adapt to the learner's current repertoire of skills and knowledge. Butterworth and Kovas said that "a promising approach involves the development of technology-enhanced learning applications - such as games - that are capable of adapting to individual needs for each of the basic disciplines." Indeed, one potential solution and particularly for disengaged students who are not performing as well as they could, is to combine games with coursework.

Problems related to VSPS measurements

In the literature, measures of VSPS can be grouped into recognition tests (e.g., copying task, embedded figure and visual memory, mental rotation of shapes) and manipulation tests (e.g., block counting, block rotation, solving mazes, and paper folding) (Eliot & Smith, 1983). Despite the availability of numerous tests that have been devised to assess various aspects of spatial ability Johnson and Meade (1987), among others, have drawn attention to the fact that tests such as mental rotation (e.g., Shepard-Metzler Mental Rotation Test, Flags and Cards), spatial visualization (e.g., Hidden Patterns, Paper Form Board, Progressive Matrices, and the Vandenberg test, Block Design, and Guilford-Zimmerman spatial visualization), and tests for spatial perception (e.g., the Rod and Frame Test and the water level task) were originally designed for adults and adjusted to be used with children. Such adjustment for children involve clarifying the test instructions, reading aloud instructions or showing model items—all of which is likely to alter the nature of the test.

Others are debating the purpose and goal of standardized tests. For instance, current neurological or intelligence psychometric tests for children (e.g., Pattern Reasoning, Block Design of WISC or Matrix Reasoning of Kaufman Assessment Battery for Children) can provide an objective and standardized measure of particular VSPS sub-skills of a sample. However, the test is limited to assessing only the current performance, which may not be the best manner to assess how well a child can learn (Benson, 2003; Flanagan & Kaufman, 2004; Stenberg & Grigorenko, 2002).

Typically, psychometric (norm-referenced) tests focus on detecting learning disabilities, and the candidate's eligibility for special education or related services. Such testing is considered as a "Discrepancy Model"—if a student's score on the IQ test is at least two standard deviations (30 points) higher than his or her scores on an achievement test, the student is described as having a significant discrepancy between IQ and achievement and, therefore, as having a learning disability (e.g., NCLD, 2003, 2009). As pinpointed by psychologists and educators, this method has several limitations: (a) such measures do not provide enough information that educators can use to create programs to remedy a child's learning problems (e.g., Grigorenko, 2009; Haywood & Lidz, 2007); (b) they do not allow schools to identify children as having learning disabilities while they are still in the primary grades; and (c) students often struggle for years prior to being identified as having learning disabilities rather than receiving the support they need in the early grades (e.g., NCLD, 2003, 2009). The National Research Center on Learning Disabilities (2010) reports that "a variety of factors can cause students to be misidentified as having learning disabilities, yet many states and districts have experienced a disproportionate representation of students from culturally and linguistically diverse backgrounds, based on traditional identification method". The current trend favours classroom based assessments or formative evaluation as an added method to psychometric test.

Classroom based assessment or Formative assessment as coined by Black and Wiliam (1998) refers to "all those activities undertaken by teachers, and/or by students, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged." Classroom based assessment models can best be described by contrasting a traditional testing situation and assessment within training. In a traditional testing situation, one may receive a short instruction such as "Solve the following problems or select the best fit option below in the empty box" and an example problem may be provided. Typically, the test-taker is asked to proceed solving a number of such problems without receiving further help or feedback and generally within a limited time frame. Assessment within training differs to testing in regard to guidance and feedbacks that are provided through the problem solving process. In this process individuals are guided toward more successful achievements (e.g., Shute, 2008).

Despite the promises of such assessments, the implementation of these techniques remains challenging (for overviews see, Hale, et al., 2010). Some of the barriers include, but are not limited to the complexity of the interventions in term of materials and resources, time required implementing them, and lack of evidence of the effectiveness. More importantly, many forms of cognitive assessment are not related to training and intervention (Fletcher-Janzen, 2008; Hale, et al., 2010). Given this state of affairs, one of the main challenges in designing TangSolver was to circumvent these barriers (for more details see chapters 2, 3 and 4).

Steps toward the development of a VSPS assessment and intervention: The TangSolver

There is increasing interest in the use of games as an educational technology, and there is evidence that 'good' games already embody sound pedagogy (e.g., Prensky, 2006, 2010). However, while uncountable educational games exist, the number of games that are designed for VSPS assessment and enhancement in children is very limited. In the following chapters, more detail on structure and use of the application developed is provided; so here I will restrict myself to the very first steps taken toward the development of TangSolver.

Typically, teaching visuospatial problem solving can be addressed through learning theories (how individual can learn and the development concepts), and individuals in their approaches to learning (Omrod, 2008; Pashler, McDaniel, Rohrer & Bjork, 2008), and different instructional type such as dual coding theory (DCT) (Paivio, 1986), and cognitive theory of multimedia learning (CTML; Mayer, 2001, 2009; Mayer & Moreno, 2003). In designing TangSolver, three issues discussed by these theoretical frameworks were of particular importance:

The game type: computerized vs. manipulative

One of the hindering difficulties of assessment and training is that both are time consuming—a cost effectiveness issue that seems to favour computer-based assessment and intervention. Unfortunately, there is no conclusive evidence that computerized assessment and training produces equal or even better performance gains than face-to-face instruction (e.g., Pennington, 2010; Ramdoss, et al., 2011). However, computerized applications have a number of practical and methodological advantages, including the promotion of autonomy and self-learning, and the generation of more accurate measures of the learning process, such as the time between mouse clicks, solution moves etc., that are tapping into the use of strategies (e.g., Aleven et al., 2010; Baker et al., 2010; Feng & Heffernan, 2010; Shute & Zapato-Rivera, 2012).

Individual differences in response to instruction

Individuals differ greatly with respect to their preference for face-to-face instruction or autonomous, computerized learning without much personal interaction (Omrod, 2008; Pashler, McDaniel, Rohrer & Bjork, 2008). Furthermore, games used for teaching are distinct from other forms of classroom teaching, so that the instructional design for games is also distinct. Arguably, what matters for efficient instruction is not just the medium being used, but much more research effort has been spent on the type of instruction that supports literacy down to the type of instruction supporting the enhancement of VSPS. Indeed, a wide variety of theories and instructional approaches exist, as I will describe in more detail in chapters 2 and 3. In short, instructional or guidance can be purely verbal (i.e. check this part, give concrete examples, suggestions for what to do next), purely visual (scaffolding, showing partial or complete solution), or both. Clearly, “different modes of instruction might be optimal for different people because different modes of presentation exploit the specific perceptual and cognitive strengths of different individuals” (Pashler et al., 2008, p.109).

Adapting existing games or designing new ones

Obviously, designing a new game requires a lot of effort, time, and money, so that our first consideration was to adapt an existing game for our purposes. However, even though many Tangram games are freely available, none of them allowed for integrating the program parts necessary for testing and assessment of particular VSPS sub-skills. Adjusting existing games, in turn, was impossible because of legal issues, because the source code was not available, and because the necessary structural modifications would have taken more time than developing an independent game—a frequently observed cost-effectiveness issue (Iuppa, Borst & Terry 2009). Given these problems, we developed "TangSolver", together with an equivalent manipulative version of the game suitable for face-to-face training; see chapters 2 and 3. In this project a pretest-training-posttest format was used. The computerized TangSolver Test was administered for pre- and post-testing, whereas in the training we used either the TangSolver Training application for the face-to-face version; see chapters 2, 3 and 4.

Measures of VSPS sub-skills

Geometric knowledge has been used to evaluate various visuospatial problem solving abilities (Dehaene et al., 2006; Lovett & Forbus, 2010, 2012; Van Hiele, 1999). For example, Raven's Matrices, Block Design of WISC, or Kohs' blocks, measure an individual's ability to analyze, synthesize, and reproduce an abstract design. To evaluate children's performance on a visuospatial task we have chosen the puzzle-like Tangram game. The classical Tangram puzzle consists of creating particular shapes or figures by assembling seven geometrical forms. Importantly for our purposes, there is evidence that dealing with puzzles of that sort tap into spatial visualization abilities (for a review see, Hegarty et al., 2007). However, there is no unique method and/or procedure of assessing VSPS, and the definitions and numbers of components mentioned earlier vary among authors; in the development of TangSolver we focused on two of these components: spatial visualization and mental rotation.

Spatial visualization. A widely accepted definition proposed by Linn and Petersen (1985) is that "spatial visualization is the ability in which complex spatial information is manipulated when several stages are needed for solving the tasks" and spatial visualization skills involve multi-step manipulations of spatially presented information that require analysis of the relationship between forms and different spatial representations. TangSolver can be compared to the pattern modeling tasks of Block Design (BD) of WISC are that measure spatial visualization. The BD tasks consists in assembling red-and-white blocks to re-create a constructed model or a picture from the stimulus book. While such tasks are good predictors of individual's variance in spatial visualization performance, they do not allow an evaluation of visual discrimination (distinguishing whole/part relationships). To overcome this issue we adopted a method from researchers in the domain of autism (Shah & Frith, 1993), who used the BD test to evaluate whole/part relationships (global vs. detail) visual processing of autistic individuals. They argued that while the standard picture of the stimulus book represents a whole figure (the composite parts of the figure were not visible) taps global processing, segmented figures (the composite parts of the figure were visible) tap details processing. Shah and Frith thus state that the BD test can be used to assess both top-down (whole) and bottom-up processing, based on whether local connections (lines, contours) between the puzzle pieces are applied globally or to detail. As I will explain in more detail in chapters 2 and 3, I have used a similar technique to assess global and local processing in my participants.

Mental-rotation. Mental rotation involves the ability to rapidly and accurately rotate mentally two- or three-dimensional figures (Linn & Petersen, (1985). Solving tasks employed in my experimental material required that one notices different possible shape transformations. I constructed two sub-tests: One did not require any mental rotation but could easily be solved by media dragging and dropping puzzle pieces—a condition that I will refer to as "simple transformations test." The other did require mental rotation, an initial flip or rotation of MPs followed by drag and drop—a condition I will refer to as "complex transformations test."

Selection of item pool

According to Flaugher (2000), in the development of any assessment there is a need for a systematic approach that entails an analysis of the pedagogical quality of the items, evaluation of the degree of discrimination, satisfactory number of items for each level of ability, and a reasonable estimated testing times (notably, there is little that educational technology can contribute to improve formal or informal student learning without intensive involvement of teachers and pedagogically knowledgeable instructional designers). Accordingly, I developed a pool of test items together with six teachers of primary schools, who were also involved in the final item pool construction. The results of several pilot studies (not reported in this thesis) and suggestions were considered and discussed prior to the eventual study design.

For item construction, we used the Simple Logistic Model of Rasch (one-parameter logistic model within item response theory), that is based on the probability of a specified response to a set of items (such as score 0/1 for in/correct response). The two parameters, one for the respondent's (person's) ability, and one for item difficulty are estimated on a single scale in the form of a graph which allows comparison of the person distributions with the item distributions. From both statistical analysis as well as clinical judgment, we made the choice on the final item inclusions and the development of the manipulative material (see chapter 2). Based on our primary results of the manipulative material and other pilot studies the current TangSolver application was developed.

The reliability of the computerized TangSlover test is reported in chapter 3, however, item pool construction, and the design of strategies and the process of finding successful interventions is a dynamic and ever changing process that cannot be reached straightforwardly. Hence, a single statistic cannot determine the validity or the reliability of any test or experiment material. Furthermore, outcomes vary according to individuals who are being tested. It is acknowledged that TangSolver is just a means to an end in the process of promoting the assessment and training of VSPS within standard courses, and that there is a need for further experiments.

Overview of the research

The major aim of this research project was to move one step toward assessment and training of VSPS of school age children. To this end, we have developed a computerized application called TangSolver. Such project entails a holistic multidisciplinary approach and requires a thorough understanding of programming and software design, as well an understanding of learning theories, their application, and instructional design theories. Ultimately mapping the terrain for such project requires more than one introductory chapter and as well further report on the almost unlimited potential of measurement and interpretation of findings. Although the development of the application has been an important concern of the author, we do not seek to provide a review of technical and software design that is beyond the scope of a psychological thesis. I will thus confine this thesis to the conceptual framework of VSPS, VSPS enhancement, and the evaluation of the relative effectiveness of TangSolver for this purpose.

This introductory chapter has outlined the challenges associated with the importance of assessment and training of visuospatial processing skills - almost an unexplored arena in particularly among young children (Spatial Intelligence and Learning Center). Chapter 2 provides a theoretical rational for the development of the manipulative set and evaluation of its effectiveness. Chapter 3 describes the effectiveness of TangSolver as compared to a conventional face-to-face training regime and a non-training control group. The efficacy of visual cues (picture scaffolding) vs. multimodal teacher instruction, and the effect of training in a simple transformation test vs. a complex transformation test is reported. Chapter 4 tests a specific hypothesis related to possible differences in global and local VSPS between children with autism and typical children. Chapter 5 concludes with a general discussion of findings.

My main hypotheses were that: (a) learning by doing can improve VSPS (Shute, 2007); (b) multimodal instruction (verbal and visual cue) and visual cues can be used to further support students' VSPS; and (c) both computerized and face to face instruction can improve VSPS. Ultimately, it is hoped that implementing such applications in school promotes teaching and training VSPS and related skills in young children and inspires researchers to further develop VSPS assessment and training procedures. Finally, the data obtained in my experiments are likely to motivate changes to the gaming environment and the creation of new assessment and intervention games (e.g., Aleven et al., 2010; Baker et al., 2010; Feng & Heffernan, 2010; Shute & Zapato-Rivera, 2012).

Chapter 2

Effectiveness of visual and verbal prompts in training visuospatial processing skills in school age children

Ellahe Chabani & Bernhard Hommel
Manuscript submitted for publication

Abstract

Recent decades have witnessed a growing interest in intervention-based assessment to promote and enhance children’s learning. In this study, we explored the potential effect of an experimental visual-spatial intervention procedure and possible training benefits of two prompting modalities: one group received training with verbal and visual prompts, a second group training with visual prompts only, while a third, control group did not receive any training. The two training methods led to significant improvements of performance in visuospatial tasks as compared to control group, and they did so about equally well. Our findings provide evidence for the efficiency and benefits of interventions targeting VSPCs. The success of such interventions does not seem to be bounded by age or gender, and it seems that visual cues are particularly effective.

Introduction

The recent years have seen a trend away from a unitary concept of human intelligence and towards concepts that allow for multiple types and varieties of intelligence. Among those, visual-spatial processing skills (VSPSs), which reflect the ability to generate, retain, retrieve, and transform visual stimulus material (e.g., Gardner, 1983; Linn & Petersen, 1985; Lohman, 1993; Sternberg, 2003; Van Garderen & Montague, 2003), have been considered particularly important. Indeed, there is evidence suggesting a pivotal role of VSPSs in performance related to STEM (science, technology, engineering, and mathematics; e.g., Lubinski, 2010; Uttal, Meadow, Tipton, Hand, Alden & Warren 2012; Wai, Lubinski & Benbow, 2009) and in early academic skills (e.g., math, reading, writing; Assel, Landry, Swank, Smith & Steelman, 2003; Cheng & Mix 2012; Holmes, Adams & Hamilton, 2008; Passolunghi & Mammuarella 2010; Rasmussen & Bisanz, 2005).

Furthermore, education is undergoing a profound change worldwide and coming generations will grow up in an increasingly visual multimedia environment; recent technological developments (Webs, App's applications) rely heavily on VSPS. Theoretically, success at school and at future workplaces will thus largely depend on visualization, grasping the big picture, visual memory, pattern-finding and thinking graphically (Stieff, 2007; Carr, 2008, 2010). Yet, it has been frequently observed that VSPS are not adequately practiced, addressed, and assessed at school (National Research Council, 2006; Principles and Standards for School Mathematics, 2006; Webb, Lubinski & Benbow, 2007). For instance, recently, the National Council of Teachers of Mathematics (2010) and the US-American National Research Council (2006) have warned that visuospatial intelligence is not just under-supported but under-valued, and therefore under-instructed—which has been taken to call for a national commitment to the development of visuospatial thinking across all domains of the school curriculum.

To move one step forward into this direction, our project aimed at developing a VSPS instrument that can serve for both assessing and enhancing VSPS in school age children, which we thought might not only promote teaching and training in that domain but may also stimulate researchers to further develop related assessment and training procedures.

Visuospatial processing skills (VSPS)

Researchers and theorists in different areas have acknowledged that VSPS is not a unitary construct, but rather can be broken into a collection of sub-skills or components (e.g., Carroll, 1993; Eliot & Smith, 1983; Kaufman, 2007; Lohman, 1988; Sutton & Williams, 2007). Unfortunately, meta-analyses, factor-analytical assessments (Carroll, 1993), and other approaches have failed to find clear evidence for a particular number of separable factors, so there is currently no consensus on how many factors are involved. What seems to be clear, however, is that spatial perception, spatial visualization, spatial orientation, spatial sequencing, mental rotation, and working memory are among them (

Allen, 2003; Carroll, 1993; Eliot & Smith, 1983; Hegarty, & & Waller, 2004; Linn & Petersen, 1985; Kaufman, 2007; Lohman, 1988; Sutton & Williams, 2007; Willcutt, Doyle, Nigg, Faraone, & & Pennington, 2005). Regardless of confusion regarding the definition, its underlying factors or sub-skills, and the classification (e.g., D'Oliveira, 2004; Hegarty & Waller, 2005), there is evidence for the malleability of VSPS (Uttal, Meadow, Tipton, Hand, Alden & Warren, 2012). Uttal, et al.'s meta-analysis of over 217 studies on VSPS confirmed the theoretical and practical importance of visuospatial skills at any age and indicated that even short training procedures can significantly improve VSPS. The authors also emphasize the lack of studies in younger children (four out of 217 studies investigated children below 13 years), which contrasts with the large amounts of studies involving adolescent and adults in STEM education. According to Uttal et al., (p. 54) "playing active games has the potential to enhance spatial thinking substantially, even when compared to a strong control group." One potential explanation for the lack of studies in younger children is the lack of child-friendly testing and assessment instrument. Even though the experimental material developed for the present study does not aim to reconcile the different theories and conceptions of VSPS, it aimed at providing means to overcome this shortcoming.

Testing and Assessment of VSPS

Eliot and Smith, (1983) have distinguished between VSPS recognition tasks (e.g., copying task, embedded figure and visual memory, mental rotation of shapes) and manipulation tasks (e.g., block rotation, block counting, solving mazes, and paper folding). A wide variety of tests and assessment instruments exists and many psychometric intelligence tests for children include visuospatial tasks such as Pattern Reasoning, Block Design of WISC-IV (2004), Matrix Reasoning of Kaufman Assessment Battery for Children (2004), or the Test of Visual-Perceptual Skills–Revised TVPS–R; Gardner, 1996). While there is significant debate about what exactly these tests measure (e.g., Mathewson, 1999), it is recognized that the subtests for children provide an objective and standardized measure of particular subskills– i.e. visualization. For instance, in the Block Design test individuals are asked to reproduce a design from colored plastic blocks. Such tasks require the ability to analyze and synthesize an abstract design, which is considered a measure of spatial visualization. A critical point is that such tests measure the broad concept of spatial visualization but do not address isolated subskills, such as mental rotation or visual discrimination.

Others have argued that the main goal of such summative and normative sub-tests is to compare a given child's scores to the age-group standards (Flanagan & Kaufman, 2004; Haywood & Lidz, 2007; Sternberg & Grigorenko, 2002). In particular, the purpose of such tests is often to detect learning disabilities and eligibility or special education or related services. This leads to a strong focus on current performance rather than on the potential that a given child may possess. Accordingly, most available tests do not provide enough information for educators to create programs to remedy a child's learning problems (e.g., Haywood & Lidz, 2007; Sternberg & Grigorenko, 2002). This shortcoming has motivated the idea of a more intervention-based assessment of cognitive abilities that considers both current performance and the potential to improve.

Intervention-based assessment

Intervention-based assessment or formative evaluation, as coined by Black and Wiliam (1998), refers to "all those activities undertaken by teachers, and/or by students, which provide information to be used as feedback to modify the teaching and learning activities in which they are engaged." The last decade has witnessed the development of different types of formative evaluation—classroom-based assessment, such as Dynamic Assessment (DA) or Response to Intervention (RTI). Notwithstanding differences within and between such approaches in terms of theoretical premises, historical roots, and procedure (for an overview see, Archer & Hughes, 2011; Fuchs & Fuchs, 2006; Grigorenko, 2009), both DA and RTI approaches are learner and process oriented. Basically, both concepts aim at systematic screening and information gathering procedures to monitor students' progress efficiently. Ideally, information provided through assessments enable the identification of instructional modalities, material, and technologies to promote active learning, as well as developing pedagogical strategies for children with special strength/weakness or educational needs. Theoretically, by implementing screening, progress monitoring, and outcome assessments in a reliable and valid way, it is possible to reduce the use of time-consuming and expensive formal diagnostic instruments (Cortiella, 2011) and provide more efficient help to learners.

In view of the role played by VSPSs in learning (Assel, Landry, Swank, Smith & Steelman, 2003; Cheng & Mix 2012; Holmes, Adams & Hamilton, 2008; Passolunghi & Mammuarella 2010; Rasmussen & Bisanz, 2005), it is reasonable to assume that some of the difficulties children exhibit at school and in other learning environments can be explained by weaknesses in VSPSs rather than in some general capacity to learn. Therefore, assessment and trainability of such skills can have important implications for guiding educational interventions and/or helping teachers in their teaching approach.

Verbal and visual feedback in VSPS learning

In any intervention-based assessment or formative evaluation, instruction and feedback play a critical role. Providing guidance and feedback to learners about the performed action or task is an important factor that affects learning and skill acquiring (see Hattie & Timperley, 2007; and Shute, 2008, for two particularly influential studies). The main purpose of feedback is considered "to reduce discrepancies between current understandings and performance and a goal" (Hattie & Timperley, 2007, p.86) and to "signal a gap between a current level of performance and some desired level of performance or goal" (Shute, 2008, p.157). Hattie and Timperley have identified four levels of feedback with differential effect on learning: (1) feedback on the task, (2) feedback about the processing of the task, (3) feedback about self-regulation, and (4) feedback about the self as a person. Their conclusion was that feedback about the self (i.e., “good girl/boy,” “great try,” etc.) represents the least effective form of feedback. Such feedbacks have no instruction-related content and might improve the student’s investment of effort or attitude toward learning but do not affect achievement. In contrast, feedback on the task and feedback about the processing of the task are effective in enhancing and facilitating depth learning. The third level about self-regulation guide learners how to engage in future learning situations and helps students attribute their success or failure at a task to a particular and specific cause rather than to their self-efficacy. Along the same lines, Shute (2008) considers feedback effective to the degree that it focuses on the task, and he suggests that it should be presented in manageable units and not be too elaborated.

While these frameworks are helpful in guiding the design of interventions using feedback and instructions, it remains unclear of which kind and modality efficient feedback should be. Classroom-based instructions are commonly verbal (e.g., “check this part”, “give concrete examples”), sometimes accompanied by visual information, such as images or graphs. Even though verbal instructions are certainly important in guiding the child’s attention to the relevant information, there is a need to also consider students with different learning needs and preferences. For instance, students with hearing impairments (Dye, Hauser & Bavelier, 2008) and children with language-based learning disabilities or different linguistic backgrounds may have a hard time decoding verbal instructions (e.g., Cortiella, 2011; Paul, 2007) and would thus profit more from purely visual feedback such as visual scaffolding, or showing complete or partial solutions.

Visual feedback or visual cues has generally been studied within multimedia learning (e.g., Butcher, 2006; Hegarty & Just, 1993; Kalyuga, Ayres, Chandler & Sweller, 2003; Moreno & Mayer, 1999; Olina, Reiser, Huang, Lim & Park, 2006). Two major theoretical frameworks have guided empirical research in multimedia learning. The Cognitive Load Theory (CLT) describes learning in terms of information processing system involving working memory storage (e.g., Moreno, 2010; Paas, Renkl & Sweller, 2004; Schnotz & Kurschner, 2007). In short, if in the learning process mental resources (working memory) are exhausted then learning may fail to occur. The optimal solution is then modifying the instructional material to lower the level of cognitive load. CLT-motivated studies have argued that cognitive processes involved in active coordination of visual and verbal information during learning can promote students’ understanding, in particular with complex materials. Another influential theory is the cognitive theory of multimedia learning (Mayer, 2005). It is based on Paivio’s (1986) assumption that information processing occurs in two complementary channels: a visual/pictorial channel and an auditory/verbal channel, which are sensitive for different kinds of information. Mayer (p. 47) states that “people learn more deeply from words and pictures than from words alone” and he suggests that instructional designs should avoid cognitive overload in learners by using both channels to provide instructions. However, while multimedia studies have provided evidence for efficient learning with visual–verbal prompts, to our knowledge no study has used manipulative tasks and classroom-based instructions.

The current study

The primary objectives of the present study were threefold. Firstly, we were interested to evaluate whether the VSPSs of children could be improved by training at all. We expected that children who were trained would perform better on the posttest than children in a control group in which no VSPS training was provided. Second, we compared two types of instruction and guidance in a pre-train-posttest design. As mentioned above, there is evidence for the efficacy of combining visual and verbal prompts during training (e.g., Resing & Elliott, 2011), but little is known about the efficacy of purely visual prompting—which however would be more suited for children with verbal difficulties. Accordingly, we compared two training modalities by providing some children with both verbal and visual hints and other children with visual hints only. Although this manipulation was thought to inform later studies on children with verbal problems, the present study focused on typically developing, healthy children. We considered that children with no particular verbal or language difficulty might profit more from multimodal support (Mayer, 2005).

Our third aim was more explorative. Studies of gender differences—in particular on VSPS—have generated considerable controversy among researchers (for an extensive review, see Halpern, 2012; Newcombe & Learhmont, 2005). Among other issues, one important question raised by Uttal et al., (2012) was whether the gender differences that were observed in a wide variety of spatial tasks reflect true (structural) gender differences or mainly differential degrees of practice. While Uttal et al., pointed out that the "gender gap in spatial skills did not shrink due to training" (p.43), other researchers (e.g., Terlecki & Newcombe, 2008; Tzuriel & Egozi, 2010) reported that gender differences can often be removed by training. A similar discussion in the literature refers to age. Piaget (1977) considered that early spatial understanding is topological in nature, while Euclidean representations would emerge no earlier than at the age of 9 or 10. This prediction is not consistent with findings reported by Sophian (2000), who demonstrated that 4- and 5-year-olds can compare proportions and figures and are able to correctly match a shrunken picture to the original. Even though we are not committed with regard to the existence and cause of gender and age effects, and even though we consider the available evidence as too inconclusive to justify directed predictions, we were interested to see whether gender and age might mediate possible training benefits.

Method

Participants

The sample consisted of 281 typical children (152 boys and 129 girls) with a mean age of 95 months, SD=13.14, with no known histories of developmental, neurological, or learning problems. Children came from a number of primary schools in the Netherlands (two standard Dutch schools, the International school, and the French school of The Hague) and a school in France. In all cases, children were trained in language spoken at school and parental consent for participation was obtained.

Design and procedure

The study utilized a pre-test—training—post-test control-group design, with two training groups and a control group. Before dynamic testing started, the children were quasi-randomly assigned to three groups, but matched for general inductive reasoning ability. The three groups consisted of the verbal plus visual training group, the visual training group, and the control group. Pre-test and post-tests of the dynamic test were administered to all children. Children in both training groups received two trainings between pre- and post-test, while the control group was engaged in discussion and drawing tasks during this time (see Table 1 for the design). The prompting during the combined verbal-visual training consisted of verbal instructions in the children's native language and of visual aids. Children in the visual training group received only visual aids. Children were tested individually by three students of psychology and the first author. Testing and training sessions were scheduled weekly, in separate rooms at the children's own school and each session took approximately 35-40 minutes. However, children who finished earlier joined the control group and all get back to class at the same time. The posttests take place +/- 2 weeks after the second training session. We have tried to keep the time between pre- and post-testing as equivalent as possible; nonetheless due to school's activities (i.e., holidays, school trips, end of the school year party etc.) some post-testing was delayed by +/- 2 or 3 weeks.

Table 1.
Experimental design

	RPM	**Pretest**	**Trainings**		**Post-test**
Groups (N)	Session 1 (45 min)		Session 2 (35-40 min)	Session 3 (35-40 min)	Session 4 (45 min, +/- 2 Wks. after session 3)
VeVis (88)	X	X	X	X	X
Vis (99)	X	X	X	X	X
Control (94)	X	X	Discussion & drawing	Discussion & drawing	X

VeVis = Verbal and visual Dynamic Intervention, RPM= Raven Progressive Matrices.

Instruments

Development of VSPS instrument

The rationale. The experimental VSPS developed for this study is based on the Tangram Chinese game (putting together seven geometrical forms to form shape). This choice was initially motivated by the fact that geometric knowledge has been used to evaluate various visuospatial solving problem abilities (Dehaene et al., 2006; Lee, Lee & Collins, 2009; Lovett & Forbus, 2010; National Council of Teacher's Mathematics, 2003). For instance, Block Design of WISC or Kohs' blocks assess an individual's ability to analyse, synthesize, and reproduce an abstract design. Bodies of studies on spatial visualization ability and studies on general problem-solving ability suggest that such tasks tap into the same cognitive abilities and are useful in many advanced disciplines such STEM (science technology engineering and math) (for a review see, Hegarty et al., 2007). Arranging geometrical forms not only display the grouping and the fact that there is not a unique solution is associated with problem solving theories (e.g., Ford, 2003; Foster, 2007; Mayer & Wittrock, 2006; Slocum, et al., 2003).

From an educational point of view, Tangram assists in developing geometrical knowledge, reasoning, geometrical imagination, development of creative thinking, including the understanding of geometrical shapes, size, and position in space, as well as the reliance of perceived shape on position in space (Van Hiel, 1983). For example, Tangram games allow the consideration of shapes and relationships between shapes (e.g., two triangles can make a square), which links performance to other domains, such as mathematics, without having to resort to formulas but rather by developing a geometric, basic understanding of concepts such as "area" and "congruence" (for an overview, see, Bohning & Althouse, 1997; Gardner, 1996). Another argument for a Tangram-based intervention is that it requires or at least benefits from all visuospatial abilities that so far have been related to but are not limited to: the ability to understand how objects appear in different positions that is referred as spatial visualization (Lohman, 1988; Kaufman, 2007; Linn & Petersen, 1985). Spatial visualization includes the ability to manipulate information sequentially and spatially, the skill to conceptualize how objects relate to each other in space, the ability to visualize mental rotation of objects, 2-dimensional understanding, recall of something seen some time ago, or immediate and delayed memory related visual memory (Carroll, 1993; Eliot & Smith, 1983; Lohman, 1988; Kaufman, 2007; Linn & Petersen, 1985; Hegarty & Waller, 2004; Sutton & Williams, 2007; Willcutt, et al., 2005).

Furthermore, with Tangram material, understanding the task is straightforward. The child can evaluate the correctness of his/her actions and his/her progress relatively easily. Moreover, solving Tangram puzzles does not rely on verbal capacity or typical academic knowledge (i.e. reading, writing, calculating), the puzzles are challenging and yet manageable and they provide a motivating context in which children are more likely to experience enjoyment rather than the stress of a testing situation. In short, the foremost argument for our choice was that in geometric-puzzle construction individuals are likely to use qualitative, and/or categorical, representations to reason about shapes or space (spatial visualization and visual discrimination), and process the spatial relations between elements in a visual scene.

Composition of Items

In a typical Tangram game a large variety of shapes can be created by arranging seven geometrical forms. In our Tangram game, we made use of master pieces (MPs) that were constructed by pre-combined forms (e.g., a MP could be the combination of a triangle and square) and as well the standard forms. Thus shapes could be created by using range of MPs starting with 4 MPs, 5 MPs, 6 MPs to 7 MPs (that correspond to the 7 classical geometric forms). The number of MPs needed for making each shapes was considered an index of the difficulty level of the items.

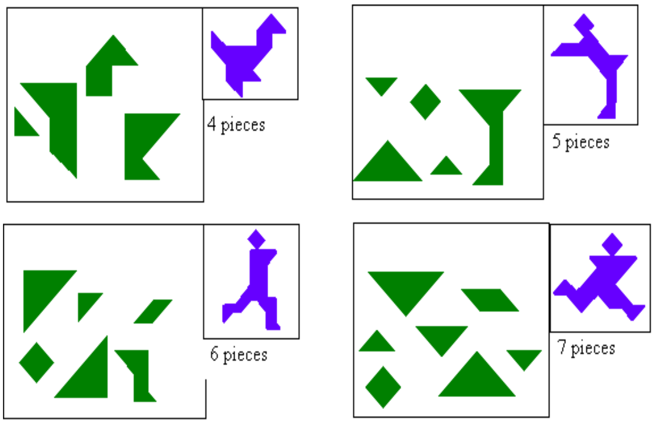


Fig. 1

An example of items according to each difficulty level (4 MPs, 5 Mps, 6Mps, and 7 Mps) of pre- and posttest

Testing Items and testing procedure

To evaluate children's VSPS before and after training in standard way (without any feedback or guidance), 8 items (8 different figures)--two items at each of four difficulty levels—were selected. All MPs were made of green sticky plastic that were placed on a white board (see fig1). For both pre- and post-test the same material was used. During the tests a puzzle figure, printed on a card, and a white board with the necessary MPs were presented to the child. The child task was to pick up the forms and solve the puzzle as quickly as possible. However, the testing was time limited, and for solving each item a max of 2 minutes was attributed, after which independently of in/correctness of the task the next item was presented to the child. The items were order from low to high complexity. During the tests the feedback consists in encouragement i.e. "well done", or in case of unsuccessful attempt i.e. "that is a really difficult one, let's try another one". The condition for termination was three consecutive failures.

Inductive reasoning

The Raven Progressive Matrices (RPM), (Raven, Raven & Court, 1998) were used to match children with regard to their inductive reasoning ability. The Raven test is a broadly used non-verbal multiple-choice test of visuospatial inductive reasoning. In each test item, the child is asked to identify the missing element that completes a pattern.

Intervention Items and intervention procedure

The intervention consisted in providing guidance when a child could not solve the problem alone. The two intervention were namely, Verbal & Visual (VeVis) training and Visual (Vis) training. To this end, six different items similar to those used in the testing were selected (e.g. other birds or cat etc.), and for each item four boards (with 4, 5, 6 and 7 MPs) were made. The aim was to provide intervention at all four levels for each of the six selected items. We used the same material but with three different colors (blue, red, and yellow) (see Fig. 2). It was assumed that children who have more developed analogical capacity would recognize how different master pieces were either combined or divided, and that this would lead to more independent successful task accomplishment.

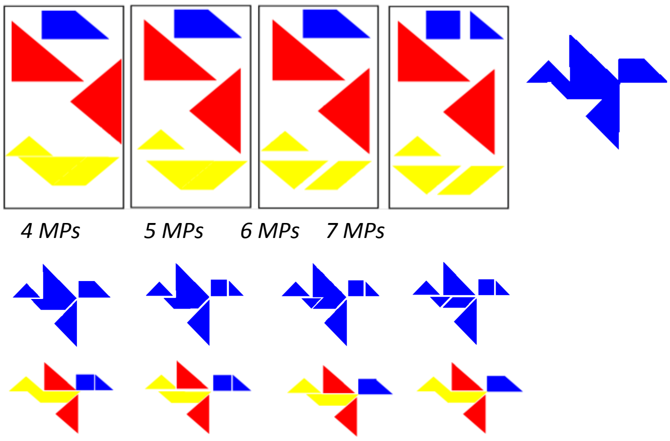


Fig 2.
An example of training material and visual cues

The verbal prompts as of metacognitive level were mainly based on self-exploration, and gradually moved to more specific instruction (see table 2) that were similar to studies of Resing and Elliott (2011). There were two kinds of visual prompts: Monochrome cues showing how MPs could be broken up and colored cues doing the same, only that here all pieces were in the same color as in the master piece (see fig. 2). Both interventions started with the presentation of a board with 4MPs (the easiest level) and then progressed to the most difficult level with five, six, and seven MPs, respectively. The children were asked to make the puzzle in their own rhythm and were told that, if they would encounter difficulty in solving the problem, we would work together. After 1-2 minutes of unsuccessful trying, the intervention took place, in the modality of the respective group (VeVis or Vis). In the VeVis group, visual cues were provided when verbal prompts were not sufficient. With both kinds of interventions, the child would first be presented with the monochromic cards (see table 2). If the children would be able to derive the general spatial composition principle from these cards, they should be able to solve the task. However, we considered that some children might not be able to abstract from the actual colors of the puzzle components, which is why then presented the colored cards. If the child was struggling with an item or at a particular level, the intervention was abandoned momentarily to avoid frustration. After a short break of a few minutes, the intervention was continued with the next item or level and all previously completed boards were put on the table in front of the child.

Table 2.
Order of Verbal & Visual Prompts Offered During the Training Procedure

		Prompts type and order	Frequency of use
Verbal graduated prompts	Self-exploration	Please compare those boards Which changes do you see? Can you recognize which pieces were combined or were divided? Are you sure, that is how they were combined? Are you sure that this form should be here? Please check again?	The amount was adapted to child responsiveness & assessor's judgment.
	Specific	This form should be here. This is the head and not the body or foot	
Visual cues	solution card		
	AVC	Puzzle picture with one color with breaking lines	VeVis: 10 sec and 2 times Vis: 10 sec and up to 3 times
	CVC	Puzzle picture with color match to master pieces with breaking lines	VeVis: 10 sec and 2 times Vis: 10 sec and up to 3 times

Note: AVC = Abstract visual cue; CVC= concrete visual cue; VeVis= Visual&verbal training; Vis= Visual training.

Performance during pre- and post-test was assessed by creating three scores: the Time On Task score, mainly a "bonus" variable (in the sense of "going through" in the face of difficulty) that represents the time taken to complete the task with a maximum of 2 min/item; the Accuracy score, a variable that represents the total number of correctly pieces placed per item; and the Tasks Completed score, another variable that counts whether a given task was completed (1) or not (0). Of main interest were changes in these variables from pre- to post-test, and in particular changes that were restricted to, or more pronounced in the two actual training groups than in the control group.

Results

Before assessing the effect of training, we checked whether the three training groups were initially comparable. To do so, we entered the three pretest scores (Time On Task, Accuracy, and Tasks Completed scores) into separate three-way ANOVAs with Training Group (verbal-visual, visual, and control group), Gender (male vs. female), and Age Group (three age intervals: AgeG1= 6-7.5 years, AgeG2= 7.6-8.5 years, and AgeG3= >8.5 years) as between-participants factors. Neither Training Group [Time On Task, F(1,281)=2.40, p=.09; Accuracy, F(1,281)=2.40, p=.06; and Tasks Completed, F(1,281)<1] nor Gender [Time On Task, F(1,281)<1; Accuracy, F(1,281)<1; Tasks Completed, F(1,281)<1] showed any significant pre-intervention difference between groups. Age Group also showed no effect for two of the three scores

[Accuracy, F(2,281)<1; Tasks Completed, F(2,281)<1]. The only significant difference was found for Age Group regarding Time On Task, F(2,281)=3.44, p=.033, ηp^2=.027. LSD post-hoc tests indicated that AgeG1 (M= 681.7, SD=82.08) spent less time on completing puzzles than AgeG2 (M=709.63, SD=82.08, p=.028) and AgeG3 (M=712.65, SD=106.67, p=.026), while there were no significant differences between AgeG2 and AgeG3.

As pointed out, our main interest was whether and where changes from pre- to post-test were more pronounced in the two training groups than in the control group. To identify these effects, we analyzed each of the three dependent measures (Time On Task, Accuracy and Tasks Completed score) by means of a four-way ANOVA for repeated measures with Session (pre- and post-test) as the within-participant factor, and Training Group (verbal-visual, visual, and control), Gender (male vs. female), and Age Group (see above) as between-participants factors. Gender and Age Group were included to identify possible individual differences in the effectiveness of the training. The theoretically most interesting result pattern would consist of a two-way interaction involving Session and Training Group and higher-order interactions including these two factors. See table 3 for descriptive statistics. An alpha level of .05 was used for all statistical tests.

Table 3.
Descriptive statistics of Pretest and Posttest for Time On Task, Accuracy and Tasks Completed scores per condition, gender and age groups

Pretest								
			Time On Task(sec)		Accuracy		Task completed	
		N	M	SD	M	SD	M	SD
Groups	Control	94	691.44	96.19	14.71	4.80	0.85	2.82
	Vis	99	691.79	90.80	16.11	5.85	0.69	0.86
	VeVis	88	716.69	87.91	16.58	5.92	0.81	1.04
	Total	281	699.47	92.17	15.79	5.58	0.78	1.80
Gender	Male	152	700.49	97.11	15.93	5.56	0.84	2.28
	female	129	698.27	86.35	15.62	5.61	0.71	0.99
	Total	281	699.47	92.17	15.79	5.58	0.78	1.80
Age	AgeG1(6-7.5)	110	681.70	88.47	15.93	5.43	0.87	2.67
	AgeG2(7.6-8.5)	99	709.63	82.08	15.72	5.58	0.69	0.80
	AgeG3=>8.5	72	712.65	106.67	15.68	5.86	0.76	1.00
	Total	281	699.47	92.17	15.79	5.58	0.78	1.80
Posttest								
			Time On Task(sec)		Accuracy		Task completed	
		N	M	SD	M	SD	M	SD
Groups	Control	94	738.38	110.81	15.97	4.35	1.11	.99
	Vis	99	792.78	74.33	17.89	5.44	1.85	1.42
	VeVis	88	753.36	72.33	19.48	5.11	1.98	1.55
	Total	281	762.24	90.46	17.74	5.17	1.64	1.38
Gender	Male	152	759.22	98.35	17.33	5.33	1.59	1.33
	female	129	765.79	80.41	18.23	4.96	1.70	1.46
	Total	281	762.24	90.46	17.74	5.17	1.98	1.54
Age	AgeG1(6-7.5)	110	750.17	96.05	17.73	5.44	1.60	1.42
	AgeG2(7.6-8.5)	99	767.37	87.60	17.67	4.94	1.55	1.34
	AgeG3=>8.5	72	773.61	84.39	17.88	5.13	1.83	1.39
	Total	281	762.24	90.46	17.74	5.17	1.64	1.38

Time On Task

The four-way ANOVA yielded main effects of Session, F(1,263)=83.39, p<.001, ηp^2=.24, Training Group, F(2,263)=3.18, p=.043, ηp^2=.02, and Age Group, F(2,263)=4.09, p=.018, ηp^2=.03, indicating that participants spent more time on task after the intervention (763 vs. 700 sec), that less time was spent in the control group (717 sec) than in the two training groups (742 and 734 sec for Vis and VeVis, respectively), and that the youngest group spent less time on task (715 sec) than the two older groups (739 and 740 sec). More importantly, however, Session interacted with Training Group, F(2,263)=11.07, p<.001, ηp^2=.08, was involved in a reliable three-way interaction including Session, Training Group, and Age Group, F(4,263)=2.59, p=.037, ηp²=.04. The latter was due to that the interaction of Session and Training Group was significant in the two older age groups, F(2,93)=9.44, p<.001, ηp²=.17, and F(2,66)=5.16, p<.01, ηp²=.14, respectively, but not in the youngest group, p>.5.

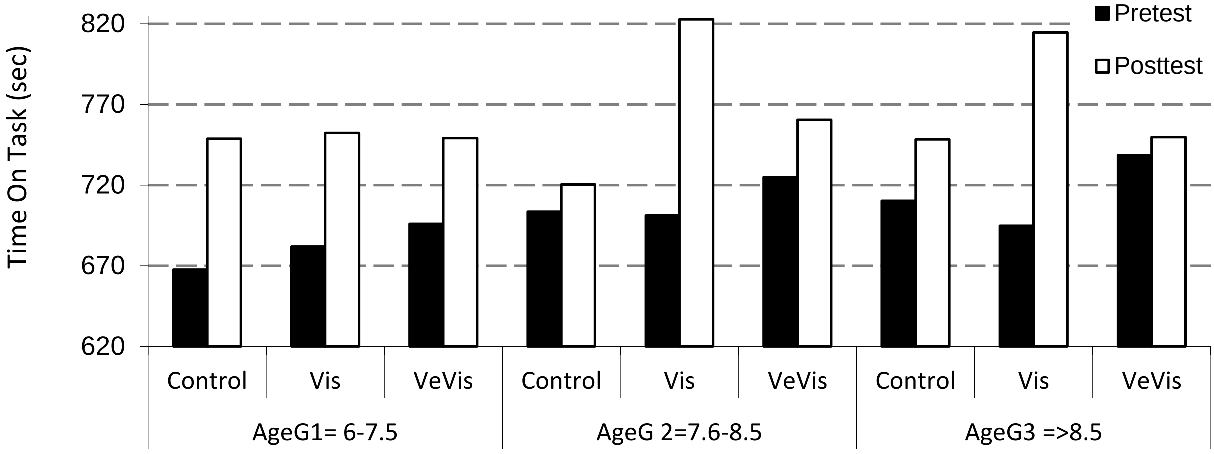


Fig 3

Changes from Pretest to Posttest of Time On Task, for Groups (Verbal-Visual, Visual and control), and Age Group.

As Figure 3 indicates, the time on task increased from the pre- to the post-test in the youngest group, but it did so for all three types of training alike, that is, independent of the presence and the type of training. In other words, training had no specific impact on the youngest age group. In contrast, in the two oldest groups the time on task did not significantly increase over session in the control group (p's > .37), while purely visual training led to an increase of time on task in both the medium, t(32)=7.17, p<.001, and the oldest age group, t(26)=5.49, p<.001. The effect of combined verbal and visual training was less clear, producing a significant effect in the medium age group, t(31)=2.07, p=.047, and no significant effect in the oldest age group, t(20)<1. Hence, intervention-specific effects on the Time on Task "bonus" score) in the two older groups were strongest with purely visual interventions.

Accuracy

The four-way ANOVA yielded main effects of Session, F(1,263)=67.40, p<.001, ηp²=.20, and Training Group, F(2,263)=6.75, p<.001, ηp²=.05, indicating that participants were more accurate after the intervention and that they were most accurate in the combined (verbal-visual) training group (18.1), least accurate in the control group (15.4) and intermediate in the Vis group (16.9). Furthermore, Session interacted with Gender, F(1,263)=7.17, p<.01, ηp²=.08, and was involved in a significant three-way interaction including Session, Gender, and Age Group, F(2,263)=4.04, p=.02, ηp²=.03. The latter was due to that the interaction of Session and Gender was reliable in the two older age groups, F(1,97)=8,64, p=004, ηp²=.08, and F(1,70)=6,41, p=.014, ηp²=.08, respectively, but not in the youngest group, p>.57. As Figure 4 indicates, all groups benefitted from training but girls from the older age groups did so in particular. The interaction of Session and Training Group just missed the significance criterion (p=.066) as did the four-way interaction (p=.062). However, numerically speaking the strongest improvement across sessions was observed with VeVis training (15.4, 16.9, and 18.1 for Control, Vis, and VeVis, respectively).

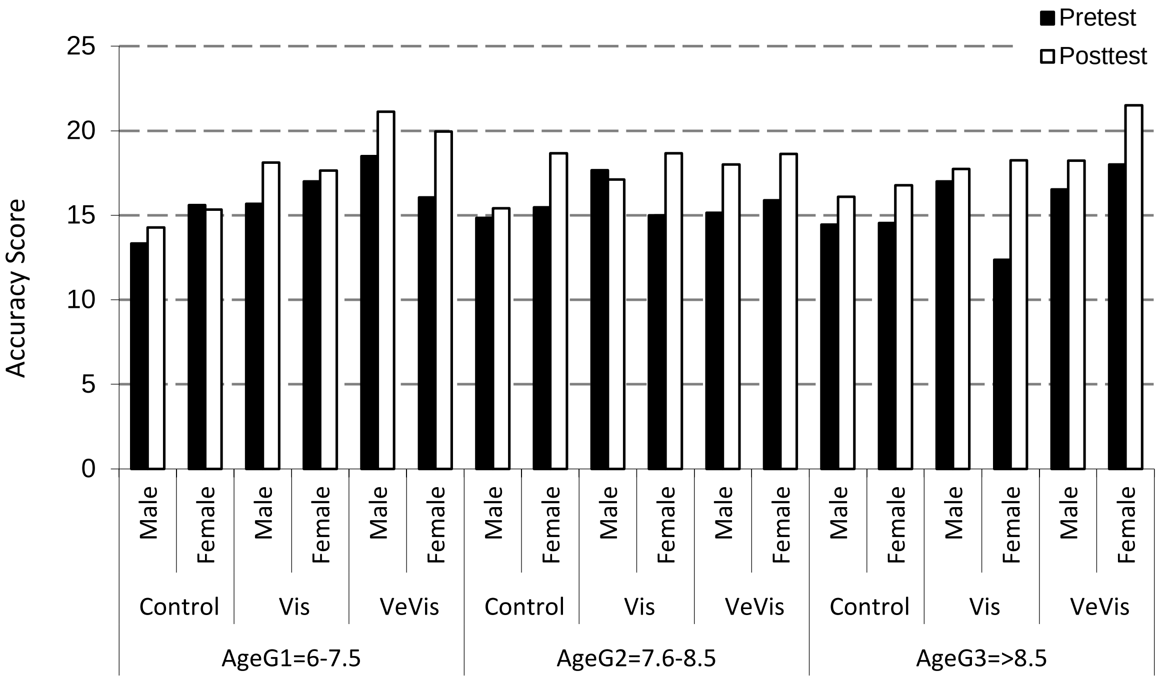


Fig 4

Changes from Pretest to Posttest of Accuracy, for Groups (Verbal-Visual, Visual and control), Age and Gender.

Tasks Completed

The four-way ANOVA yielded main effects of Session, F(1,263)=201.03, p<.001, $\eta p^2=.43$, and Training Group, F(2,263)=7.01, p<.001, $\eta p^2=.05$, indicating that participants completed more tasks after the intervention (0.7 vs. 1.7) and that children in the verbal-visual training group completed the most tasks (1.4), the control group the fewest (0.9), while the Vis group fell in between (1.3). More importantly, however, Session interacted with Training Group, F(2,263)=10.91, p<.001, $\eta p^2=.08$, and was involved in a significant three-way interaction including Session, Training Group, and Age Group, F(4,263)=3.05, p=.018, $\eta p^2=.04$. The latter was due to that the interaction of Session and Training Group was significant only in the youngest group, F(2,104)=12.84, p<.001, $\eta p^2=.20$, but did not reach significance in the two older age groups, F(2,93)=2.24, p=.11, and F(2,66)=2.33, p=.10, respectively. The effect in the youngest group showed that Session had no effect in the control group, p = .4, but improved performance in both intervention groups, ps < .001.

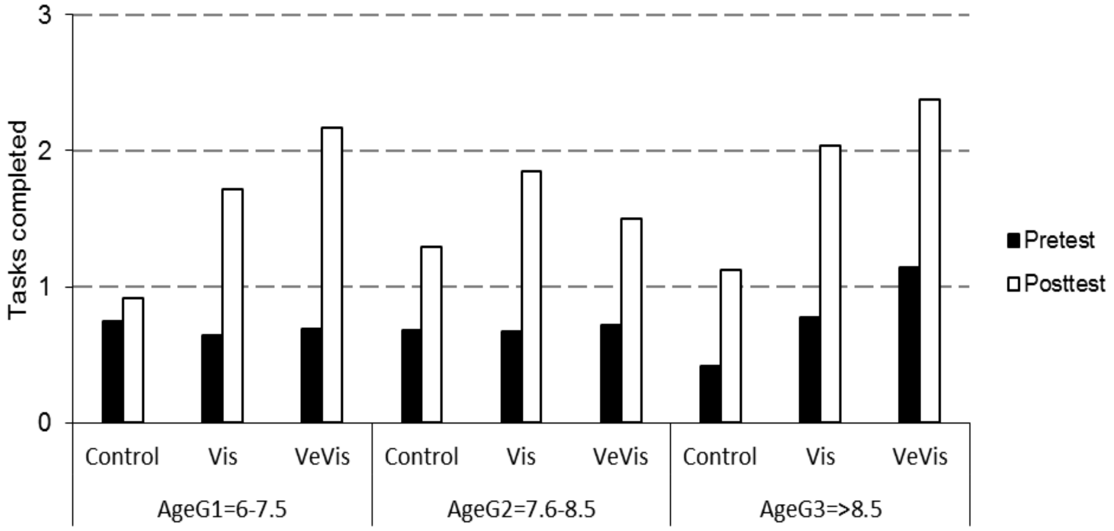


Fig 5
Changes from Pretest to Posttest of Tasks Completed (TC) scores for Groups (Verbal-Visual, Visual and Control), and Age.

Discussion

The aim of the present study was to evaluate the potential effect of VSPS interventions with an experimental intervention. To this end, we compared two training modalities: verbal and visual hints vs. visual hints only. We expected that children who received training in one of these two groups would improve more than children in the control group, considered that VeVis training might be more effective than Vis training, and we explored whether training effects might be mediated by age and/or gender. With regard to the intervention effect on VSPS, our results are consistent with recent studies on dynamic assessment (e.g., Resing & Elliott, 2011). Both VeVis and Vis training boosted performance in a VSPS-sensitive task from pre- to posttest as compared to the control group. This provides strong evidence that VSPSs can be improved by relative simple forms of training, and supports arguments in favor of more dynamic testing methods to reveal the true potential of cognitive skills, at least in children.

Surprisingly, the outcome pattern suggests that, if anything, Vis training provides more benefits than VeVis training. From a dual-coding perspective (Mayer, 2005), this could be taken to suggest that our visual cues were particularly effective, and more effective than the verbal cues—perhaps because spatial information is particularly suited for visual processing, and vice versa (Paivio, 1986). This is of particular importance for the training of students with hearing impairments or langue difficulties (Cortiella, 2011;

Dye, Hauser & Bavelier, 2008; Paul, 2007). However, it is also possible that the type of verbal prompts used in the present study (which were inspired by Resing & Elliott, 2011) were not appropriate for this task and/or the subjects being tested. For example, in Resing and Elliott's analogy task, self-evaluation of one's response is not as straightforward as in solving puzzles. In puzzle solving, children do not necessarily rely on extra cues to evaluate whether the task is completed, and it may be easier to see how to modify one's actions. Thus, prompts such "Are you sure that pieces should be here, please check, or which changes do you see" might be too simple or inappropriate and might have distracted and interfered with learning more than they helped. Furthermore, is it well known that outcome can be highly dependent on the variability of expertise and experience of the assessors (Caffrey et al., 2008; Haywood & Lidz, 2007; Jeltova, et al., 2007). Moreover, judging the necessity of the most suitable degree of prompting is difficult and subjective, which might explain part of the problem with verbal cues. Besides, two training sessions may not have been enough to demonstrate reliable intervention effects (Uttal et al., 2012). In future studies, a direct contrast of verbal-only and visual-only cues, together with extended training, might increase our insight into these possibilities.

A limitation of our study method is that it does not allow for more detailed analyses is of the components underlying VSPSs (Mathewson, 1999). A potential solution might be computerized task versions, which might allow for the independent assessment of sub-skills, such as imagery or mental rotation. Such an approach would also address another limitation that relates to the experimental material we used. Note that solving a puzzle depends not only on cognitive skills, which were the target of our study, but also on motor skills (e.g., Grissmer et al., 2010), which may or may not be sensitive to training. Another concern is data recording; reaction times were recorded by having the experimenter click on a key as soon as the child started and completed the task. Obviously, the accuracy of this measure depends on the attention the experimenter devoted to the task. Again, computerized versions would help addressing this problem and improve accuracy and reliability (e.g. De Beer, 2005; Shamir, Tzuriel & Guy, 2007; Resing, Steijn, Xenidou-Dervou, Stevenson & Elliott, 2011). Moreover, they would have the advantage of increasing the game-like character of the test and allow for a swifter and more systematic presentation of feedback.

Another concern is the distinction between performance and learning. Soderstrom and Bjork (in press) have argued that it is only performance that is measurable (in terms of improvement from pre- to posttest) while learning must be inferred from performance. They point out "there are many instances where learning occurs but performance in the short term doesn't improve, and there are instances where performance improves, but little learning seems to happen in the long term." From that perspective, all we can say is that our interventions improved performance, but we cannot or should be sure whether this was due to actual learning. Assessing learning proper would require a follow-up test, which should be included in further studies.

With regard to age as a potentially mediating factor, our results support the findings of Peter, Glück, and Beiglböck (2010) that children younger than 7.5 years old are capable of creating symbolic representations and use spatial relations. The intervention did not affect all outcome measures alike and they were mediated by age and to some degree by gender. Both motivational and cognitive measures suggest that specific training effects are restricted to, or at least drastically stronger in older children, that is, children at an age of 7.6 years or older. The only exception to this trend is the Tasks Completed score, which showed the only specific training effect in the youngest group. The fact that the three dependent variables we were considering were not equally affected by age makes it difficult to rule out possible effects in even younger children. However, a closer look at the outcome pattern suggests that this is not so much due to a lack of training effects in the older groups but a reflection of the fact that in these older groups even the control condition shows a strong improvement. This issue was addressed in the review of Grigorenko and Sternberg (1998), who found that approximately 30% of the investigated children improved to a statistically significant extent simply because of retesting. In terms of gender differences, our findings do not fit with those of Tzuriel and Egozi (2010), who found a gender difference at baseline while we did not. A specific result was that in the oldest group girls were particularly benefiting from training. This might be because girls are or became more interested in making such puzzles than boys.

Taken altogether, our study provides evidence for the efficiency and benefits of interventions targeting VSPCs. The success of such interventions does not seem to be bounded by age or gender, and it seems that visual cues are particularly effective. At the same time, we consider our findings preliminary and note that more research on the functional implications of different outcome measures, on suitable verbal cues, ideally with computerized versions is necessary.

Chapter 3

Face-to-face versus computer-based visuospatial training in children

Ellahe Chabani & Bernhard Hommel
Manuscript submitted for publication

Abstract

Growing evidence highlights the importance of visual-spatial processing skills (VSPS) but teaching and training of these skills at early age in schools remain understudied. In this study, we compared the effectiveness of an experimental computerized VSPS-enhancing approach, a conventional face-to-face training regime, and a non-training control group in improving performance in a tangram game. We also compared the effect of training on a simple transformations test tapping into visual memory and on a complex transformations test involving mental rotation. Findings suggest that both computer-based and face-to-face training can reliably improve VSPS and that the two training methods are equally effective. Most positive findings were restricted to performance on the complex transformations test.

Keywords: Visuospatial skills; visualization; mental rotation; computer based instruction; visual cues.

Introduction

Over the past two decades, various abilities and skills have become increasingly valued in schools, including visual spatial processing skills (VSPS). The continued growths of multimedia that rely heavily on VSPS have added further emphases to the issue. Broadly speaking, VSPS refer to the ability of carry out processes responsible for generating, retaining, retrieving, and transforming visual images (i.e., non-linguistic information; e.g., Linn & Petersen, 1985; Lohman, 1993). Among other things, these skills play an important role for performance in the STEM (science, technology, engineering, and mathematics) domain (e.g. Lubinski, 2010; Miller & Halpern, 2013; Sorby, Casey, Veurink & Dulaney, 2013; Uttal et al., 2012; Wai, Lubinski & Benbow, 2009) and in the acquisition of related academic skills (e.g., math, reading, or writing; e.g., Assel et al., 2003; Cheng & Mix, 2012). Yet, it has frequently been observed that VSPS at school is not just under-supported but under-valued (National Council of Teachers of Mathematics, 2010; National Research Council, 2006; Webb, Lubinski & Benbow, 2007). The Learning to Think Spatially (2006) report has emphasized the need of identifying and developing methods and procedures that support and enhance VSPS at early ages, to consider how to integrate VSPS-related performance into the curriculum in more general ways, and to think about how and when the use of new technologies with young children can lead to improvement. Recently, Krakowski, Ratliff, Gomez, and Levine (2010) from the Spatial Intelligence and Learning Center reported that important hindering factors are teachers' lack of awareness of the VSPS concept, and lack of knowledge about how to teach VSPS and how to integrate that teaching into their curriculum, difficulties that go hand in hand with the lack of adapted training instruments or materials, in particular for school age children.

While addressing such calls will require considerable concerted efforts, the present project aimed to take a preliminary, first step in this direction and set the stage for further, more extended and differentiated investigations. To this end, we have developed a tangram based game (TangSolver) that we think can support VSPS enhancement at earlier ages and facilitate the integration of these skills into the school curriculum. In the present study, our main focus was to evaluate the efficacy of traditional training (face to face) employing multimodal instruction (verbal and visual cues) to computerized training that relies on visual-only cues (image scaffolding).

Malleability of VSPS

VSPS involve the process of perceiving, transforming, and recreating different aspects the visual and spatial world (e.g., Linn & Petersen, 1985; Lohman, 1993). The importance of VSPS has been widely acknowledged, however, a great deal of confusion regarding the underlying components, definition, and the classification of these remain (e.g., Carroll, 1993; Eliot & Smith, 1983; Lohman, 1988; Kaufman, 2007; Sutton & Williams, 2007). These skills and their development have been attributed to a number of variables, including cognitive development, spatial experiences, aptitude, age, and gender (e.g., Hegarty & Waller, 2006).

Numerous researchers have asked whether these skills can improve as a result of training and experience. Does the training in particular spatial tasks transfers to other spatial tasks, is there a critical or sensitive period for influencing the development of VSPS, and what are the major determinants of individual differences in response to training (e.g., gender, age, mental rotation capacity)? Recently, Uttal, Meadow, Tipton, Hand, Alden, and Warren (2012) have carried out a meta-analysis of over 217 studies on VSPS to identify possible training moderators and the magnitude, durability, and generalizability of training effects. The analysis confirmed the theoretical and practical importance of VPSP at any age and indicated that they can be significantly improved by even short training procedures. The authors suggest that adding spatially-challenging activities to standard courses can further improve VSPS and can lead to transfer to other spatially-demanding tasks. They also highlight the relevance of videogames for improving spatial skills: “playing active games has the potential to enhance spatial thinking substantially, even when compared to a strong control group” (Uttal et al., 2012; p. 54). Importantly for our present purposes, the authors also emphasize the lack of studies in younger children (four out of 217 studies investigated children below 13 years), which contrasts with the large amounts of studies involving adolescent and adults in STEM education.

Importance of teaching and training VSPS at early age

Recent findings suggest that practicing VSPS is not just important for STEM education, as indicated by the bulk of research considered by Uttal et al., (2012) and even more in recent studies (Miller & Halpern, 2013; Sorby, Casey, Veurink & Dulaney, 2013), but it is also highly relevant for younger learners. This is because VSPS develops through lifetime and as emerging deficits in one sub-skill or ability can often be compensated by excellence in others (e.g., Van Garderen & Montague, 2003). Mastery and understanding scale, quantity, direction, interval, size, shape recognition, and sequence of number or letter ordering are the basis for comprehending arty and academic topics (math, arithmetic skills, reading, and writing) that rely greatly on VSPS (e.g., Aunio & Niemivirta, 2010; Cheng & Mix, 2012; Holmes, Adams & Hamilton, 2008; Levine, Kwon, Huttenlocher, Ratliff & Dietz, 2009; Newcombe & Frick, 2010; Passolunghi & Mammuarella 2010; Vasilyeva & Huttenlocher, 2004). Considering that developing children’s spatial thinking at young age improves symbolic and numerical representation, it seems important to aim for the earliest-possible training regimes.

Furthermore, in a world of constant change, our “cyber children” are growing up immersed in an increasingly visually oriented and technology-driven society. This suggests that mere exposure to digital multimedia and everyday living is sufficient to impact cognitive development and there is evidence that various interventions can enhance the development of VSPS in particular (Blazhenkova & Kozhevnikov, 2009; Kaufman, Steinbügl, Dünser & Glück, 2005; Wright et al., 2008; Uttal et al., 2012). Indeed, it can be argued that individual and collective success in our technological era will depend largely on VPSP that include visualization, speed in grasping the big picture, thinking graphically, visual memory, and pattern-finding (Carr, 2008, 2010; Newcombe & Frick, 2010; Pink, 2005). In short, “Literacy in the future will include the ability to read both text and image, together and separately. The creative use of images is no longer an added extra for a text but a vital link in the cognitive processing of information and essential in the creation of sound pedagogy” (Sankey, 2002, p.1). If so, students with underdeveloped VSPS might increasingly lag behind their peers.

The integration of VSPS-enhancing activities into standard courses remains limited, while there is strong evidence that VSPS-related skills do not need to be taught formally. For instance, playing videogames such as Tetris has been found to increase visual-spatial attention and a number of other spatial skills (Gee, 2007; Green & Bavelier, 2003, 2006; Spence & Feng, 2010; Rafi, Samsudin & Said, 2008). In addition, studies on games and instructional software as viable medium for learning have provided solid ground for making use of them in the classroom (e.g., Doering & Veletsianos, 2009; Klopfer, Osterweil & Salen, 2009). We argue that an optimal solution might be game-based classroom training, as possible with the tangram game. Although uncountable numbers of physical and computerized tangram games exist, these are not designed for the testing and training of particular VSPS sub-skills, which motivated us to develop the TangSolver test.

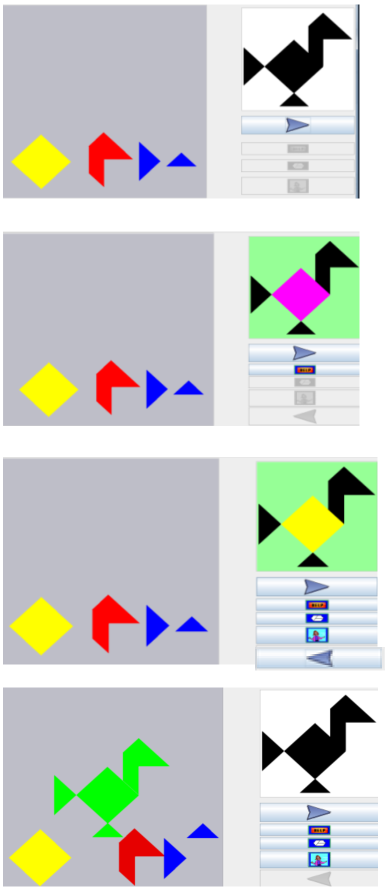
Development of VSPS’s game based training: TangSolver

The Chinese Tangram puzzle game requires assembling seven geometrical pieces to form a bigger shape or figure. Such a game taps into the processing of shapes and relationships between shapes (e.g., between two triangles that make a square) and has been used to evaluate various visual spatial skills or diagnostic for visuospatial problem solving abilities (Bohning & Althouse, 1997; Crawford, 2002; Ford, 2003; Foster, 2007; Gardner, 1974; Slocum, et al., 2003; Van Hiele, 1999). As shown by various authors (e.g., Lee, Lee & Collins, 2009; Siew & Abdullah, 2012; Yang & Chen, 2010), and by Van Hiele (1999) in particular, the solution of geometrical puzzles relies on and promotes skills in handling qualitative spatial relations between elements in visual scenes and categorical representations to reason about shapes or the space they encode—VSPS that is.

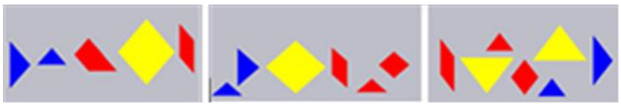
While the definitions and assumed components of VSPS vary among authors, one widely accepted differentiation stems from Linn and Petersen (1985), who divide VSPS into spatial perception, spatial visualization, and mental rotation. According to these authors, spatial perception is the ability “... to determine spatial relationships with respect to the orientation of their own bodies, in spite of distracting information”, spatial visualization is “the ability in which complex spatial information are manipulated when several stages are needed for solving the tasks”, and mental rotation is the ability to mentally rotate two- or three-dimensional figures as quickly and accurately as possible. In the development of TangSolver we focused on spatial visualization and mental rotation.

a) Spatial visualization

According to Linn & Petersen (1985), spatial visualization skills involve multi-step manipulations of spatially presented information, which require analysis of the relationship between forms and different spatial representations. Typically, learner's spatial visualization performance is related to the focus of attention in shape characteristics, such as size, contour, lines, space, or color (Gibson, 1969). To manipulate size and complexity of forms, we used the seven classical geometric forms and combinations thereof (e.g., a triangle and a square), which we will refer to as master pieces (MPs). The same shape could be constructed by assembling 4 MPs, 5 MPs, 6 MPs or 7 MPs, which resulted in four difficulty levels (L1: 4 MPs, L2: 5 MPs, L3: 6 MPs, and L4: 7 MPs; see fig. 1 and fig.2). Another important characteristic of shapes is color (Gibson, 1969). We used monochrome MPs for the test items and colored MPs (red, yellow, and blue) for the training items. Theoretically, we assumed that children who have better developed spatial visualization would demonstrate better performance at baseline. As training MPs were colored, we thought that children who have better developed analogical reasoning capacity would recognize better how different master pieces were either combined or divided, and this would lead to more improvement.



Partial screenshots of 5MPs , 6 MPs and 7 MPs of this item.

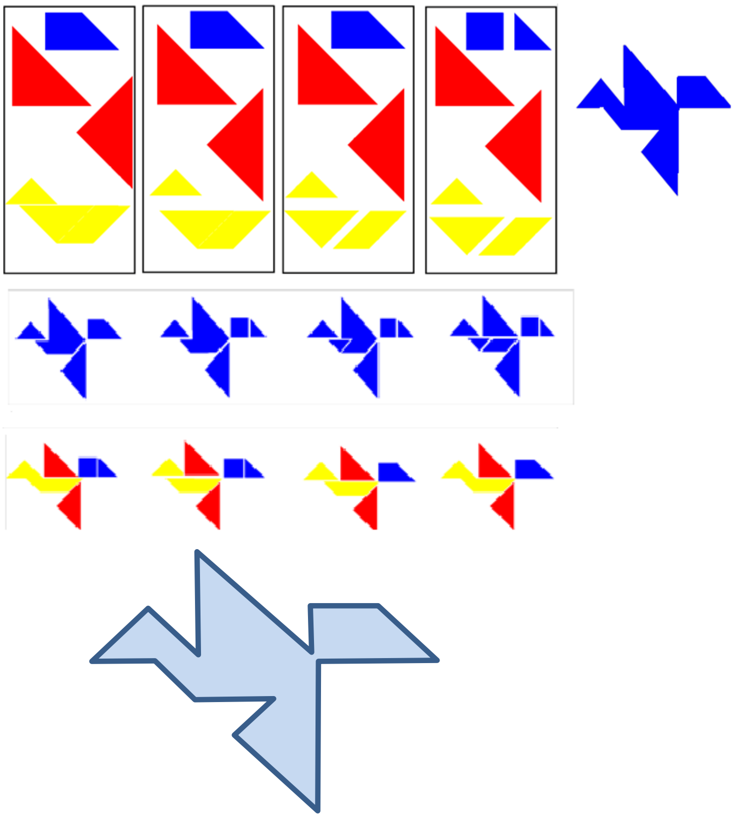


Monochrome visual cue (MVC)
Master pieces are highlighted step by step in an unrelated color than master pieces in use.
This visual cue was provided automatically after 1 min of unsuccessful try. After that the flowing visual cues were enabled and the child could active as much as necessary.

Color visual cue (CVC) -master pieces are highlighted step by step in the same color of master pieces in use.

Back and forward arrow
Allows backward and forward to a lower/higher level or only checking how MPs were combined/splintered.
Out-line- the shape is presented on the working spaces that allow the drag and drop on the top of

Fig 1.
Screenshots of the Computer training and different visual cues.



The four boards with 4 MPs, 5 MPs, 6 MPs and 7 MPs of an item. MPs were made with sticky colour plastic and were placed on fixed position on a white board.

Monochrome visual cue (MVC) – solution cadre was presented for 10 sec.

Color visual cue (CVC) - solution cadre was presented for 10 sec.

Out-line- A big shape was presented, thus MPs could be put on top of the shape.

Back and forward, the child could take each of the board (lower/higher level) and see how MPs were

Verbal prompts: teacher based instruction i.e., are you sure that should be here? Please have a look at the previous board.

Fig 2.
An example of Manipulative material used in Face to Face training

b) Mental rotation

The second VSPS sub-skill we considered was mental rotation, which involves the ability to rapidly and accurately rotate mentally two or three-dimensional figures (Linn & Petersen, 1985). Mental rotation performance correlates with level in math, geometry, and reading (Dehaene, Cohen, Sigman & Vinckier, 2005; Dehaene, 2009; Hegarty & Kozhevinkov, 1999). In typical mental rotation tasks (e.g., Shepard & Metzler, 1971; Vandenberg & Kuse, 1978), individual are asked to match pairs of shapes that differ in orientation (mirrored vs. non-mirrored, or rotated), with speed and accuracy being the main measures. Some authors have argued that different test items might be prone to different solution strategies (e.g., Cherney & Neff, 2004; Geiser, Lehmann & Eid, 2006; Glück & Fitting, 2003): test items can often be solved by holistic matching (involving mental rotation) or by means of feature comparison (an analytic step-by-step strategy rather than one relying on mental rotation proper)—often with better performance related to the former than to the latter.

To assess both of these strategies, we developed two subtests. One did not require any mental rotation but could easily be solved by media dragging and dropping MPs—we will refer to this version as "simple transformations test" (STT; see fig 3). The other did require mental rotation: an initial flip or rotation of MPs followed by drag and drop was needed—to this version we will refer to as "complex transformations test" (CTT; see fig 3). In a nutshell, the former taps more into visual memory while the latter assesses mental rotation capacity proper. Theoretically, it can be expected that performance differences between children with lower and children with higher mental rotation capacity be more pronounced in the complex-transformations task than in the simple-transformations task.

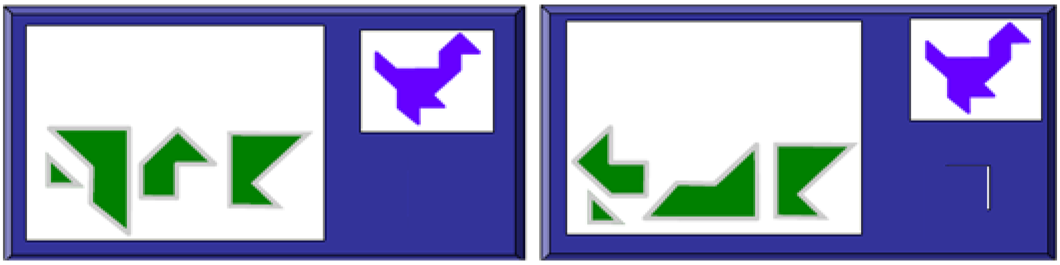


Fig. 3
An illustration of Simple transformation test & Complex transformation test of item with 4 MPs.

Instructional software vs. traditional (face-to-face) instruction

An extensive body of research has promoted the use of instructional software in the classroom (e.g., Doering & Veletsianos, 2009; Klopfer, Osterweil & Salen, 2009) but the debate about the effectiveness of instructional software as compared to traditional instruction is still open (e.g., Cheung & Slavin, 2012; Fleischer, 2012; Tamim et al., 2011; see www.edutopia.org). This debate is partly fueled by insufficient software-induced improvement in particular content areas (mathematics, reading, etc.) and the expectation that instructional software might eventually replace teachers altogether. However, as pointed by Ross, Morrison, and Lowther (2010), "educational technology is not a homogeneous 'intervention' but a broad variety of modalities, tools, and strategies for learning. Its effectiveness, therefore, depends on how well it helps teachers and students achieve the desired instructional goals" (p.19). Indeed, the intent of most instructional software is to maximize student's growth and individual success by meeting each student's needs, not to replace teachers. Thus, the overarching goal of successful education cannot be to conceive of instructional software and traditional instruction as mutually exclusive alternatives but to create successful learning experiences that facilitate learning and transfer of knowledge (e.g., Archer & Hughes, 2011; Fadel, 2008; Picciano, 2009).

Although our study will not be able to close the debate, we investigated whether and to what degree visuospatial processing skills in young children can be enhanced, and which method might be best suited. In particular, we compared a custom-made, computerized visuospatial training program to the same program delivered in the traditional way (face to face). Even though there are reasons to assume that children might benefit from VSPS training (e.g., Lee, Lee & Collins, 2009; Siew & Abdullah, 2012; Yang & Chen, 2010; Uttal, et al., 2012), to date there is no evidence which method might be most successful in reaching that goal.

Multimodal instruction vs. visual cues

Arguably, the kind of instruction is as important for successful learning as the medium being used, in particular in the context of VSPS enhancement. Unfortunately, however, individual differences between learners make it difficult to determine which kind of medium might be the most suitable. Various authors have suggested to give consideration to individual information processing differences and their particular strength or weakness regarding the given task (e.g., Gardner, 1983; Omrod, 2008; Pashler, McDaniel, Rohrer & Bjork, 2008). According to Gardner, everyone possesses all forms of intelligence or capacity (i.e., musical, interpersonal, spatial-visual and linguistic) but to different degrees. One individual might thus have high verbal/linguistic capacity, which would suggest providing verbal information rather than graphs or pictures, while another with high visual intelligence would strongly benefit from visual material. Likewise, learners with language-based disabilities are likely to prefer visual over verbal communication (Newhall, 2012; Smith & Tyler, 2009). Hence, “different modes of instruction might be optimal for different people because different modes of presentation exploit the specific perceptual and cognitive strengths of different individuals” (Pashler et al., 2008, p.109).

Even though the development of a fully individualized learning program was beyond the scope of the current study, we want to emphasize that our comparison of face-to-face instruction, which combined verbal and visual information, and computer-based instruction, which relied on visual-only cues, implied a comparison of multimodal and unimodal instruction means. This is important because some theories suggest that the efficiency of multimodal and unimodal instruction may differ in principle. For instance, dual coding theory assumes that information is processed along two separate processing routes, one dedicated to verbal information and another to nonverbal, visual information (Paivio, 1986). This account has been extended to literacy, written composition, spelling, of reading comprehension (e.g., Kintsch, 2004; Krasny, Sadoski & Paivio, 2007; Krasny & Sadoski, 2008; Sadoski & Paivio, 2001, 2004; Sadoski, Willson, Holcomb & Boulware-Gooden, 2005). It would suggest that multimodal (verbal/visual) information might lead to better learning because two rather than one system are activated. Other accounts allow for different predictions. For instance, the cognitive theory of multimedia learning (Mayer, 2001, 2009; Mayer & Moreno, 2003) suggests that learning occurs when relevant information can be selected and organized into a coherent representation and integrated into the existing knowledge base. Given that information needs to pass the learner's working memory, which is considered a limited cognitive resource, less information may be more, as too much information can easily exhaust working memory capacity. If so, restricting learning cues to just one modality might be beneficial. However, while visual cues have been studied in the context of learning with text and pictures for comprehension (Anglin et al., 2004; Eitel et al., 2013; Fletcher & Tobias, 2005; Hegarty & Just, 1993; Hegarty, 2011; Schnotz, 2005), to our knowledge there is no study that compared visual-only to multimodal cues.

Typically, visual cuing refers to "the addition of design elements that direct the learner's attention to important aspects of the learning material" (Plass, Homer & Hayward, 2009, p. 39). In tasks such as puzzle construction, visual cuing might consist in simply presenting the solution or by attracting attention to the critical part (e.g., by increasing the luminance of relevant parts in the visual display). The former technique can be considered to relate to global visual memory, while the latter refers to spatial visual memory, which has been aimed at in the development of TangSolver. Accordingly, our study does not speak to the relative efficiency of the two cuing techniques.

Given the conflicting theoretical account, it was difficult to predict the impact of training modality. According to dual-coding theory, it would make sense to assume that the typical learner would benefit more from traditional (multimodal) instruction (Fadel, 2008) as compared to the unimodal computer-based instruction. However, cognitive theory seems to make the opposite prediction, as our unimodal computer-based instruction might be less likely to overload working memory.

Overview of main questions

In sum, our guiding questions were:

i. Will the two experimental groups show better performance than the control group after the training? Even though there is some evidence that VSPS can improve through training (Uttal et al., 2012), more evidence is necessary, especially with regard to our new, custom-made program.

ii. Will the two training modalities (face-to-face versus computer-based) differ in efficiency, will thus one training regime produce stronger improvement than the other? As pointed out, different theoretical approaches suggest different directions into which such a difference might go.

iii. Will training effects be visible in simple and complex-transformations tests alike (and, thus, rather non-specific) or be stronger in the more visually demanding complex-transformations test?

Note that the current study does not aim to reconcile different conceptions of VSPS but, rather, advocate the integrating assessment and training of VSPS in primary schools. Obviously, TangSolver is just a means to an end in the process of promoting the assessment, and training of VSPS within standard courses. It is hoped that implementing such application in school promotes teaching and training VSPS-related skills in young children and inspires researcher to further develop assessment and training procedures.

Method

Participants

A total of 104 typical developing children (48 boys, mean age=8.5 years +/- 9.9 months; range 7-10.5 months; 56 girls, mean age=8.5 years +/- 8.9 months; range 7-10.5 months) from a number of standard primary schools in the Netherlands was tested. Participants had no specific academic, learning or behaviour problems and came from diverse ethnic backgrounds and socio-economic classes.

Design

The study involved a pre-test, two training sessions, and a post-test, with two experimental training groups and a control group. Children were matched as much as possible for gender and age and were randomly assigned to the Computer training (n=41), Face To Face training (n=42), and Control group (n=21) with a ratio of 2:2:1 respectively. This unequal RCT ratio was chosen because of time constraints. It is assumed that only ratios of 3:1 or more are likely to reduce the power of a study significantly (Pocock, 1995) and according to Torgerson and Campbell, (1997) oversampling of experimental groups (below the critical ratio of 3:1) in evaluations of new learning technologies is not problematic.

Procedure and material

Children were tested and trained during school time in separate rooms at their own school by three psychology master students. For the computer training group, the respective software was installed on the school's PCs. Testing and training sessions were scheduled weekly within respect to school constraints, and each session took approximately 35-40 minutes over a period of three months.

Pretest and posttest. During the first and last session, all children's VSPS were assessed by means of the TangSolver test. The TangSolver[1] application that served for both assessment and training of participants' VSPS is composed of three layers (TangSolver-Try-out, TangSolver Test, TangSolver Training). The application contains features that support interaction via computer mouse; it can be run on PC or Mac and requires installation of Java's virtual machine, which is freely available. The screen consists of two windows: a smaller "model window" that shows the required shape and a "working space" in which participants can drag and drop MPs, and rotate or flip them by means of the mouse (see fig. 1).

Before starting the pre-test all children received training on how to drag, rotate and flip with the computer mouse by means of the TangSolver-Try-out. The try-out comprises of three parts requiring

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[1] The application used can be obtained by request from the first author (echabani@gmail.com).

dragging, rotating, and flipping, respectively; it was not time limited and participants could practice until the mouse manipulation was satisfactory. To evaluate children's VSPS before and after training in a standardized way (without any feedback or guidance) we used the TangSolver Test. TangSolver Test is composed of two subtests (described above), a simple transformations test (STT) and a complex transformations test (CTT) (see fig 3). Each subtest contained eight items. The items were similar in terms of difficulty with two items at each of the four difficulty levels (2x4MP, 2x5MP, 2x6MP, and 2x7MP). None of the STT items required mental rotation, all solutions could be achieved by dragging and dropping MPs (see fig 3). In contrast, CTT items did require mental rotation; they called for an initial flip or rotation of MPs followed by drag and drop (see fig 3).

The pre-test and the post-test were time-limited (max time of 1:30 min/item). However, children who were quick (task completion <= 1:30) could make use of the "Next" bottom press, which displayed the following item. For children who were slow (task completion > 1:30), a window asking "Do you need more time? Yes - No" appeared, which allowed them one extra minute, after which the next item appeared automatically. Each test took 10-20 min, depending on how much extra time was used.

Cronbach's alpha for the 16 items of pre- and post-test task completed scores based in the current sample (n=104) was .73, and .77, respectively. The internal consistency for the three groups (Computer, Face to Face and Control) was .70, .82, and .70 at pre-test and .57, .81, and .79 at the post-test, respectively—indicating rather high scale reliability. The test-retest reliability in the control group (n=21), who did not receive any training and completed the post-test at least 6 weeks after the pre-test, was .84, with a correlation coefficient of .8, indicating sufficient stability over the time.

Training sessions. The aim of the training was to support the participant when s/he could not solve the problem independently. The two training modalities we considered were Computer and Face to Face, while children in the Control group were engaged in discussions or drawing tasks. The two types of training differed in respect to the material used (computer vs. manipulative material) and in the manner children were tutored. The former practiced on computers and the guidance was exclusively through different visual cues (see fig. 1). The Face to Face groups practiced with manipulative material which required the presence of one assessor per child and the guidance was through visual hints and verbal prompts (teacher based instruction i.e., are you sure that should be here? Please have a look at the previous board) (see fig. 2).

There were two training sessions and during each session the child was trained on three items. Both types of training used six different items similar to those used in the pre/post-test at each of the four difficulty levels; training started with the easiest level (4 MPs) and progressed to the most difficult level (7 MPs). The child could start on a new level or item only when the task was completed successfully at the previous level. Therefore, neither the time for completing the task nor the instruction was limited.

Measures and scoring. Although the range of outcomes measures provided by the application is extensive, in the current study VSPS were scored according to three criteria for each subtests (simple and complex transformation test). The *Tasks-completed score* counted the number of items (max 8 pts.). *Accuracy scores* considers partial task performance by referring to the number of MPs correctly placed in incomplete puzzles (max 44 pts). For instance, in a puzzle with 7 MPs, the range is between 6 MPs correct (85.7%) to 2 MPs correct (28.6%), irrespective of the fact that the entire range would be associated with a "0" score in the binary Tasks-completed score. Finally, the *Time on task* score refers to the total time spent on the test, which we took to reflect individual differences in processing speed (Jensen, 1998). As the variance in time limited tests does not accurately reflect processing speed (Karweit, 1984), we calculated the score by dividing the total time (sec) spent on successful tasks by the number of successful tasks.

Results

Our main questions were whether and how training would change performance from pre- to post-test in "simple" or "complex" transformations tests and the two training groups (Computer vs. Face to Face), and whether these changes would be more pronounced in the experimental groups than the control group. To identify these effects, we analysed each of the three dependent measures (Accuracy, Tasks Completed scores and Time-on-task) by means of three-way ANOVAs for repeated measures with Session (pre- and post-test) and Test (simple transformations test (STT) vs. complex transformations test (CTT)), as within-participants factors and Training Group (Computer, Face to Face and Control) as between-participants factor. The theoretically most interesting result pattern would consist of a three-way interaction involving Session. Higher-order interactions were disentangled by means of independent samples t-tests, and effect sizes were assessed by means of Cohen's d (where effect sizes of .20 are considered small, of .50 as medium, and of .80 or more as large). The analysis of gender effects was beyond the scope of this study but to inform future studies, we will provide gender-specific descriptive statistics for each of the variables. An alpha level of .05 was used for all statistical tests.

Before assessing the effect of training, we checked whether the three training groups were initially comparable. To do so, we entered the three pre-test scores (Accuracy, Tasks Completed and Time on Task) of the two subtests (STT and CTT) into one-way ANOVAs within Training Group (Computer, Face to Face and Control) as factor. There were no statistically significant group effects for either STT (p= .9, p=.8, p=.6 for Accuracy, Tasks Completed, and Time on Task, respectively) or CTT (p= .3, p=.8, p=.2, respectively).

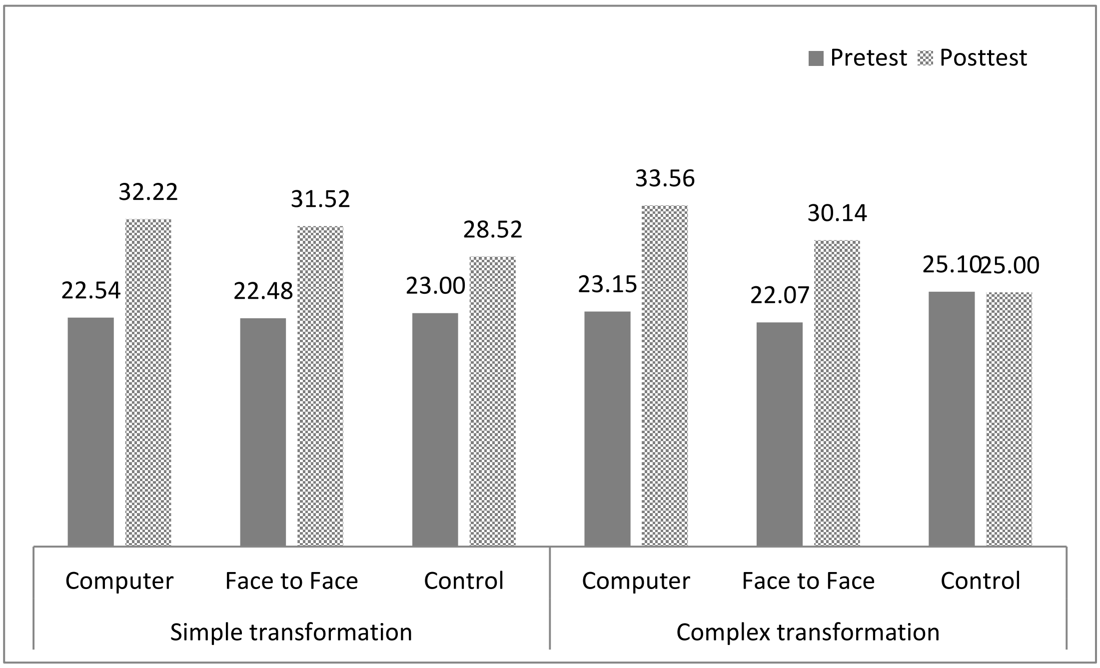
Accuracy

The three-way ANOVA yielded a main effect of Session ($F(1,101)=46.78$, $p<.001$, $\eta p^2=.32$), indicating that participants improved from the first to the last session. The interaction effect of Session by Group ($F(1,101)=3.8$, $p=.026$, $\eta p^2=.070$) showed the three training groups improved differently however. A one-way ANOVA of gain scores (posttest minus pretest) for each Test (STT, CTT) revealed no significant differences between groups ($p=.37$) in STT but a significant effect in CTT ($F(2,101)=4.42$, $p=.01$ $\eta p^2=.08$). The latter was due to that performance in the Control group differed from that in both the Computer group (t(60)=3.24, p=.002, d=.087) and the Face to Face group (t(61)=2.03, p=.046, d=-.56), while performance was comparable in the Computer and the Face to Face group (p=.4). As can be seen in fig. 4, the control group improved on the simple transformations test that relies on memory while in the complex transformations test involving mental rotation only the two training groups improved. This highlights the importance of training in a mental rotation task, irrespective of training modality.

Table1.
Descriptive Statistics of Accuracy, of Simple and Complex Transformation Tests (Pre- and Post-test), per Training Group (Computer, Face to Face and Control) and by gender.

			Simple Transformation test				***Complex Transformation test***			
			Pretest		Posttest		Pretest		Posttest	
		N	M	SD	M	SD	M	SD	M	SD
Computer	Male	17	22.53	8.86	37.12	4.50	24.12	7.90	35.59	7.54
	Female	24	22.54	7.10	28.75	10.77	22.46	8.68	32.13	9.07
	Total	41	22.54	7.77	32.22	9.60	23.15	8.31	33.56	8.55
Face to Face	Male	21	24.14	7.09	32.33	7.12	23.10	7.84	30.86	11.65
	Female	21	20.81	6.22	30.71	9.93	21.05	7.57	29.43	11.04
	Total	42	22.48	6.80	31.52	8.57	22.07	7.68	30.14	11.24
Control	Male	10	22.00	8.68	28.50	5.02	24.30	5.81	26.20	17.03
	Female	11	23.91	9.17	28.55	8.00	25.82	7.00	23.91	6.04
	Total	21	23.00	8.77	28.52	6.58	25.10	6.35	25.00	12.25

Fig. 4
Accuracy (max. 44 pts) of Pre and Post-test by Training Groups (Computer, Face to Face and Control) of Simple and Complex Transformation Tests.



Tasks completed

The three-way ANOVA yielded main effects of Session (F(1,101)=60.62, p<.001, ηp²=.37), indicating that participant improved from the first to the last session, and of Test (F(1,101)=48.48, p<.001, ηp²=.33), showing that performance was better on STT than on CTT. The interaction effect of Session by Training group (F(1,101)=3.22, p=.044, ηp²=.060) indicated that the three training groups improved differently. A one-way ANOVA of the gain score of each test revealed that the significant difference between groups were again on CTT (F(2,101)=4.7, p=.01, ηp²=.085) but not on STT (p=.4). Performance on CTT differed between Computer (1.9) and Control groups (9.14), (t(60)=57, p=.003, d=0.85), and between Face to Face (2.07) and Control groups (.14), (t(60)=-2.29, p=.02., d=-.62), while the two training groups did not differ—even though numerically the Computer group showed better performance (see fig. 5). That is, the two training modalities were about equally efficient.

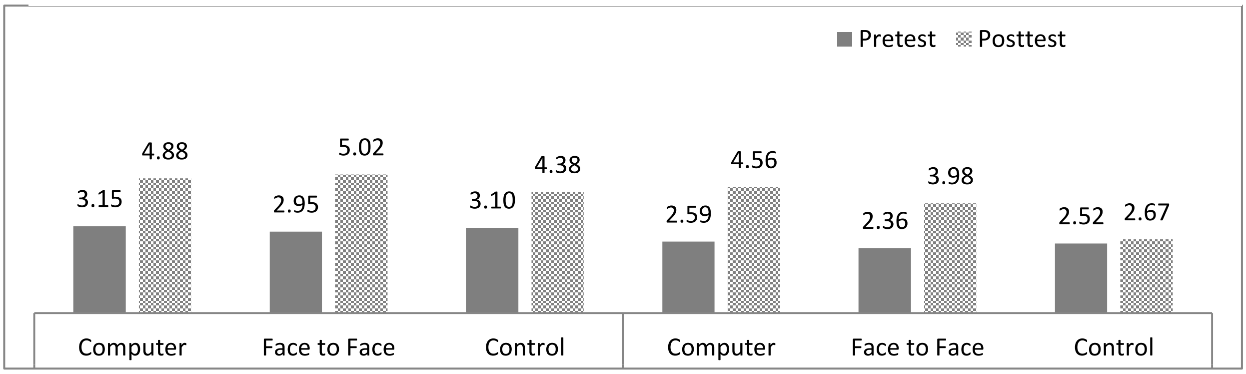
Table2.

Descriptive Statistics of Tasks Completed, of Simple and Complex Transformation Tests (Pre- and Post-test), per Training Group (Computer, Face to Face and Control) and by gender.

			Simple Transformation test				***Complex Transformation test***			
			Pretest		Posttest		Pretest		Posttest	
		N	M	SD	M	SD	M	SD	M	SD
Computer	Male	17	3.41	1.62	5.88	1.05	2.88	1.45	4.82	1.47
	Female	24	2.96	1.40	4.17	1.88	2.38	1.71	4.38	1.53
	Total	41	3.15	1.49	4.88	1.79	2.59	1.61	4.56	1.50
Face to Face	Male	21	3.38	1.28	5.05	1.75	2.30	1.57	4.10	2.02
	Female	21	2.52	1.33	5.00	1.84	2.73	2.05	3.86	1.96
	Total	42	2.95	1.36	5.02	1.77	2.52	1.81	3.98	1.97
Control	Male	10	2.80	1.75	4.70	1.49	2.57	1.69	2.50	1.90
	Female	11	3.36	1.91	4.09	2.12	2.14	1.62	2.82	1.89
	Total	21	3.10	1.81	4.38	1.83	2.36	1.65	2.67	1.85

Fig. 5

Tasks Completed (max. 8 pts) of Pre and Post-test by Training Groups (Computer, Face to Face and Control) of Simple and Complex Transformation Tests.



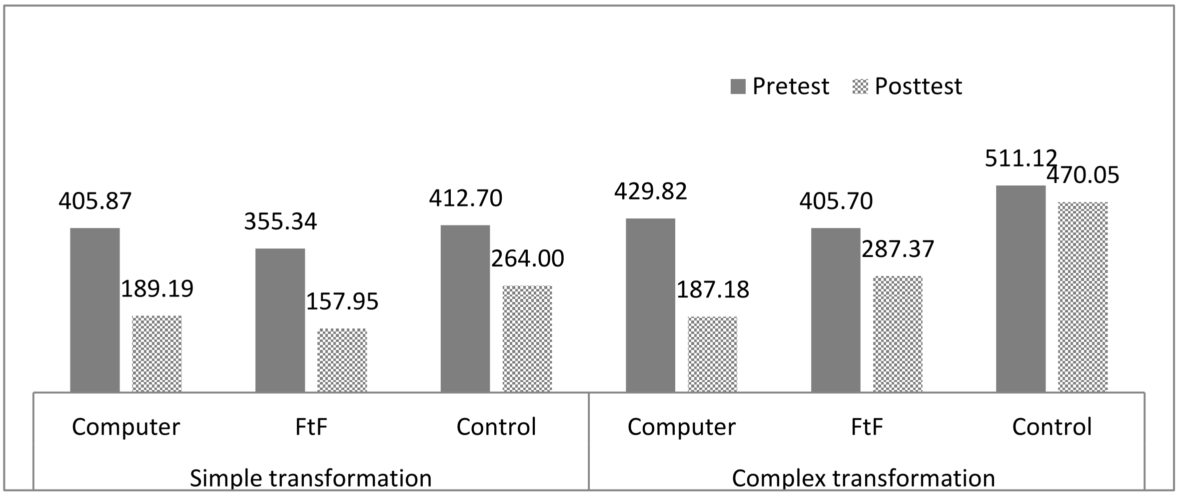
Time on task

The three-way ANOVA yielded a main effects of Session (F(1,85)=24.6, p<.001, ηp²=.22), showing that time on task decreased from the first to the last session (420 vs. 259 sec.), and of Test (F(1,85)=10.24, p=.002, ηp²=.10), due to that participants spend more time on CTT (382 sec.) than on STT (297 sec.). There were no other significant interactions (see fig. 6).

Table3.
Descriptive Statistics of Time on task (sec), of Simple and Complex Transformation Tests (Pre- and Post-test), per Training Group (Computer, Face to Face and Control) and by gender.

			Simple Transformation test				***Complex Transformation***			
			Pretest		Posttest		Pretest		Posttest	
		N	M	SD	M	SD	M	SD	M	SD
Computer	Male	16	341.27	232.91	116.72	54.69	387.23	238.36	182.40	120.82
	Female	20	457.55	369.96	247.16	277.28	463.89	344.22	191.00	91.96
	Total	36	405.87	317.78	189.19	217.57	429.82	300.27	187.18	104.24
Face to Face	Male	18	268.52	131.14	175.33	219.05	404.53	350.18	247.45	296.78
	Female	16	453.01	324.47	138.40	97.71	407.02	248.47	332.28	300.67
	Total	34	355.34	255.84	157.95	171.49	405.70	302.05	287.37	297.17
Control	Male	8	385.83	413.42	136.21	92.53	520.14	371.59	392.19	390.96
	Female	10	434.20	307.80	366.23	394.38	503.91	416.89	532.34	432.83
	Total	18	412.70	348.06	264.00	315.75	511.12	385.92	470.05	408.97

Fig. 6
Time on Task (sec) of Pre and Post-test by Training Groups (Computer, Face to Face and Control) of Simple and Complex Transformation Tests.



Discussion

In order to assess the potential of computerized VSPS training vis-à-vis traditional (face to face) training, we compared the effectiveness of these training methods against a control group that did not receive any training. Our results showed that both training methods were equally efficient in significantly improving VSPS in terms of accuracy and the number of completed tasks (see fig. 4, 5 and 6). These observations support the conclusions of Uttal et al., (2012) and provide evidence that the combination of computer-based instruction and visual-only cues can be very effective (Mayer & Moreno, 2003; Mayer, 2009). This encourages the use of visual information in training children with language-based learning disabilities (e.g., Guarnera, Commodari & Peluso, 2013; Dalton & Proctor, 2007; Newhall, 2012; Smith & Tyler, 2009).

We suggest that applications like TangSolver provide methods and procedures that enhance VSPS at earlier ages, and that can assist teachers in several ways. For example, school-based interventions have been reported to suffer from numerous limitations, such as the necessity of well-trained tutors, the difficulty to find a way to provide standard instructions, and very high time demands on the involved personnel. Computer applications like Tangsolver have the potential to overcome such limitations, as they provide very standardized training conditions (which need not exclude individualized training levels) and an environment in which the learner can practice independently, at his or her own pace. Not only does this help reducing demands on teachers and well-trained tutors, it also encourages autonomous learning and self-management. As stressed by Black et al., (2006), the principle of learner's autonomy implies that learners need to be given opportunities for strategic thinking and reflection about their own learning, and this is what such computer-based training can offer (Doering & Veletsianos, 2009). In conclusion, greater focus on the individual's performance deficiencies would help concentrating training resources—the aim of blended learning (e.g., Picciano, 2009), which seeks to combine technology and traditional instruction rather than pitting one against the other (e.g., Cennamo, Ross & Ertmer, 2013).

However, the probably most important result of our study was the effect of training on the simple and complex transformations tests. Interestingly, the positive findings were mainly restricted to performance on tasks that required flipping or rotating MPs as assessed through the complex transformations test (see fig. 4, 5 and 6). In contrast, training had little impact on performance in the simple transformations test, which assesses visual memory. Thus, while a simple transformations test might be appropriate for younger children or children with structural mental-rotation impairments (e.g., Guarnera, Commodari & Peluso, 2013), only performance on the complex transformations test seems diagnostic for VSPS proper. This supports previous claims that VSPS relies on the ability to grasp complex systems and to discover complex spatial relationships and possible transformations (e.g., Davis, Rimm & Siegle, 2011; Golon, 2008; Subotnik, Olszewski-Kubilius & Worrell, 2011). As noted by many authors, the failure to identify and nurture these abilities does not only do a disservice to the children involved, but also to society as a whole (Dai, Swanson & Cheng, 2011; Subotnik, et al., 2011).

While our findings demonstrate that training in spatially demanding construction tasks is effective, further analysis is needed to identify the role of individual strategies and changes therein–which include holistic mental rotation and step-by-step feature-based comparison (Cherney & Neff, 2004; Geiser, Lehmann & Eid, 2006; Glück & Fitting, 2003). In particular, there is a need to investigate training data by using mathematically based data mining methods (see, www.ed.gov/technology and http://myweb.fsu.edu/vshute/publications.html). Indeed, the wide variety of outcome measures, such the number of click, moves, and so forth allows the construction of knowledge tracing models (e.g., Aleven et al., 2010; Baker et al., 2010; Feng & Heffernan, 2010; Shute & Zapato-Rivera, 2012). Hence, the potential of applications like TangSolver goes beyond demonstrating training outcomes by inviting process-based analyses. However, good models guiding such finer-grained analyses are rare and a main challenge will be to find the most diagnostic performance indicators to predict the trainees' performance (Shute & Ke, 2012) and persistence (Ventura & Shute, 2013), self-regulation, control strategies, motivation, etc. (Shute & Ventura, 2013).

The current study presents several shortcomings. First, without a follow-up study we cannot know to which degree the increase of performance we observed was able to induce long-term learning. In particular, while keeping items constant from pre- to posttest was important for valid comparison, we cannot tell task mastery from learning proper (Guskey, 2007). Thus, further studies should use test items that are significantly different from training items (e.g., convex tangrams) and should look into longer post-training intervals (Uttal et al., 2012). Moreover, even though processing speed is frequently assessed in mental rotation tasks to check for gender differences in performance, future studies should consider dropping the time limit to allow for different processing styles. Finally, while our findings show that visual cues can be effective, more empirical research is needed to test for the most efficient format of cues and instructions, as well as for possible interactions with individual processing styles.

Our present study is but one step into the direction of cognitive enhancement in children and there is certainly a need for further research to substantiate our findings. It would be interesting to see whether more, or longer spatial training, or training on different spatial tasks, lead to more, or more enduring enhancement. Also interesting is whether our training effects scale up to a less selected population, especially to children with special needs, and to older children and teens. Finally, in evaluating the efficacy of training, it is important to consider that it needs to be an on-going process (an integral part of an individual's learning) rather than a short event assessed mainly by experimental research, which calls for more collaboration between research and educational agents.

Chapter 4

Visuospatial processing in children with autism: No evidence for (training-resistant) abnormalities

Ellahe Chabani & Bernhard Hommel

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Abstract

Individuals with Autism Spectrum Disorders (ASD) have been assumed to show evidence of abnormal visuospatial processing, which has been attributed to a failure to integrate local features into coherent global Gestalts and/or to a bias towards local processing. As the available data are based on baseline performance only, which does not provide insight into cognitive/neural plasticity and actual cognitive potential, we investigated how training-resistant possible visuospatial processing differences between children with and without ASD are. In particular, we studied the effect of computerized vs. face-to-face visuospatial training in a group of not-high-functioning children with ASD and typically developing children as control. Findings show that (a) children with and without ASD do not differ much in visuospatial processing (as assessed by a tangram-like task) and the few differences we observed were all eliminated by training; (b) training can improve visuospatial processing (equally) in both ASD and normally developing children; and (c) computer-based and face-to-face training was equally effective.

Keywords: Visual spatial, visualization, school based intervention, response to intervention, and computer based instruction.

Introduction

Autism spectrum disorder (ASD) falls under the wide umbrella of Pervasive Developmental Disorders that have neurodevelopmental origins. ASD is characterized by behavioural and cognitive problems that include attention deficit and hyperactivity disorder (ADHD), as well as learning disorders such as dyslexia (Centers for Disease Control and Prevention [CDC], 2012). The heterogeneity of individuals with ASD remains poorly understood (Herbert & Anderson, 2008; Ronald et al., 2006). The severity and pattern of ASD impairments vary from individual to individual and range from people with exceptional abilities (i.e., in visual skills, music, and academics) to those who are severely handicapped and cannot live independently (CDC, 2012).

In a recent CDC (2012) report, the prevalence of ASD is estimated to be 1.3 per 1,000 (1 in 88) U.S. children between the ages of 6 and 17. Boys are nearly five times more likely to have autism than girls. Whilst it is argued that the alarming increases in prevalence estimates might reflect changes in diagnosis or methodological issues, the CDC recognizes autism as an emerging public health problem. The 2011 strategic plan for ASD research (for a comprehensive review, see The Interagency Autism Coordinating Committee [IACC], 2011) stresses the need for research that not only deepens our understanding of ASD, but also develops efficient interventions that address both the strengths and weaknesses of affected individuals. The focus of the present study is on the latter by evaluating an intervention that targeted the supposedly atypical Visual Spatial Processing Capacity (VSPC) in children with ASD.

Atypical Visual Spatial Processing Capacity in ASD

ASD is characterized by impairments in social interaction, restricted communication, repetitive, and stereotyped patterns of behaviour (DSM–IV, 1994). In addition, individuals with ASD have been claimed to demonstrate atypical VSPCs and perceptual abnormalities, which can be associated with both strengths and weaknesses in spatial cognition. On the one hand, individuals with ASD have difficulty recognizing familiar faces and correctly interpreting facial expressions (Behrmann, et al., 2006; Dawson, Webb & McPartland, 2005; Gross, 2004; Kim & Johnson, 2010 ; Klin et al., 2002; Simmons, et al., 2009). On the other hand, they show superior visuospatial skills as compared to typically developing individuals, such as in Embedded Figures or Block Design Tests from the Wechsler Intelligence Scales (WISC) (Bonnel et al., 2003; Happé & Frith, 2006; Koyama, Kurita, 2008; O'Riordan & Plaisted, 2001; Pellicano et al., 2006). Such atypical VSPC have been taken to reflect differences in global versus local information processing. Global information processing refers to the ability to integrate piecemeal information (e.g., ‘trees’) into a coherent whole (“the forest”), while local information processing refers to the ability to focus on details (e.g., Poirel, Mellet, Houdé & Pineau, 2008).

Weak Central Coherence (WCC) Theory (Frith & Happé, 1994; Happé, 1999) is one of the major, most influential accounts that address the atypical VSPC in ASD. The original concept of WCC assumes that while typically developing children have a natural tendency to integrate visual elements into global perceptual Gestalts (Farroni, Valenza, Simion & Umilta, 2000; Johnson & 2010; Quinn & Bhatt, 2006; Quin et al., 2002), individuals with ASD have a bias towards local processing and a focus on details, with corresponding problems in integrating information into a coherent whole. Evidence for this assumption comes from studies showing superior performance of individuals with ASD on perceptual tasks requiring attention to detail, such as in Embedded Figures Task. In these tasks, subjects are required to decide as quickly as possible whether or not a visual target shape is hidden in a complex visual figure, and there is evidence that individuals with ASD respond both faster and more accurately than matched controls (Shah & Frith, 1993; Jolliffe & Baron-Cohen 1997). Moreover, some of the ASD children scoring substantially below average on IQ tests (<70) and demonstrating deficits in executive functions (in working memory, planning, sequencing, set-shifting, and verbal ability) were found to outperform typically developing children on the WISC Block Design Test (Happé´ & Frith, 1996; Joseph, et al., 2009; Hill, 2004; Robinson et al., 2009; Shah & Frith, 1993). Superior performance of ASD children has also been demonstrated in discrimination tasks (Plaisted et al., 2003), in visual search (Plaisted et al., 1998a; O'Riordan et al., 2001; O'Riordan, 2004; Jarrold et al., 2005), rote memory (Frith & Happé´, 1994), and in map learning (Caron, Mottron, Rainville & Chouinard, 2004).

However, results are often mixed, and some studies suggested that both children and adults with ASD show poorer global processing than matched controls (Behrmann et al., 2006; Grinter, 2010; Rinehart et al., 2000; Nakano, 2010; Wang et al., 2007). Other studies using the same type of task have reported no difference (Brain & Bryson, 1996; Hayward et al., 2012; Iarocci et al., 2006; O'Riordan & Plaisted, 2001; Ozonoff et al., 1994; Plaisted et al., 1999; Pring et al., 2010; Ropar & Mitchel, 2001; Scherf et al., 2008; Van den Broucke et al., 2008). Only recently, however, Perreault et al. (2011) found enhanced global processing in adults and adolescents diagnosed ASD. Such mixed results have led to a modification of the original WCC theory. Instead of attributing the atypical VSPC in individuals with ASD to impaired global processing, the theory now claims a "local processing preference" in ASD (Happé & Frith, 2006). In fact, Happé and Frith suggest that there is neither impaired global processing nor enhanced perceptual functioning, but a mere preference in ASD to focus more on local than on global information. Note that this theoretical shift from assuming a rather "irreparable" impairment to a mere preference has important implications for training and teaching.

Studies using hierarchically structured visual stimuli (e.g., Navon figures: large letters made of small letters; see Navon, 1977) revealed that individuals with ASD respond to the global stimulus level more efficiently than controls (Lopez & Leekam, 2003; Mottron et al., 1999, 2003, 2006; Ozonoff et al., 1994; Plaisted et al., 2003; Hayward et al., 2012; Iarocci et al., 2006; Scherf et al., 2008). As pointed out by

Mottron et al. (2006), this does not support the assumption of a deficiency in global context processing in ASD but rather suggests a relative superiority in local processing, with global processing being unaffected. Mottron and colleagues therefore propose an “Enhanced Perceptual Functioning (EPF)” model as an alternative to the (original) WCC account. They assume that “*superiority of perceptual flow of information in comparison to higher-order operations led to an atypical relationship between high and low order cognitive processes in autism, by making perceptual processes more difficult to control and more disruptive to the development of other behaviours and abilities*” (Mottron et al., 2006, p.2). In addition, López, Leekam, and Arts (2008) have argued that local vs. global processing can occur at two levels, a conceptual and a perceptual one, and individual with ASD can show weak central coherence in one, the other, or both. Others suggested that the hypothesis of bias towards local processing reflects a difference between ASD and typical controls in brain structure or functioning, e.g., related to face processing (Critchley et al., 2000; Schultz et al., 2000; Pierce et al., 2001; Hubl et al., 2003). Yet others have attributed the atypical spatial processing in ASD to decreased connectivity between cortical regions (Just et al., 2004, McAlonan et al., 2004) or a tendency to use visual–spatial regions to compensate for higher-order cortical regions (Koshino et al. 2005).

However, as more research accumulates, so do inconsistent findings and unexpected differences with regard to global vs. details information processing of individual with ASD. The inconclusive results can be partly explained by the inclusion of a broad range of ages in the same study (e.g., cases with participants as young as four years of age through early adulthood; for an overview see, Happé & Frith, 2006). In many studies, exclusively high-functioning ASD (Asperger’s) participants are compared with a healthy control group. As the former do not have clearly defined cognitive impairments, finding significant differences may often not be expected (e.g., Edgin & Pennington, 2005). Others have pinpointed the influence of prior knowledge (Mitchell & Ropar, 2004) and question formulation (Brosnan et al., 2004), which can result in unexpected or misleading outcomes. For example, Brosnan et al. (2004) reported that participants with ASD were more accurate than controls when being asked whether two lines of an illusion-inducing display “looked the same length” but performed more poorly than controls when being asked whether the lines “were the same length”.

Given the rather static views of earlier theoretical accounts, previous studies assessing atypical VSPC in ASD were always based on traditional testing procedures–a single time-point of testing. Such a procedure provides valuable information on the baseline abilities or “default” performance of a participant’s VSPC, but fails to assess the potential for change and improvement through intervention and instruction. Assessing this potential seems particularly important early in life, when the brain is most flexible and plastic (Johnson, 2010; Dawson, 2008). In the present study, we employed a more dynamic approach to see whether interventions at an early age may allow children with ASD to develop perceptual abilities that are comparable or at least more similar to those exhibited by typically developing children. In particular, the main aim of this study was to evaluate ASD-diagnosed children's responsiveness to instruction within a short VSPC-enhancing intervention.

Face to Face versus computerized VSPC intervention

Individuals with ASD often exhibit unusual and distinctive behaviours, including a restricted range of interests, inflexibility and resistance to change, and impairments in reciprocal social interaction (e.g., Richler, Bishop, Kleinke & Lord, 2007; Wolfberg, 2009). Learning in these individuals is often characterized by its spontaneous and implicit nature, which can lead to mastering very complex material, while they tend to show considerable resistance to learning in conventional ways (e.g., Dawson**,** Mottron & Gernsbacher, 2008; Landa, 2007; Ogletree, 2007). Even though a variety of intervention methods exists, to date there is no standard method that would match the specific learning needs and preferences of students with ASD. These students have the best chances of success in school through behavioral interventions and within an individualized educational model (Ben Itzchak & Zachor, 2007; Cohen, Amerine-Dickens & Smith, 2006; Lord et al., 2005; Magiati, Charman & Howlin, 2007). They respond well to a structured learning environment and learn best through consistency and repetition of newly acquired skills.

Given the high costs of individual interventions ("$2.3 million in the U.S. and $2.4 million in the UK for each person with autism affected by intellectual disability through his or her lifespan", www.autismspeaks.org) and the shortage of qualified staff to implement them, computer-based interventions (CBI) are often conceived as an optimal medium. Proponents of CBI argued that CBI applications allow compensating for verbal and interaction problems, as obvious in individuals with ASD, and overcoming the social, emotional, and communication difficulties associated with ASD while at the same time easing the burden of caregivers (e.g., Newman, 2004; Schilling & Schwartz, 2004; Myers et al., 2007). Undeniably, CBIs are taking on a progressively important role in the research, and the development of effective interventions for people with ASD, such as in literacy (Moore & Calvert, 2000; Bosseler & Massaro, 2003; Blischak & Schlosser, 2003), social communicative skills, and emotion detection (e.g. Bölte, 2004; Bölte et al., 2006; Golan & Baron-Cohen, 2006; Golan et al., 2009 ; Goodwin, 2008; Wolfberg, 2009) or problem solving (Bernard-Opitz, Sriram & Nakhoda-Sapuan, 2001).

The overall results of CBIs are promising but vary in terms of significant gains for children with autism (Golan et al., 2009). For example, Bosseler & Massaro's (2003) application aimed to improve vocabulary and grammar in children with autism. They found significant gains: children identified more items and were subsequently able to recall 85% of the newly learned items at least 30 days after the completion of training. Bernard-Opitz et al. (2001) implemented a computerized Social Stories program to teach social understanding to children with autism. The children improved more with computerized visual Social Stories than without. Tanaka et al. (2010) used a computer-based game to teach facial recognition skills to children with ASD. After 20 hours of intervention with the software, the children showed significant improvements in their ability to recognize mouth and eye features in faces as compared to a control group. Travers et al. (2011) examined the effectiveness of two methods of teaching early literacy skills among 16 preschool children with ASD: a traditional teacher-led group instruction that used alphabet books and a multimedia computer-assisted instruction. They did not found significant differences between the intervention groups, and children demonstrated high rates of attention to task and low rates of undesirable behaviour in both.

Recently, Pennington (2010) reviewed 15 articles that utilized experimental or quasi-experimental designs and included a total of 52 participants about teaching academic skills using CBI. Pennington concludes that despite the fact that all studies reported an increase in academic skills, the small number of studies and participants which consider CBI as best practice, the results must be taken with caution. Ramdoss et al. (2011) reviewed 12 studies using CBI for literacy competency improvement in 94 students with ASD. They suggested that both the wide variety of literacy skills targeted by instruction and the heterogeneity of the participants make it difficult to identify the variables that determine the effectiveness of CBI.

In summary, advantages of CBI over traditional Face to Face methods are unclear. At least some individuals with ASD express more interest in computers than manipulative material and are less resistant to computers than to teachers, or even prefer computer instruction to personal instruction (e.g., Koppenhaver & Erickson 2003; Williams et al., 2002).

The current study

The emphasis of previous research within WCC (Happé & Frith, 2006) and EPF (Mottron et al., 2006) theory was on assessing atypical VSPC in ASD and on finding out whether global and/or local information processing are impaired, superior, or unaffected. As the available studies assessed the performance of individuals with ASD at just a single point in time, their findings reflect baseline abilities, and the fact that often only high functioning ASD patients were considered represents a further restriction. Whether and how low-functioning ASD patients are affected is unclear and whether spatial cognition in ASD can change through intervention and instruction is unknown.

Furthermore, existing interventions (face to face or CBI) were mainly targeting literacy, social communicative skills, face recognition, or emotion detection of individuals with ASD. To our knowledge, there is not any game-based training or intervention that addresses the atypical VSPC in ASD. However, given the evidence for the trainability of VSPC in typical developing children (for an overview see Uttal et al., 2012), it is not unreasonable to assume that systematic training might modify the hypothetical spatial processing biases in individuals with ASD. Accordingly, we conducted the present study with three main aims in mind.

First, we investigated to what extent VSPC of children with ASD might be subject to change as a results of practice on a visuospatial task. To the degree that children with ASD could be trained to improve on VSPC, so the idea, efficient training programs for ASD children could be developed. Second, we evaluated the responsiveness to two kind of instruction: In a “Computer” training group (COMP) the main instructions were presented by means of a computer program while in a “Face to Face” group (FtF) a human teacher was tutoring. Our third aim related to the fact that our task to assess local vs. global biases in processing spatial information (as some others, but not all) required skills in mental rotation, i.e., in manipulating and transforming mental representations of objects and their spatial characteristics. It has been shown that some individuals use a holistic mental rotation strategy to solve visuospatial tasks, such as cube comparison problems, while others employ a step-by-step strategy instead (Cherney & Neff, 2004; Geiser, Lehmann & Eid, 2006; Glück & Fitting, 2003)—often with better performance related to the former than to the latter. Recently, Falter et al. (2008) found that individuals with ASD are faster than non-autistic individuals at mental rotation involving three-dimensional geometric shapes, while Soulieres et al. (2009) did not find any difference between autistic and non-autistic adults. To address that issue, we investigated whether children’s performance would differ between a sub-test (test A, see below) that did not require to mentally rotate (representations of) visual stimuli forms and a sub-test that did (test B). In addition to these three major aims, we also explored whether higher demands on global or local processing would reveal group differences in performance, and whether these differences might predict training performance.

To address these aims, we compared non-high-functioning children with ASD to typically developing children on a visuospatial task that we developed and validated in healthy children in a previous study (Chabani & Hommel, 2013). The visuospatial task used, called the “TangSolver”, is a modified version of tangram game (see below). In the original tangram game, the objective is to create a specific shape by assembling seven classical geometric forms. The forms used in the tangram game and figure construction require breaking up completed patterns into its component parts, which makes the task comparable to figure construction of the WISC Block Design Test. However, in contrast to the Block Design Test or similar standard tests that do not allow or encourage training, the “TangSolver” was developed for that exact purpose.

Method

Participants

Forty-nine children diagnosed with ASD (42 boys and 6 girls; mean age=124.04 months, SD= 12.29) were recruited from special educational schools in the Netherlands. The diagnosis of ASD, which is a requirement for admission in such schools, and the full scale of intelligence scores (FIQ), Performance IQ and Verbal IQ scores were obtained from the children’s files. The exclusion criteria for this group were: relevant vision impairments; behaviour, verbal and comprehension problems (such as inability to comprehend the instructions of the experimental tasks); and IQ scores below 70 or above 120. In addition, a control group of 96 typically developing children (40 boys and 56 girls; mean age=105.3 months, SD=10.04) with no specific academic, learning or behavioural problems was recruited from a number of regular primary schools. Participation was voluntary, and all parents/caretakers signed informed consent prior to participation in the study.

Instruments

VSPC. The TangSolver application developed for, and tested in our previous study (Chabani & Hommel, 2013) was used for both assessment and training of participants' VSPC. This application contains three modules: TangSolver-Try-out, TangSolver Test, and TangSolver Training. TangSolver is an adapted version of the tangram game that consists in arranging seven geometrical forms to construct a large variety of shapes. To tap global processing we created composed forms by combining more than one classical geometric form, and to tap local processing we used the seven classical geometric forms of the tangram game. We will refer to these simple and composed forms as *Master Pieces* (MPs). An example of a MP could be the combination of a square and a triangle or a standard geometric form, such as a triangle. The same shape could thus be constructed by assembling 4, 5, 6 or 7 MPs. These constituted our four difficulty levels, ranging from L1 (4 MPs) to L4 (7 MPs). In addition, figures requiring the fewest MPs (L1) were considered to tap global processing while the figures requiring the most MPs (L4) as assessing local processing. See Fig. 1 for an example of TangSolver Test and Training screens.

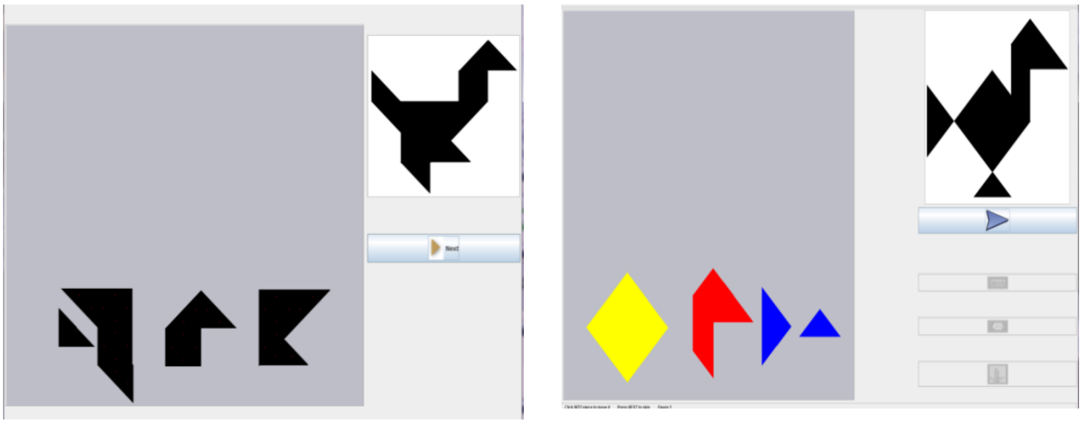


Fig 1.

An exemplar of the TangSolver Test and Training screen.

The ***TangSolver-Try-out*** assessed participants' skill in manipulating the computer mouse and provided practice in rotating and flipping forms. The task in this module consists in moving the forms placed at the centre of the working window according to requested placements. The try-out comprises of three parts requiring dragging, rotating, and flipping, respectively; it was not time limited and participants could practice until the mouse manipulation was satisfactory.

The ***TangSolver Test*** assessed participants VSPC prior to and after training. It was composed of two subtests that differed in the possibility to move MPs: Subtest A allowed only dragging the pieces (which we considered to not require mental rotation; see Chabani & Hommel, 2013) while Subtest B allowed dragging, flipping and rotating the pieces—which made that test more diagnostic for the individual mental-rotation capacity. Each subtest contained eight items. The items were similar in terms of difficulty with two items at each of the four difficulty levels. MPs used in pre/post-test were all in one colour, in contrast to the three colours (blue, yellow, and red) used for the training items. The pre-test and the post-test were time-limited (max. duration 1:30 min/item). However, children who were quick (task completion <= 1:30) could make use of the "Next" bottom press, which displayed the following item. For children who were slow (task completion > 1:30), a window asking, "Do you need more time? Yes - No" appeared, which allowed them one extra minute, after which the next item appeared automatically. Each test took 10-20 min, depending on how much extra time was used.

Training material. The aim of the training was to support the participant when s/he could not solve the problem independently by providing different types of hints (verbal or nonverbal). The two training modalities we considered (COMP and FtF) required the development of manipulative material for FtF training groups and of a computer application (TangSolver Training) for COMP training. For the FtF group, the MP was made of tick plastic and placed on a white board (see Fig 2.), while training in the COMP group was similar but displayed on computer screen. Both types of training used six different items similar to those used in the pre/post-test. To facilitate the learning through drill and practice, the content had to be scaffolded and sequenced. Accordingly, each training items was composed by its four difficulty levels, meaning that a training item could be done with 4, 5, 6 and 7 MPs. MPs were in three colors (blue, yellow, and red), which provided more options for constructing different types of hints and facilitating the learning by making analogies.

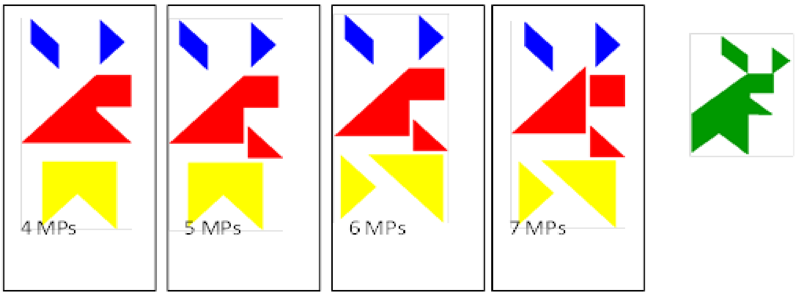


Fig 2.

An exemplar of the manipulative material

Design and Procedure

This study used a between-subject design that involved a pre-test, a training period, and a post-test, with two experimental training groups. The two experimental groups (typically developing children=TD and children with ASD=ASD) were matched as much as possible for age and their pretest score and were assigned to Computer (COMP) training and Face to Face (FtF) training.

During the first and last session, all children's VSPC capacity was assessed by means of the TangSolver test. However, before starting the pretest all children received training on how to drag, rotate and flip with the computer mouse. Children in both training groups received training on six items either with a computer or face to face between pre- and post-test. Children were trained and tested in separate rooms at their own school. For COMP children, the respective software was installed on the school's PCs. Testing and training sessions were scheduled weekly, nonetheless an adaptation was necessary among children with ASD. Each session took approximately 35-40 minutes over a period of three months.

The Training Procedure

Children in both training groups received training on six different items similar to those used in the pre-test at each of the four difficulty levels. The training started with the easiest level (4 MPs) and progressed to the most difficult level with five, six, and seven MPs of the same item, respectively. The child could start on a new level or item only when the task was completed successfully at the previous level. Therefore, neither the time for completing the task nor the use of hints was limited. The two types of training differed in respect to the material used (computer vs. manipulative material) and in the manner, the children were tutored. In FtF training, learning was individual and occurred in the presence of one assessor per child.

The instruction within the training consisted of guidance and gradually reducing that guidance as the learner's expertise increased. Verbal hints consisted of teacher guidance such as "are you sure those are the correct pieces?", "maybe you should try with these pieces!" to manual modelling. The visual hints with manipulative material were as the segmented structure used in the Block Design Test (showing the solution- figure with apparent breaking lines). In the computerized tasks, the segmentation consisted in highlighting MPs step by step. The visual hints ranged from unicolor segmented figures to segmented figures that fit the MPs colors. For those needing more support, learning was facilitated by making the puzzle directly on the top of the figure. In this way, children could easily see which MPs were missing.

Scoring

During the pre- and post-test time-on-task scores were computed as well as an accuracy score representing the total number of correctly placed pieces per item and a tasks-completed score that counted the number of tasks being completed (1) or not (0). The data collected during the training are not reported in the present paper.

Results

Before assessing the effect of training, we first checked for pre-experimental differences between members of the two training conditions (Comp and FtF) within each experimental group (TD and ASD). We considered three dependent variables, the pre-test scores of Time on Task, Accuracy, and Tasks Completed, and added the WISC scores (verbal, performance and total) for the ASD group. Within both experimental groups, no significant pre-training differences were found (See Table 1 for an overview). Second, we checked whether the training groups (COMP and FtF) were comparable across the experimental groups. T-tests on the three main dependent variables (df-adjusted in cases of a significant Levene's test of equal variances) showed reliable group differences for the two COMP training conditions for Time on Task, t(41.4)=4.32, p<.001, and Accuracy, t(39.97)=2.46, p=.01, but not for Tasks Completed scores, t(39.58)=.67, p>.5. That is, ASD children were faster, but less accurate than TD children, which is in line with previous studies (e.g., Caron et al., 2006; Shah & Frith, 1993; Jolliffe & Baron-Cohen 1997). For the FtF training conditions, the only significant group difference was found for Time on Task, t(58)=3.06, p=.003, while there was no effect of Accuracy, t(31.5)=-.015, p=.9, or Tasks Completed, t(35.45)=.7, p=.48.

Table 1.
Pretest (pre-yoking) scores of Time On Task, Accuracy, and Tasks Completed score of Groups (TD= typical children, ASD= Children with ASD) and Characteristics of ASD Participants, as a Function of Training Condition (COMP vs FtF).

		COMP		**FtF**		**Diff. COMP/FtF**		
		M	**SD**	**M**	**SD**	**T**	**df**	**P**
TD	**Pretest scores**							
N(Comp/FtF)	Time on Task (sec)	1820.8	394.6	1745.6	527.23	.74	81	.46
=41/42	Accuracy	45.7	14.36	44.55	12.9	.38	81	.75
	Tasks Completed	5.7	2.7	5.3	2.7	.71	81	.48
ASD	**IQ score**							
N(Comp/FtF)	VIQ	94.81	11.81	93.53	11.20	.32	31	.75
=25/24	PIQ	94.82	17.77	94.24	18.41	.10	32	.93
	FIQ	94.95	15.43	92.29	14.12	.54	34	.60
	Pretest scores							
	Time on Task (sec)	1305	509.87	1388.1	409.7	.63	47	.53
	Accuracy	34.64	19.43	44.63	22.89	1.64	47	.106
	Tasks Completed	5.16	3.7	5.96	4.03	.72	47	.47

Note. VIQ = Verbal IQ scores; PIQ = Performance IQ scores; FIQ = Full-Scale IQ scores

As pointed out earlier, our main interest was whether and where changes from pre- to post-test occurred, and whether they were differently pronounced in the two groups and the two training conditions. To identify these effects, we analyzed each of the three dependent measures (Time On Task, Accuracy and Tasks Completed score) by means of a four-way ANOVA for repeated measures with Session (pre- and post-test) as the within-participant factor, and Training Condition (Computer and Face to Face), Groups (TD and ASD), and Sub-test (subtest A and B) as between-participants factors. The theoretically most interesting result pattern would consist of a two-way interaction involving Session and Training Condition and higher-order interactions including Group or Training condition. We will group the outcomes of the three ANOVAs according to their theoretical relevance and implications.

To deal with these pre-experimental differences we yoked the subjects in the two groups on the basis of their pre-test data, which left us with a smaller subset of the entire sample but allowed us to equate pre-experimental performance appropriately. We yoked participants by considering the best match of pre-test scores for each of three dependent measures (Time-on-task, Accuracy, and Tasks Completed), across the training conditions (COMP and FtF). This reduced the sample to N=96 (4x24). Table 2 provides the resulting descriptive statistics. An alpha level of .05 was used for all statistical tests.

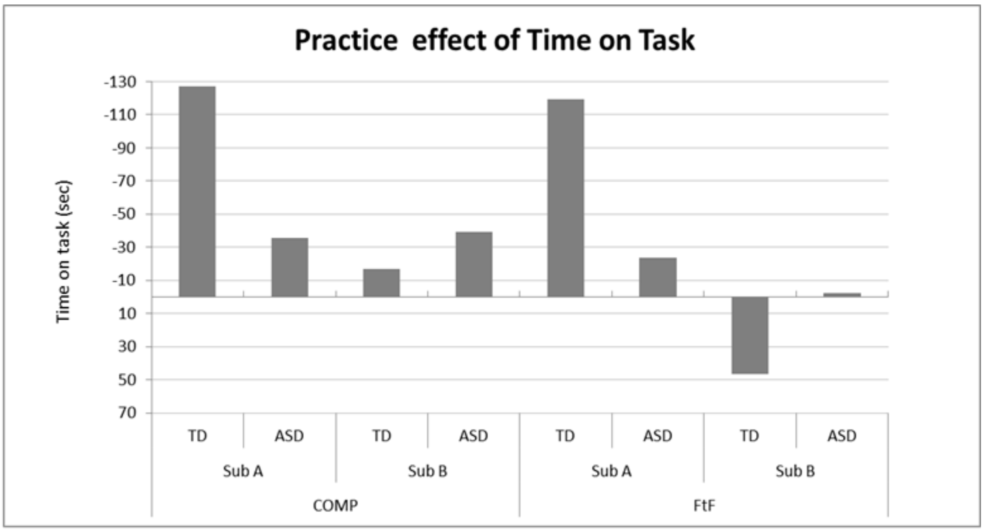
Table 2.
Descriptive statistics of Pre- and Post-test of Time-on-task, Accuracy and Tasks Completed scores per Group (TD= typical children, ASD= Children with ASD) and Training Condition (COMP and FtF) after yoking.

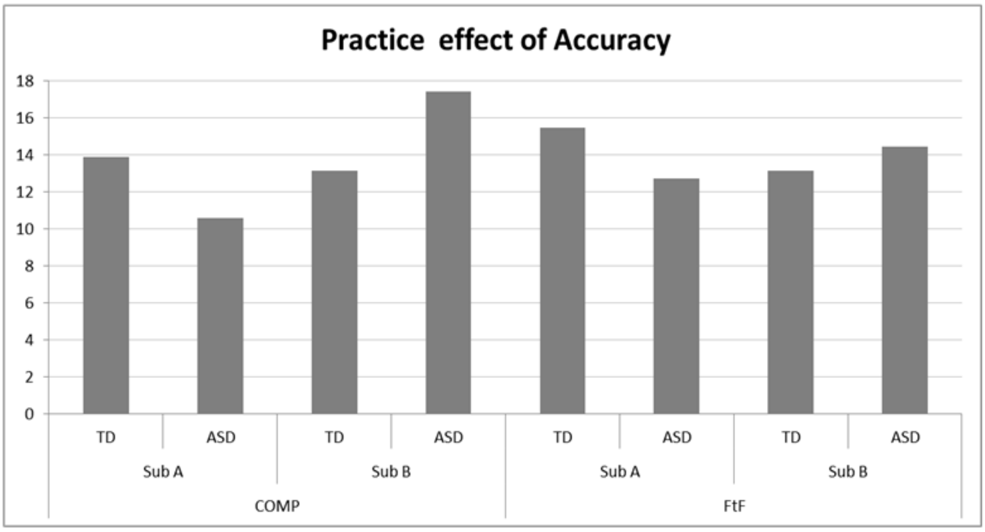
		Time on task (sec)				**Accuracy**				**Tasks completed**			
		Pretest		**Posttest**		**Pretest**		**osttest**		**'retest**		**osttest**	
		M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
Subtest A													
TD	COMP	849.67	190.58	722.46	542.13	18.25	4.79	32.13	8.58	3.08	1.41	4.21	1.79
	FtF	712.75	240.60	593.58	229.95	22.13	6.11	37.58	2.98	3.33	1.55	4.96	1.73
ASD	COMP	642.58	227.05	607.00	201.99	21.58	11.26	32.17	8.81	3.42	2.02	5.25	2.03
	FtF	679.67	192.87	655.83	243.28	20.00	11.11	32.71	8.75	3.17	1.95	4.96	2.05
Subtest B													
TD	COMP	721.58	232.55	704.67	154.24	18.79	6.72	31.96	8.70	2.38	1.61	4.04	1.55
	FtF	643.46	204.90	690.13	276.02	21.75	8.67	34.88	11.95	2.54	2.06	4.00	2.04
ASD	COMP	696.54	308.19	657.08	264.91	16.04	10.14	33.46	7.47	1.96	1.94	4.21	2.21
	FtF	708.50	277.78	706.29	194.98	18.21	11.38	32.67	9.60	2.79	2.21	4.29	2.03

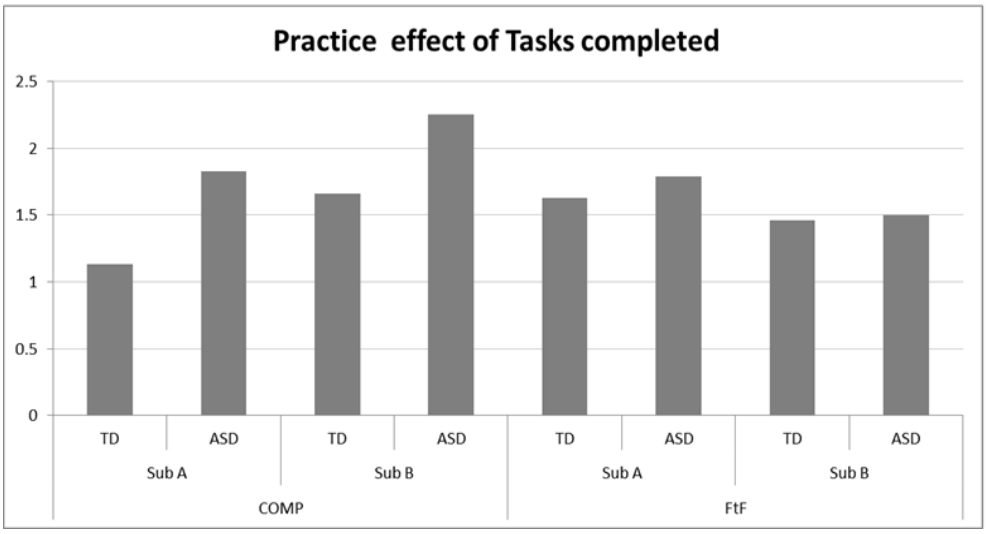
Training effects in TD and ASD children

Our first question was whether and how the training would change performance from pre- to post-test and whether these changes would be more pronounced in TD than ASD. Figure 3 provides an overview of the training effects as a functions of the groups and the various conditions. We first assessed these issues without considering main effects of, or interactions involving Training Condition and Sub-test (see below).

Time on task. There was neither a main effect of Session, p=.14, nor a significant interaction with Group, p=.60, suggesting that both groups were equally unaffected by training.







Accuracy. The highly reliable main effect of Session, F(1, 92)=274.8 p<.001, ηp²=.75, was not modified by Group, p=.94, indicating that both groups improved through training.

Tasks completed. Again, the main effect of Session, F(1, 92)=95.14, p<.001, ηp²=.50, was not modified by Group, p=.27, indicating that both groups benefitted equally from training.

Effects of training method (Computer vs. Face to Face)

Our second question was whether training-related changes would be mediated by the Training Condition (COMP and FtF). We assessed this issue by focusing on main effects of, and interactions involving Training method.

Time on task. There was no hint to a main effect of, or any interaction involving Training. The only effect that approached significance (p<.1) was an interaction of Group and Training on Time on Task, p=.057, indicating that the ASD groups were doing about equally well under COMP and FtF training (651 vs. 688, respectively), while the TD groups tended to be better under COMP than FtF instruction (750 vs. 660, respectively).

Accuracy. There was no hint to a main effect of, or any interaction involving Training, all ps>.18.

Tasks completed. The only reliable effect involving Training method was a three-way interaction of Training, Group, and Sub-test, F(1, 92)=7.12, p=.009, ηp²=.072. Separate ANOVAs revealed that Group and Sub-test interacted in the COMP condition, F(1, 46)=6.61, p=.013, ηp²=.13, but not in the FtF condition, p=.44. Under FtF training, performance was roughly comparable for the TD group (4.1 and 3.3 for sub-test A and B, respectively) and the ASD group (4.1 vs. 3.5). In contrast, under COMP training, the difference between the sub-tests was much smaller in the TD group (3.6 and 3.2) than in the ASD group (4.3 and 3.1). However, as this effect was not modified by session, F=0, it is more likely to reflect pre-experimental group differences than true effects of the training method.

Mental rotation capacity

Our third question was whether and how performance would differ between sub-test A, that did not rely on mental rotation, and sub-test B, that did. We assessed this issue by focusing on effects involving the Sub-test factor.

Time on **task.** There was not any effect reaching or approaching significance, including the main effect of Sub-test, p=.7, and the interaction Sub-test, Group, and Training, p=.2.

Accuracy. The main effect of Sub-test F(1, 92)=4.08, p=.046, ηp²=.04, was modified by a significant interaction of Session, Group, and Sub-test, F(1, 92)=5.36, p=.023, ηp²=.055. TD participants performed and improved equally over sessions in both sub-tests (from 20.2 to 34.9 in sub-test A and from 20.3 to 33.4 in sub-test B). ASD participants showed comparable performance in sub-test A (improvement from 20.8 to 32.4) but started off from a lower baseline in sub-test B (improvement from 17.1 to 33.1). Importantly, an

ANOVA of the post-training data only did not show any effect of Group or Sub-test, ps>.26, suggesting that the training eliminated all possible pre-experimental differences.

Tasks Completed. Apart from the main effect of Sub-test, F(1, 92)=49.7, p<001, ηp²=.35, and the (presumably less interesting) three-way interaction of Training, Group, and Sub-test discussed in the previous section, there were no reliable effects involving the Sub-test factor, ps>.12.

Global vs. local visuospatial processing

In addition to our three main research questions we were also interested to see whether the TD and ASD groups would differ regarding global vs. local visual processing, and whether such differences, if any, would change after training. To be able to compare our findings to the WISC Block Design Test we restricted this analysis to Time on task and Tasks completed scores. As described above, we considered the L1 data to represent global processing and the L4 data to represent local processing, while the data from the L2 and L3 conditions were dropped. Based on these L1 and L4 data we then reran the ANOVAs but added a fifth factor representing Global/Local processing. This resulted in two five-way ANOVAs with the three within-participant factors Session (pre- and post-test), Sub-test (A and B), and Global/Local processing, and the two between-participant factors Training condition (COMP and FtF) and Group (TD, and ASD). Given that the effects of Session, Sub-test, Training condition, and Group were discussed already, we will focus on the effects including the Global/Local factor.

Time on task. There were four reliable effects: a main effect of Global/Local processing, F(1, 92)=67.87, p<001, ηp²=.43, that was modified by two-way interactions with Group, F(1, 92)=7.31, p=008, ηp²=.074, Session, F(1, 92)=8.35, p=.005, ηp²=.083, and Sub-test, F(1, 92)=10.93, p=001, ηp²=.106. The interaction with Group was due to that TD and ASD groups were roughly comparable in global processing (152 vs. 140 in TD and ASD, respectively) while the TD group spent considerably more time on the local processing part of the task than the ASD group (250 vs. 189). The interaction with Session revealed that practice did not affect local processing (222 vs. 218 from pre- to post-session) but reduced time on task regarding global processing (170 vs. 122). The interaction with Sub-test showed that the two sub-tests differed regarding global processing (126 vs. 166 for sub-test A and B, respectively) but not regarding local processing (226 vs. 214).

Tasks Completed. There were three significant effects including the Global/Local factor: The main effect of Global/Local processing, F(1, 92)=375.58, p<.001, ηp²=.803, was modified by a two-way interaction with Group, F(1, 92)=10.79, p=.001, ηp²=.105, and a four-way interaction with Session, Sub-test, and Training condition, F(1, 92)=4.70, p=.033, ηp²=.05. The two-way interaction was due to that the ASD group outperformed the TD group in local processing (.39 vs. .60 for TD and ASD, respectively), t(94)=2.45, p=.016, while the two groups were comparable in global processing (1.5 vs. 1.4), t(94)=1.02, p=.31 (n.s.). The four-way interaction reflected a theoretically less interesting pre-experimental difference. Separate analyses on the global and the local data showed that Session, Sub-test, and Training produced a reliable interaction for the global condition, F(1, 92)=5.93, p=.003, ηp²=.06, but not for the local condition, F<1. Next, we analyzed the global data separately for the pre- and the post-training session, which showed that Sub-test and Training interacted significantly in the pre-training session, F(1, 92)=4.53, p=.04, ηp²=.05, but not in the post-training session, p=.29. As it turned out, the task-completed scores for sub-test B were comparable for the two training conditions (1.2 and 1.3 for COMP and FtF, respectively) while the score for sub-test A was higher in the COMP than in the FtF condition (1.7 and 1.5).

Discussion

The three major aims of this study were to see whether normally developing children and children with ASD would benefit from a short visuospatial training, and whether they would benefit equally, whether the kind of instruction would modulate training effects, and whether training effects would be modulated by the demands on mental rotation. In addition, we explored whether normally developing children and children with ASD would differ in conditions with higher demands on either global or local processing, and how such possible differences would relate to training effects.

With respect to the first question, the results are straightforward: both groups clearly benefitted from the training and they benefitted equally. The two groups were rather comparable from the beginning and the yoking procedure made them even more comparable, so that the training effect is a rather pure measure of the learning potential in the two groups. If so, we can conclude that children with ASD are equipped with the same learning potential as normally developing children, at least with respect to the visuospatial skills assessed in this study. It is true that the positive training effects were restricted to accuracy and task completed scores, while time on task was unaffected. However, it is important to consider that time on task is a relatively complex variable that integrates task difficulty (with longer time reflecting greater experienced difficulty), motivation (with longer time reflecting more effort and endurance), and strategy (with shorter time reflecting more insight into one's limited skills). This makes the interpretation rather difficult and it is possible that practice affects the different subcomponents in different ways (e.g., Travers et al., 2011). Moreover, as we did not include a control condition without practice, we cannot exclude that at least part of the practice affects might be unrelated to learning and are thus independent of instruction. And, indeed, we by no means suggest that such practice-unrelated effects cannot or should not occur. However, our main argument here is that single tests of visuospatial performance do not provide a valid assessment of an individual's true abilities, and that practice with a task helps to get a more comprehensive and more realistic picture. This practice may generate or trigger both practice-specific and practice-unspecific processes that are helping the true performance potential to unfold. Once this is achieved, children with and without ASD do longer seem to differ in their VSPC, at least as assessed in this study.

With respect to our second question, we can say that there was no systematic impact of the instruction method and none of the two instruction-related effects we obtained was modulated by session. That is, there are no reasons to assume that computer training would be in any way less effective than face-to-face training (e.g., Koppenhaver & Erickson 2003; Pennington, 2010; Ramdoss, et al., 2011). We suspected that computer training might be more suited for participants from the ASD groups. Even though no reliable effect supported that expectation, it is interesting to see that the best performance that the ASD group showed was in the more difficult sub-test B, and in fact the best performance that this group showed overall, was obtained in the computer-instruction condition; see Figure 3. Thus, even though it seems safe to conclude that face-to-face interaction does not provide any specific benefit as compared to computer instruction, we still consider it possible that computer instruction has benefits for individuals with ASD (e.g., Williams et al., 2002).

As to our third question, the only hint to a disadvantage of mental rotation capacities in ASD children was the relatively poor accuracy in the pre-interventional measure on the rotation-intensive sub-test B. However, this disadvantage was entirely eliminated after practice, suggesting that our intervention was successful in revealing the full potential of ASD children in visuospatial tasks. This observation is consistent with findings from Soulieres et al. (2009), who did not find significant group difference. However, it might be interesting to note that studies showing an advantage of individuals with ASD in mental rotation (Faltter et al., 2008) used computer-generated 3D images, while our study employed 2D material. This leaves the possibility that tasks using 3-D material are more successful to reveal an advantage of individuals with ASD.

As to our fourth question, it is fair to say that we could not find any evidence that ASD children might be systematically impaired with respect to either global or local processing. In fact, the only two effects that involved the Group factor suggest an advantage of ASD children in local processing: while the ASD and TD groups were comparable on the more global task, ASD children were faster and more accurate on the more local task. The time on task effect is somewhat ambiguous. It might indicate greater speed but it may also reflect less effort. The latter interpretation would fit with the often pronounced impulsivity and the lack of self-regulatory capacity in ASD (e.g., Prizant et al., 2006; Robinson, et al., 2009). In contrast, the benefits related to accuracy provide support for the assumption of a “local processing preference” in ASD (Happé & Frith, 2006), even though our findings might also be consistent with the assumption of a more structural local-processing benefit.

Taken altogether, our findings provide strong evidence for the trainability of visuospatial processing in both normally developing children and children suffering from ASD. We found a few processing advantages for ASD children, which were stable across training, and a few disadvantages that were eliminated by training. Given the relatively heavy emphasis that theoreticians have placed on the role of visuospatial processing differences in explaining autism, these findings might be considered surprising. In any case, they demonstrate that single-timepoint testing might overestimate processing differences and underestimate the cognitive/neural plasticity in disadvantaged or cognitively challenged groups. They also highlight the importance of cognitive training in exploring the true potential of participants (e.g., Pennington, 2010; Ramdoss et al., 2011). We acknowledge that our findings are preliminary and note that more research on the functional implications of different outcome measures and training regimes is necessary. There is also certainly need for extension to longer training periods, which may help to get deeper insight into how visual spatial functions are related to deficits in the processing of social and emotional information.

Chapter 5

General Discussion

Visuospatial processing skills (VSPS) is the over-arching concept I used to refer to a set of skills in gathering visual information from the environment and integrate them to derive meaning from what one sees. VSPS is required for successful academic performance and for many activities in daily living. While there is evidence of the trainability of VSPS in adolescents and adults (e.g., Newcombe & Frick, 2010; Uttal, et al. 2012), not much is known about school age children. Moreover, despite research on spatial intelligence in school age children, spatial content is hardly considered in school activity and there is hardly any awareness of teachers that VSPS are important (e.g., Krakowski, Ratliff, Gomez& Levine, 2010). The main goal of the present project was to develop instruments and methods for assessing and training VSPS in school age children, and to stimulate interest in elaborating and advancing research on VSPS in researchers. Toward this end my colleagues and I have developed a computerized game-based instrument: the “TangSolver”. Studies presented in this thesis described the rational, development, and implementation of this instrument. In the present chapter, I will summarize my general findings and discuss the in relation to limitations of my research and its implications for education, clinical practice, and research.

Summary of findings

This project utilized a pretest-intervention/training-posttest design. The pre- and post-tests did not include feedback, which make them comparable to conventional VSPS tests. Between pre- and post-test, the experimental group received training and feedback by means of either face-to-face or computerized instruction. The performance change in the child’s ability in solving visuospatial tasks from pre- to post-test indicate the trainability of VSPS (how much can be learned from short intervention) and as well the efficacy of the training. The first step taken was the evaluation of our manipulative experimental material in typical children (see chapter 2). The second was the evaluation of its computerized version (see chapter 3), followed by comparisons of its effectiveness in typical developing children (TD) and children with ASD (ASD) (see chapter 4). With respect to trainability of VSPS the following conclusions can be drawn.

First, the greater gain observed in the experimental groups that received training than in the control group that did not receive training (see chapters 2 & 3) provides evidence of VSPS trainability in typically developing children and demonstrates the efficacy of the interventions.

Second, a particular interesting result was the trainability of ASD children reported in chapter 4. It has been frequently reported that individuals with ASD exhibit superior abilities to identify fine stimulus features in spatial tasks (Caron, et al., 2006; Mottron, et al., 2003; Shah & Frith, 1993), but are limited in their ability to derive organized wholes from perceptual parts. This atypical ability has been linked to their limited use of gestalt grouping heuristics and/or the failure to consider the entire visual context (Happé, 1996). More recently, Happe and Frith (2006) have suggested that the weakness of global processing can be overcome in tasks with explicit demands. Even though in our experiment ASD participants were not highly functioning and even though we did not stress explicit task demands in terms of local and/or global processing, we could not find any evidence that ASD children might be systematically impaired with respect to either global or local processing. The few differences we observed were all eliminated by training, which supports suggestions that task understanding can be improved through training (Hill & Frith, 2003). Furthermore, many have stressed that learning in individuals with ASD is compromised by a restricted range of interests, inflexibility to a non-functional routine, resistance to change, and deficiencies in reciprocal social interaction (Richler, Bishop, Kleinke & Lord, 2007; Wolfberg, 2009). Yet, ASDs involved in our experiment did not show specific resistance to task accomplishment, suggesting that apparent resistance to learning in conventional ways might be more depending on interest and motivation rather than intrinsic capacity. As outlined by some authors (e.g., Roelfsema, 2006; Gilbert & Sigman, 2007), tasks that rely on grouping of elementary features require both levels of Gestalt rules, low-level like similarity, and high-level of grouping cues, such as familiarity with the shape. We consider it possible that the items used in our testing and training procedures played an important role, which calls for further experiments with more abstract items.

Third, to assess the potential of the current computerized VSPS training vis-à-vis traditional face-to-face training, we compared the effectiveness of these two trainings methods. We considered the computer training more suitable for those interested in autonomous learning, while face-to-face training was more personalized by employing manipulative material. Computerized training made use of visual hints (e.g. visually scaffolding, full or partial solution showing etc.), while face-to-face training employed the usual mix of verbal and visual cues. Irrespective of all these differences, the two training methods produced a coolant outcomes in both normally developing and ASD children. These observations provide evidence for the value of purely visual instruction cues (Mayer & Moreno, 2003; Mayer, 2009), at least in tasks like ours. This provides interesting avenues for the training of children with language-based learning disabilities (e.g., Guarnera, Commodari & Peluso, 2013; Dalton & Proctor, 2007; Newhall, 2012; Smith & Tyler, 2009).

Fourth, training effects in simple transformations tasks were equivalent in all three groups, and thus independent of actual practice. In contrast, there were specific training effects of the complex transformations task, which required flipping or rotating MPs. This suggests that simple transformations tests might be more appropriate for younger children or children with impaired mental rotation abilities (e.g., Guarnera, Commodari & Peluso, 2013), while the complex transformations task is more diagnostic with respect to VSPS proper.

Taken together, I am confident in concluding that even short training (Uttal et al., 2012) can enhance VSPS considerably in both TD and ASD children. It is reasonable to consider that more intense training might results in even higher gain. While computer training can be as efficient as face-to-face training (e.g., Koppenhaver & Erickson 2003; Pennington, 2010; Ramdoss, et al., 2011), the added value is to reduce barriers such as complexity of the interventions in term of materials and resources, and time required for implementing (Hale, et al, 2010). Moreover, training through computer applications does not rely on teacher expertise. While the material developed for this study was suitable for our purposes, more items will be necessary to extend training to other age groups and populations. Moreover, more tests would be helpful to predict pre-test performance and training efficiency, to define the most influential and efficient types of feedback, to diagnose which strategies learners are using, how strategy choice can be guided by feedback, and follow-up studies will be necessary to evaluate the longer impact of VSPS training.

Future direction

The findings of the current research raise further questions regarding data analysis and design, which may be addressed in future research projects.

Pre- and post-testing evaluation. For practical purposes, I have analyzed my data with the most widely used measurement model in education, which is using the logic of True Score Theory (TST) to assess change from pre- to post-test by means of ANOVAs for repeated measures. Even though TST is mathematically simple and straightforward, it has some drawbacks however. For example, TST is oriented towards the total test score rather than the individual items, subject characteristics, and test features, based on the assumption that the total (observed) score on a test is the 'true score' plus some random error which is assumed to be the same across all individuals (e.g., de Klerk, 2008; Kline, 2005). Many authors have claimed that in TST a higher score does not necessarily mean that the person has more ability with respect to the assessed trait than a person scoring lower; that is, a person scoring 80% does not necessarily have more ability than a person scoring 60% (e.g., de Klerk, 2008; Kline, 2005; Shultz & Whitney, 2005). To address that issue, Item Response Theory (IRT) and the Rasch model (a special case of IRT model) have been suggested as an alternative or supplementary model to TST (e.g., Bechger, et al. 2003; Bond & Fox, 2007; Wu & Adams, 2007). IRT is based on the premise that a test taker's performance on a given item is determined by two factors: the test taker's level of ability and the characteristics of the item. Others have suggested a generalized mixed-effects regression model (West, et al. 2007) that is quite robust to missing data, but the disadvantage is that such models are computationally complex. Regardless of the particular statistical method, a critical issue is how to get a better insight into the process of improving on a task or ability (e.g., Romero, Ventura & Garcia, 2008), which calls for a more detailed analysis of the training data. Furthermore, informal observations during the study suggested that some weaker students who initially were relying on extra help, were managing well after few trials—an improvement that apparently was lost until the posttest was taken. Reversely, successful skill acquisition might need some time to consolidate, which may suggest that longer delays between pre- and post-test provides more reliable results. However, the testing schedule will often depend on pragmatic issues constrained by school activities, curricula, and the research timeframe, which may underestimate true learning effects. One interesting option is computer adaptive testing (Frick, 1992; Lee & Weiss, 2010), which however has the downside that the calibration of the item pool requires extensive data collection - pre-administered to a sizable sample prior to test development (Parshall, Spray, Kalohn & Davey, 2006). Such calibration requires high collaboration among researchers, teachers, and software designers, which is the main constraint but it is hoped to evolve in future. It should be kept in mind that quality control, item bank development and psychometric processes involved in construction task like the one used here is more complicated than designing multiple choice items.

Differencing Methodology. Dellow (2010) argued that experiments employing pretest, an instructional period, and an eventual posttest with identical or nearly identical items do not allow for the efficient detection of variance in learning. Dellwo suggests evaluating the initial and final levels during the training phase, which makes for a multi-stage pre/post design (see fig.1). For instance, the current training structure consists of starting with easiest level (4MPs) to hardest (7MPs) of the same figure, independently of the individual's initial level. In multi-stage pre/post testing, the child's initial level could be defined as the level that the child can manage the task easily at. Accordingly, the child could start at any level and move to an easier one if s/he cannot manage within one minute, until the "initial level" has been identified. From this initial level, the training would start up to the compilation of the last, most difficult level (7MPs in our case). The difference between initial level and finally achieve level would then serve to diagnose individual differences, which could be used to predict potential learning benefits.

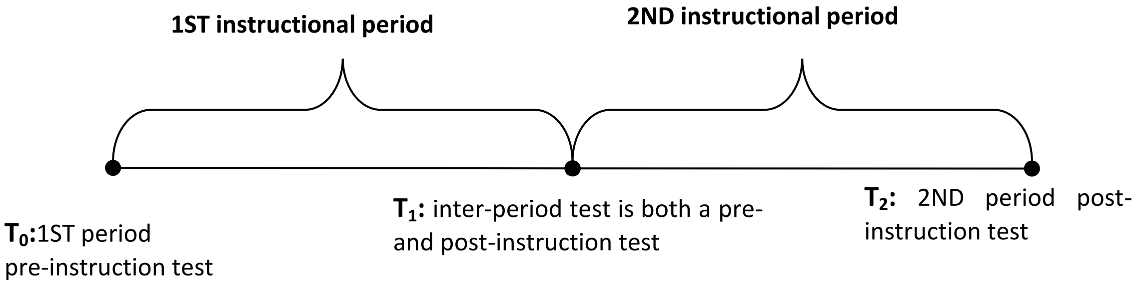


Figure 1.
The first stage of a two-stage assessment scheme is bracketed by pre- and post-instruction tests T0 and T1. The second stage is bracketed by T1 and T2. The diagnostic tests are identical or nearly identical instruments designed to assess learning of key skills and concepts. From Dellow, (2010). Course assessment using multi-stage pre/post testing and the components of normalized change. Directly reprinted with permission

Independent variables. The three variables included in our data analysis were time on task, Accuracy and Tasks completed. In contrast to Accuracy and Tasks completed, Time on task has produced disappointing results, thus we consider it unlikely that this variable is systematically related to those aspects of performance we were interested in. Possible solutions are either to increase the allocated time per items or to drop the time limits altogether. Furthermore, it is becoming more and more common for computerized games to provide large varieties of measures i.e., number of in/correct pieces moved, time from when the first move was initiated after a figure presentation, and so forth. Such outcomes might bring more insight into performance variability, especially if combined with mathematical models of educational data mining (e.g., Aleven et al. 2010; Baker et al., 2010; Feng & Heffernan, 2010; Shute & Zapato-Rivera, 2012). Indeed, a more continuous process analysis of the training/intervention phase should be the eventual goal of assessment (see, www.ed.gov/technology and http://myweb.fsu.edu/vshute/publications.html). However, the analyses of training data were beyond the scope of this PhD project, not the least because of an urgent need to rapidly turn empirical findings into significant insights that guide teachers in their teaching strategies (Bouchet, Harley, Trevors & Azevedo, 2013). Nevertheless, process analyses will be an important next step (Shute & Zapato-Rivera, 2012; Gobert et al. 2012). To conclude, such spatial training might be a great tool for educators, but there is still much to be learned in terms of interpretation of data and the significance of these.

Samenvatting

(Summary in Dutch)

Van visuospatiële informatieverwerking is sprake wanneer mensen visuele eigenschappen van hun ruimtelijke omgeving waarnemen, denk bijvoorbeeld aan schrift, tekeningen of het vinden van de weg naar huis. Mensen verschillen in de bekwaamheid om deze informatie te verwerken. Sommigen hebben goed ontwikkelde visueel-ruimtelijke verwerkingsvaardigheden (VSPS, ofwel *visuospatial processing skills*) en een goed visueel denkvermogen, terwijl anderen ermee worstelen. Desalniettemin zijn VSPS vooral belangrijk bij dagelijkse activiteiten, maar ook succesvolle academische prestaties vragen om goed ontwikkelde VSPS.

Onderzoek heeft uitgewezen dat VSPS verder te ontwikkelen zijn in jongeren en volwassenen. (Bijvoorbeeld Newcombe & Frick, 2010; Uttal, et al., 2012). Toch is er weinig bekend over de ontwikkeling van deze vaardigheden bij kinderen in de schoolleeftijd. Overigens maakt ruimtelijk functioneren, ondanks onderzoek naar ruimtelijke intelligentie onder schoolkinderen, nauwelijks deel uit van schoolactiviteiten en er is onder docenten weinig bewustzijn voor het belang van VSPS (Bijvoorbeeld Krakowski, Ratliff, Gomez & Levine, 2010).

Het kerndoel van dit promotieproject is het ontwikkelen van methoden en instrumenten ter analyse, toetsing en ontwikkeling van VSPS onder schoolkinderen. Daarnaast vormt het aanwakkeren van de belangstelling in het verbreden van VSPS-onderzoek onder wetenschappers een ander aspect van dit promotieproject. Voor dit doel hebben mijn collegae en ik een elektronisch spel-instrument ontwikkeld: de *Tang Solver.*

In dit proefschrift beschrijf ik de principes, het ontwikkelen en het implementeren van dit instrument. Het bevat een beschrijving van mijn algemene bevindingen, gerelateerd aan de beperkingen van mijn onderzoek. Eveneens wordt ingegaan op het potentieel van het trainen van VSPS middels de *Tang Solver* voor zowel het onderwijs als de klinische praktijk en toekomstig onderzoek.

In dit project werd een pretest-intervention-training-posttest-design gebruikt. De begin- en eindtoetsen waren zonder feedback om ze vergelijkbaar te maken met standaard VSPS-toetsen. Tussen de begin- en eindtoetsen werd door de experimentele controlegroep deelgenomen aan trainingssessies met feedback aan de hand van persoonlijke of elektronische instructies. Veranderingen in het prestatieniveau van het kind met betrekking tot het oplossen van de visueel-ruimtelijke taken van de begin- en eindtoetsen geven aan dat VSPS te ontwikkelen en aan te leren zijn. Met andere woorden, ze zijn een indicator van hoeveel aangeleerd kan worden door middel van een korte inventie. Deze veranderingen bewijzen tevens ook de doeltreffendheid van de training. De eerste stap was het beoordelen van ons manipulatieve experimentele materiaal onder normale kinderen (zie hoofdstuk 2). De tweede bestond uit het evalueren van de elektronische versie daarvan (zie hoofdstuk 3) onder meer door middel van vergelijkingen van de doeltreffendheid onder kinderen met een typische ontwikkeling (TO) en onder kinderen met een ASS (ASS) (zie hoofdstuk 4). Met betrekking tot het aanleren en ontwikkelen van VSPS kunnen de volgende conclusies worden getrokken.

We zien ten eerste dat de grotere opbrengsten die vastgesteld zijn onder de experimentele controlegroepen met training het bewijs leveren voor de aanleerbaarheid en ontwikkelingspotentieel van visuospatiële verwerkingsvaardigheden in kinderen met typische ontwikkeling. Dit in vergelijking met de controlegroep zonder training (zie hoofdstukken 2 & 3). Tevens is deze meerwaarde aan kennis bewijs van de doeltreffendheid van de interventies.

Een tweede conclusie betreft de bijzonder interessante resultaten omtrent het hetontwikkelingspotentieel van kinderen met een ASS (zie hoofdstuk 4). Er is al vaak gepubliceerd over het feit dat personen met een ASS in hogere mate in staat zijn specifieke prikkelkenmerken waar te nemen in ruimtelijk georiënteerde taken (Caron, et al., 2006; Mottron, et al., 2003; Shah & Frith, 1993), maar beperkt worden omdat zij geen georganiseerde gehelen kunnen afleiden uit de waarneembare onderdelen. Deze atypische vaardigheid wordt gekoppeld aan hun beperkt gebruik van Gestalt herkenningsheuristiek en/of aan het achterwege laten van de gehele waarneembare context (Happé, 1996). In een recente publicatie poneerden Happé en Frith (2006) dat dit zwaktepunt gecorrigeerd kan worden door middel van taken met uitdrukkelijke, specifieke eisen. Ons experiment heeft echter geenszins uitgewezen dat kinderen met een ASS systematisch een achterstand hebben met betrekking tot het verwerken van lokale of globale informatie, ofschoon zij niet hoog presteerden en wij geen nadruk hebben gelegd op uitdrukkelijke taakeisen. De enkele verschillen die werden opgemerkt konden d.m.v. training worden weggewerkt. Dit ondersteunt de hypothese dat begrip van de taak via training kan worden verbeterd (Hill & Frith, 2003). Tevens hebben velen benadrukt dat de leervaardigheden van personen met een ASS belemmerd worden door een beperkte interessesfeer, gebrek aan flexibiliteit in niet-functionele routines, verzet tegen veranderingen en tekorten in wederkerige sociale interacties (Richer, Bishop, Kleinke & Lord, 2007; Wolfberg, 2009). Niettemin vertoonden de ASS-deelnemers in ons experiment geen specifieke weerstandskenmerken tegen het voltooien van de taken. Hetgeen suggereert dat waarneembaar verzet tegen conventioneel leren in hogere mate afhangt van interesse en motivatie dan van intrinsieke vaardigheden. Een aantal auteurs (bv. Roelfsema, 2006; Gilbert & Sigman, 2007) hebben al gewezen op het feit dat taken die gestoeld zijn op het groeperen van elementaire onderdelen beide niveaus aan Gestaltherkenning vergen: een laag niveau aan herkenning van overeenkomsten enerzijds en een hoog niveau aan grouping cues, zoals vertrouwdheid van de vorm, anderzijds. Het is mogelijk dat de items en trainingsprocessen van ons experiment een belangrijke rol hebben gespeeld, hetgeen aanleiding geeft tot verdere experimenten met abstractere items.

Ten derde hebben we in het toetsen van het potentieel van de huidige elektronische VSPS-training, tegenover dat van traditionele face-to-face-training, de doeltreffendheid van beide trainingsmethoden vergeleken. We achtten de elektronische training geschikter voor diegenen die geïnteresseerd zijn in autonoom leren, terwijl face-to-face-training veel persoonlijker was door het manipulatieve materiaal. Onze elektronische (computer) training maakte gebruik van visuele aanwijzingen (bv. waar oplossingen deels of geheel werden getoond, enz.), terwijl face-to-face-training de gebruikelijke mengeling aan verbale en visuele aanwijzingen gebruikte. Ongeacht deze verschillen, leverden beide methoden opvallende resultaten op onder TO- en ASS-kinderen. Deze waarneming is bewijs van de waarde van puur visuele instructie ‘cues’ (Mayer & Moreno, 2003; Mayer, 2009), tenminste bij taken zoals de onze. Tevens geeft het aanleiding tot het ontdekken van nieuwe richtingen wat betreft het scholen van kinderen met talige leerproblemen (bv. Guarnera, Commodari & Peluso, 2013; Dalton & Proctor, 2007; Newhall, 2012; Smith & Tyler, 2009).

Een vierde punt betreft de resultaten. De resultaten voor de taken met eenvoudige transformaties waren in alle drie groepen gelijkwaardig en dus onafhankelijk van werkelijke praktijken. Daarentegen leverden de taken met complexe transformaties specifieke resultaten op. Daaruit kan men concluderen dat eenvoudige transformatietoetsen wellicht toepasselijker zijn voor jongere kinderen of kinderen met beperkte mentale rotatievaardigheden (bv. Guarnera, Commodari & Peluso, 2013), terwijl complexe transformatietaken meer een diagnosemethode is voor VSPS an sich.

Uit dit alles concludeer ik dat zelfs een korte trainingsperiode (Uttal, et al., 2012) kan leiden tot een verbetering van visuospatiële verwerkingsvaardigheden zowel in kinderen met een typische ontwikkeling als in kinderen met een ASS. Men kan redelijkerwijs daaruit afleiden dat intensievere training hoger rendement zou opleveren. Hoewel computertraining even efficiënt is als face-to-face training (bv. Koppenhaver & Erickson, 2003; Pennington, 2010; Ramdoss, et al., 2011) is de meerwaarde ervan dat het de beperkingen, zoals complexiteit van interventies wat betreft materialen en middelen, verlaagt (Hale, et al., 2010). Daarbij geldt ook dat training via computerapplicaties niet afhankelijk is van pedagogisch of didactische expertise. Verder kunnen we vaststellen dat het materiaal dat in het kader van dit onderzoek ontwikkeld werd toepasselijk was voor onze doeleinden er meer items nodig zullen zijn om de training te verbreden naar andere leeftijdsgroepen en doelgroepen. Daarnaast zou een verbreed aantal toetsten bijdragen aan een aantal zaken. Onder meer aan het voorspellen van prestaties in de begintoets en van de efficiëntie van de training, aan het definiëren van de meest effectieve en gezaghebbende typen feedback, aan het vaststellen van welke leerstrategieën gebruikt worden en hoe deze strategieën gestuurd kunnen worden door feedback en tenslotte aan de vervolgstudies, die nodig zullen zijn om de impact van de VSPS-training op de lange termijn te beoordelen.

Toekomstige richting

De bevindingen van het huidige onderzoek geven aanleiding tot het stellen van vervolgvragen omtrent gegevensanalyse en opzet. Deze zaken kunnen in toekomstige onderzoeksprojecten wellicht worden onderzocht.

Evaluatie begin- en eindtoets

Uit praktische overwegingen heb ik het in het onderwijs meest gangbare model gebruikt om mijn gegevens te analyseren. Hierbij wordt de logica van de Klassieke Testtheorie (CTT) gebruikt om de veranderingen tussen begin- en eindtoets te beoordelen aan de hand van ANOVA's voor herhaalde waarden. Hoewel CTT mathematisch eenvoudig is heeft het enkele nadelen. Ten eerste is CTT gericht op de totale testscore in plaats van op individuele items, kenmerken van de deelnemer en van de toets, hetgeen gestoeld is op de veronderstelling dat de totale score de 'true score' is, plus een willekeurige meetfout, die verondersteld wordt voor te komen bij alle deelnemers (bv. de Klerk, 2008; Kline, 2005). Verschillende auteurs hebben geponeerd dat bij CTT een hogere score niet noodzakelijk betekent dat die persoon een hogere vaardigheid heeft wat betreft het getoetste kenmerk dan een persoon met een lagere score. Met andere woorden, de vaardigheden van iemand met een score van 80% zijn niet noodzakelijk hogere of beter dan die van een persoon met een score van 60% (bv. de Klerk, 2008, Kline, 2005; Shultz & Whitney, 2005). Teneinde dat punt aan de orde te stellen worden Item Response Theory (IRT) en het Rasch-model (een bijzonder vorm van IRT) voorgesteld als alternatief of als aanvullend model (bv. Bechger, et al., 2003; Bond & Fox, 2007; Wu & Adams, 2007). IRT is gebaseerd op de premisse dat de prestatie van een deelnemer aan een gegeven item bepaald wordt door twee factoren: zijn of haar vaardigheden en de kenmerken van het item. Andere publicaties stellen een generalized mixed-effects regressiemodel voor (West, et al. 2007), wat heel effectief is inzake onvolledige gegevens. Het nadeel echter is dat dergelijke modellen in hun berekeningen erg complex zijn. Statistische methodiek terzijde, is één van de belangrijkste punten hoe men beter inzicht kan krijgen in het verbeteringsproces van taken en vaardigheden (bv. Romero, Ventura & Garcia, 2008), wat aanleiding geeft tot een gedetailleerdere analyse van de gegevens van de training. Daarnaast moet worden opgemerkt dat tijdens het project informele observaties hebben uitgewezen dat enkele zwakkere studenten, die aanvankelijk extra hulp nodig hadden, na een aantal proeven veel beter presteerden. Deze verbetering is kennelijk tot de eindtoets verloren gegaan. Anderzijds, kan men vaststellen dat succesvolle acquisitie van vaardigheden wellicht tijd vergt om zich te consolideren. Daarbij zouden langere tussenpozen tussen begin- en eindtoetsen mogelijk betrouwbaardere resultaten kunnen opleveren. Het plannen van de toetsen is echter dikwijls afhankelijk van pragmatische zaken en wordt beperkt door schoolactiviteiten, lesprogramma's en de onderzoeksperiode. Dit alles kan leiden tot het onderschatten van de ware resultaten op het leren. Computer adaptive testing is een interessant alternatief (Frick, 1992; Lee & Weiss, 2010). Echter een nadeel ervan is dat het een hoge mate aan verzameling van gegevens vergt om de item-pool te kalibreren (Parshall, Spray, Kalohn & Davey, 2006). Voor een dergelijke afstemming wordt ook een hoge mate aan samenwerking tussen onderzoekers, docenten en softwareontwerpers vereist. Dat laatste is de belangrijkste beperking maar hopelijk kan dit in de toekomst worden ontwikkeld. Men moet ook rekening houden met het feit dat de kwaliteitscontrole, item bank-ontwikkeling en psychometrische processen die in een dergelijk opbouwproces vereist zijn veel ingewikkelder zijn dan in het louter ontwerpen van multiple choice items.

Methodologie

Dellow (2010) beweert dat experimenten die een begintoets, een instructieperiode en een uiteindelijke eindtoets met identieke of quasi-identieke items gebruiken een efficiënte detectie van variantie in leren uitsluiten. Dellow stelt voor dat men beter de niveaus aan het begin en aan het eind van de trainingsfase kan evalueren: een multi-stage-pre-post-design in feite (zie fig. 1). De huidige trainingsstructuur bestaat bijvoorbeeld uit het eenvoudigste niveau (4MP's) en eindigt op het zwaarste niveau (7MP's) op hetzelfde fig., onafhankelijk van het individueel beginniveau. Bij multi-stage-pre-post-design, kan het beginniveau mogelijk gedefinieerd worden als het niveau waarop het kind gemakkelijk de taak kan uitvoeren. Bijgevolg zou het kind dan op enig welk niveau kunnen aanvangen en vervolgens doorgaan naar een eenvoudiger niveau indien hij/zij niet binnen één minuut de taak kan uitvoeren. En dit totdat het 'beginniveau' vastgesteld kan worden. Vanaf dat niveau zou de training dan beginnen tot het laatste niveau bereikt is (in ons geval 7MP's). Het verschil tussen beginniveau en uiteindelijke eindniveau zou dan de individuele verschillen kunnen duiden, hetgeen gebruikt kan worden om potentiële voordelen in het leren te voorspellen.

Onafhankelijke variabelen

De drie variabelen die gebruikt werden in onze gegevensanalyse waren Time-on-task (gespendeerde tijd op de taak), Accuraatheid en Voltooide Taken. In tegenstelling tot Accuraatheid en Voltooide Taken, leverde Time-on-task teleurstellende resultaten op. Dien ten gevolge achten we de kans klein dat deze variabel systematisch gerelateerd is aan de prestatieaspecten waar wij in geïnteresseerd waren. Mogelijke oplossingen betreffen het verlengen van de toegewezen tijd per item of het algeheel achterwege laten van tijdslimieten. Daarnaast wordt het steeds gangbaarder dat computerspelen een groot scala aan maten aanbieden bv. wat betreft het aantal (on)juiste verplaatste stukken, tijd vanaf de eerst verplaatsing na aanvankelijke presentatie, enz. Dergelijke resultaten kunnen wellicht meer inzicht geven wat betreft variatie in presteren, vooral in combinatie met mathematische methoden van educational datamining (bv. Aleven, et al.; Baker, et al., 2010; Feng & Heffernan, 2010; Shute & Zapato-Rivera, 2012). Bovendien zou meer continuïteit in de procesanalyse van de training/interventie-fase het uiteindelijke doel moeten zijn van de evaluatie (zie ook www.ed.gov/technology en http://myweb.fsu.edu/vshute/publications.html). Echter, een analyse van de gegevens van de training lag buiten de reikwijdte van dit doctoraal project. Dit niet alleen omdat er een zekere urgentie is om empirische resultaten om te vormen tot doeltreffende inzichten om docenten te leiden in hun leerstrategieën (Bouchet, Harley, Trevors &Azevedo, 2013). Desalniettemin, maken de procesanalyses deel uit van een belangrijke volgende stap (Shute & Zapato-Rivera, 2012; Gobert, et al., 2012). Afsluitend kan men stellen dat hoewel dergelijke ruimtelijke training een belangrijk instrument kan zijn voor educators, er nog steeds erg veel geleerd moet worden in terme van het interpreteren van gegevens en het duiden van dien.

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Curriculum Vitae

Ellahe (Elaheh) Chabani was born on May 5th 1958 in Iran and moved to France in 1977. She studied Mathematics and Physics at University Louis Pastor (ULP)–Strasbourg/France. In 1984 she graduated in Industrial Electronic - Software and Hardware development. She started her career as an electronics and computer instructor and project manager in a different Institute of Technology in Strasbourg. After her move to The Netherlands, she worked for international schools and international/ European organizations. Her scientific interests broadened to the field of psychology. She obtained her master's degree from Leiden University in 2007. In 2008, she received a 4-year NWO Mozaïek grant. Her interest was to bridge her two domains of expertise by developing and implementing a computerized visuospatial test assessment tool for children. The results of this undertaking are (partially) presented in this dissertation. Ellahe aspires to continue to evaluate and improve other computer-based assessment tools, and to continue to work with interested people.

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