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Drawing in the Dark: Limitations in Building Pictorial Representations by Adventitiously Blind Students

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Abstract

Background: This study was conducted to investigate the factors contributing to the limitations in producing pictorial representations by adventitiously blind students.

Objective: The aim of this study is to explore and assess the extent of limitations and underlying factors contributing to the constraints in generating pictorial representations by adventitiously blind students.

Method: This research employed a qualitative and observational approach, involving a single adventitiously blind subject from a special school in Malang, East Java, Indonesia. The subject was selected based on predetermined criteria: being an adventitiously blind male student in the ninth grade with an average math report score above 80. Data collection began with the subject completing a math task followed by a semi-structured in-depth interview. All subject activities were audiovisually recorded and subsequently analyzed.

Results: Several limitations were identified in generating pictorial representations by adventitiously blind students.

Conclusion: Adventitiously blind students possess a fundamental ability to build pictorial representations of rectangular shapes, but with constraints in accurately measuring line lengths, representing angles, and perspective.

Contribution: There exists an information gap regarding limitations in generating pictorial representations by adventitiously blind students. This study aims to address this gap and provide insights into such limitations.

Keywords: *Limitations, Pictorial representation, adventitiously blind students.*

1. INTRODUCTION

Blind students are those who experience either total or partial vision impairment, preventing them from using sight normally to comprehend their surroundings and information. A blind student has a visual acuity of 20/200, either with or without corrective glasses. A visual acuity of 20/200 means that a blind student can see at a distance of 20 feet, whereas a person with normal vision can see at a distance of 200 feet (Hallahan et al., 2014). The visual sense is unable to function entirely (total blindness) or retains limited functional vision (low vision). Factors contributing to this condition

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include prenatal (during pregnancy), natal (after birth), and postnatal (developmental) factors. Prenatal factors relate to parental health history and abnormalities during pregnancy. Natal factors occur during childbirth, where blindness can result from eye or optic nerve damage due to trauma during the delivery process and may also be caused by the transmission of gonorrhea bacteria from mother to child. Postnatal factors leading to blindness during development can arise from eye diseases or injuries caused by accidents (Utomo & Muniroh, 2019). Blindness occurring at a specific age is referred to as adventitious blindness or late-onset blindness (Hollins, 1989). The age at which blindness occurs significantly influences spatial representation perception and attitudes toward blindness. There is a distinction in mental visualization between congenitally blind students and those who experience blindness at a certain age, referred to as adventitiously blind students. Adventitiously blind students have visual experiences of objects in their surroundings, which serve as initial modalities for representation. It is supported by research indicating that the representation of object forms by congenitally blind students is multimodal, while for adventitiously blind students, the representation process is constructed from visual information stored in memory. Prior visual experiences provide opportunities to create a visual framework, further facilitating improved performance in low-complexity object imaging tasks for adventitiously blind students (Toroj & Szubielska, 2011).

A blind student with diminished sensory modalities for vision tends to enhance other senses, such as touch, hearing, and smell to compensate for the sensory deficit (Frasnelli et al., 2011; Kohanova, 2006; Kupers & Ptito, 2014). The reduction in visual sensory acuity enables the brain to access new pathways in an effort to overcome visual limitations, known as Neuroplasticity (Silva et al., 2018). Neuroplasticity is the brain's ability to reorganize the development of normal tissue. This allows brain regions responsible for visual information processing to maintain and even develop their functions, even when input originates from non-visual senses (Abboud et al., 2014; Maidenbaum et al., 2014). The loss of visual sensory modalities triggers the reorganization of normal networks, particularly at the cortical level, thus expanding the processing of information received by the senses and making normal networks more functional. Consequently, a blind student undergoes cortical changes resulting in increased functional capacity (Silva et al., 2018), and is illustrated in Figure 1.

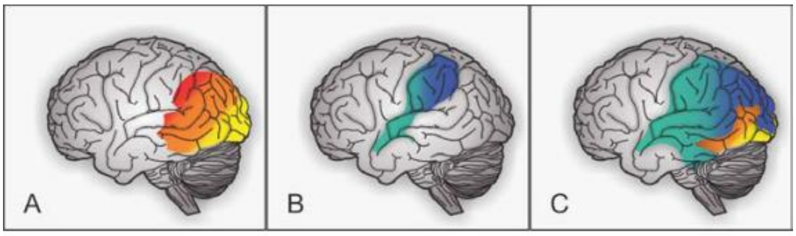

Figure 1. Expansion and Enhancement of Functional Capacity

Source: Adopted from Silva, P.R., Farias, T., Cascio, F., Santos, L. dos, Vinícius, P., Crespo, E., Ayres, C., Ayres, M., Marinho, V., Bastos, V.H., Ribeiro, P., Velasques, B., Orsini, M., Fiorelli, R., Freitas, M.R.G. de & Teixeira, S., 2018, 'Neuroplasticity in Visual Impairments', 10, 111–117

Figure 1 illustrates different brain areas involved in the context of visual processing in sighted students (A), language comprehension and semantic processing (B), and Neuroplasticity-related expansion of visual areas in the blind (C) (Silva et al., 2018). This phenomenon is underpinned by the concept that the visual information processing areas in sighted students contribute to processing stimuli from the remaining senses in the blind (Amir Amedi et al., 2003; Cunningham et al., 2011; Poirier et al., 2007; Ptito et al., 2012). Moreover, cortical visual areas have also been implicated in processing tactile and auditory information (Cohen et al., 1997; Kujala et al., 2005; Sadato et al., 1996; Saville et al., 2015; Striem-Amit et al., 2012). Additionally, after losing visual sensory modalities, blind students undergo sensory compensation, a process marked by shifting sensory functions (Braun, 2016; Pieniak et al., 2022; Sorokowska & Karwowski, 2017). The most notable compensation is observed in touch and hearing (Frasnelli et al., 2011). Various studies have demonstrated enhanced tactile and auditory skills in the blind (Fortin et al., 2008; Goldreich & Kanics, 2003; Gougoux et al., 2004; Lessard et al., 1998; Röder et al., 1999; Tinti et al., 2007). Blind students exhibit heightened tactile sensitivity compared to sighted students (Silva et al., 2018) due to the Neuroplasticity process they undergo (Radziun et al., 2023). Moreover, they possess heightened touch sensitivity, particularly in their fingertips (Kupers & Ptito, 2014). In terms of hearing, blind students exhibit superior auditory function and accuracy (Frasnelli et al., 2011; Wong et al., 2011). The loss of vision triggers a heightened overall sensory sensitivity (Pieniak et al., 2022). Blind students learn and understand objects using these heightened senses. However, the process of visualizing images (objects) by a blind student and a sighted student differs. It is due to the differing experiences utilized in the process: blind students rely on tactile experiences, while sighted students rely on visual experiences (Hallahan & Kauffman, 1988). The blind engage in repetitive tactile exploration activities until they grasp and comprehend the characteristics of the object. According to Lowenfeld, tactile exploration can be categorized as synthetic tactile exploration and analytic tactile exploration. Synthetic exploration involves small objects and can be done with one or two hands, while analytic exploration pertains to larger objects and involves sequentially exploring parts of the object. These parts are then mentally reconstructed to describe the whole object. The tactile exploration performed by blind learners serves as input information, which is subsequently utilized to understand and complete tasks (Lowenfeld, 1971). Tactile exploration activities are depicted in Figure 2.

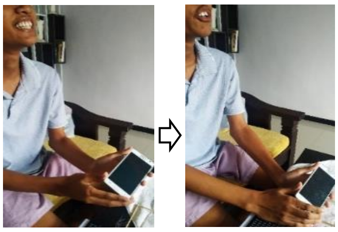

Figure 2. Tactile Exploration Conducted by the Blind

The function of tactile exploration performed by the blind is used to gather information for the purpose of representation. Representation is configuring characters, images, and concrete objects used to describe something (DeWindt-King & Goldin, 2003; Goldin, 1998b, 2002; Monoyiou et al., n.d.). Representation expresses ideas, which are then embodied in various ways, such as verbal, written, symbolic, pictorial, diagrammatic, graphic, or model-based forms (Goldin, 2002). Representation is divided into two systems, namely internal and external representation (Goldin, 1998a; Goldin & Shteingold, 2001; Janvier et al., 1993). External representation is the manifestation or form of internal representation that can be directly observed through written words, graphics, numbers, or algebra. Types of external representation include (1) verbal representation, expressed through writing or words; (2) visual representation, consisting of images, diagrams, or graphs, along with interrelated activities; (3) symbolic representation, composed of equations, operational signs and connections, algebraic symbols, and interrelated actions (Goldin & Shteingold, 2001). Visual representation is a significant form of representation in the process of learning mathematics. There are three types of visual representation, which is a pictorial representation, accurate schematic representation, and inaccurate schematic representation (Boonen et al., 2014). A blind student possesses a fundamental ability to create pictorial representations at a relatively young age and can gain understanding through experience (Eriksson, 2013; Millar, 1975). Pictorial representation in the context of blind students refers to using images or visual representation to convey information or messages, aiding those with visual impairments in understanding the surrounding world. Furthermore, pictorial representation among blind people is crucial in aiding their comprehension of mathematical concepts, developing visual thinking, and engaging more effectively in mathematical learning activities. These pictorial representations can be accessed through Braille letters and tactile graphics, for instance, representations of geometric shapes, diagrams, or graphs can be created using different surfaces that provide varying heights to form object contours that can be touched and understood by blind people. In summary, pictorial representation plays a vital role in assisting blind people to comprehend their surroundings, particularly in the pedagogical domain of learning mathematics. However, several challenges and factors can lead to limitations in generating pictorial representations for blind people. And therefore, this article explores the causes of limitations in building pictorial representations for blind people.

2. METHOD

This study was conducted at a special school (called SLB) in Malang, East Java, Indonesia. The aim was to describe and explore the limitations that arise when adventitiously blind students produce pictorial representations. The method employed in this research was qualitative and observational. Qualitative research is characterized by its reliance on subjective participant notes rather than quantitative statistics (Creswell, 2012). Subjects were selected based on predetermined criteria, which were adventitious blind students without other disabilities, enrolled in ninth grade, male, as well as have an average math report score above 80 out of 100. For this purpose, one adventitiously blind student who met the specified criteria was chosen. The subject had experienced total blindness since the fourth grade of primary school due to a head injury at the back of the head. Since then, the subject gradually experienced a decline in vision until complete vision loss.

Data collection commenced as the subject undertook a 30-minute task involving flat-plane geometry in mathematics. Subsequently, an in-depth semi-structured interview was conducted by the researcher. The mathematics task comprised Braille text accompanied by raised graphics. Additionally, the subject was provided with tools to assist in formulating responses. The provided aids included bamboo pieces, each measuring 5 – 10 cm in length and 0.25 cm in diameter. These bamboo pieces were carefully smoothed on all sides to ensure safe use by the participant, and their provision was adapted from Neumann's study (Neumann, 1971).

All activities performed by the subject were audiovisually recorded and subsequently analyzed. The recording process was conducted with the subject's consent. One week later, the subject was assigned another mathematics task and interviewed again. Data saturation was achieved by the fourth meeting when the mathematics task was administered. The researcher posed questions precisely per the interview guidelines, documented key points, and observed changes in the subject's mood and tone. The subject was afforded freedom throughout the interview process. The interview concluded upon addressing all questions outlined in the interview guide. The maximum duration for an interview was 45 minutes, with a minimum duration of 15 minutes. All interview recordings were then transcribed and utilized in the analysis process.

3. RESULTS

The data of pictorial representation outcomes are derived from the subject's responses and interviews. The subject was prompted to explain the raised graphics in the mathematics task. The collected data is presented as follows:

,4&GI PJ]1 5^P LBR Y ": YA_I @A > B`WH4 ,5^P TI=I Y ": YA_I (> > KIRI4,> 5^P

EMPAT SDT

Figure 3: Mathematics Task Responses

Meaning: A rectangle has equal width on the top and bottom. It has the same height on the right and left. And it has four corners. The following process, after the subject wrote down the answer, is the interview, with the following interview results:

Researcher: What was the shape of the raised image you touched?

Subject: It was a rectangle, ma'am.

Researcher: Could you explain the rectangle?

Subject: Certainly, ma'am. A rectangle has width, which is the upper and lower area (accompanied by touching the top and bottom sides of the rectangle image). It has the same height as the right and left areas (touching the left and right sides of the rectangle image).

Researcher: Why did you answer like that?

Subject: Because the raised image was in the shape of a rectangle. It also has width, which is the upper and lower area, and the same height, which is the right and left area. Oh, and it also has four corners."

The subject actually explored the raised image presented in the mathematics task and then reconstructed it using the tool, resulting in the representation shown in Figure 4.

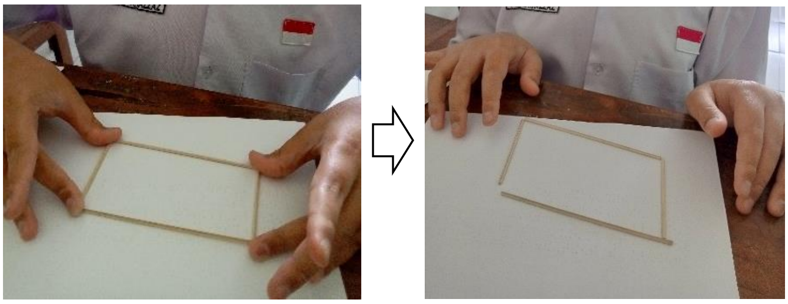

Figure 4: Pictorial Representation Result of the Rectangular Shape

Next in the process, after reconstructing the subject, is an interview. The results of the interview are as follows:

Researcher: could you explain the steps of redrawing it?

Subject: touching the image, remembering, constructing or assembling the tool to make it into a rectangular shape, and arranging the corner areas. Making them match each other, slowly holding the formed corners to align the right and left sides, top and bottom. After that, when it's aligned, slowly release it.

Researcher: why do you use these steps?

Subject: from my thoughts, to make it easier.

Researcher: what difficulties do you encounter in creating the image?

Subject: when releasing, sometimes the tool sticks to the hand, causing the image to change. Researcher: could you explain all the steps to complete the task?

Subject: reading the task, touching the raised image, writing the answer on paper, touching the raised image of the rectangle, touching the tool. Assembling and orienting the tool, aligning its sides, and shaping it like a rectangle. Holding the corner areas and then slowly releasing them. (With a confident gesture).

4. DISCUSSION (10 PT)

This paper investigated how students with acquired blindness generate pictorial representations. An student with acquired blindness possesses an essential ability to create pictorial representations at a relatively early age and can acquire understanding through experience (Eriksson, 2013; Millar, 1975). Based on these findings, we initiated a study on pictorial representation in students with acquired blindness while identifying potential limitations. Referring to Figure 3, which shows the subject's mathematical task response, the subject wrote: 'rectangle, having equal width on top and bottom. Having equal height on the right and left, as well as having four corners.' This response was confirmed twice during the interview process, as follows '...a rectangle has width, which is the top and bottom area (Touching the sides at the top and bottom of the rectangle). It has equal height, which is the right and left area (Touching the sides on the right and left of the rectangle)...' and '...the raised image is in the shape of a rectangle. And it has width on the top and bottom. It has equal height, which is the right and left area. Oh yes, it also has four corners'. Even though incomplete and constrained in linguistics, these subjects' answers may presumably result from a lack of visual stimulation for several years prior to the onset of blindness. This hypothesis is supported by several studies concluding that visual input and stimulus play a crucial role in developing lexical/linguistic and pragmatic language aspects. Visual stimulus is also important in forming hypotheses about various linguistic system aspects (Andersen et al., 1984). Other studies support our finding that a significant lack of visual ability can impact language learning (Graham et al., 2015; Tran & Pho, 2020). Language acquisition involves utilizing all five senses, then developing four language skills: listening, speaking, reading, and writing (Tran & Pho, 2020). Furthermore, variations in the linguistic development of students with acquired blindness can stem from diminished experience, differences in linguistic input, and other factors (Andersen et al., 1993).

Further research has revealed that students with acquired blindness require supportive interactions to develop oral language, awareness of Braille letters, and opportunities to explore writing (Erickson & Hatton, 2007). Despite these limitations, many blind children begin to learn the language proficiently. This achievement can be explained by the cognitive Neuroplasticity system, wherein children with deficiencies in one modality often compensate using other modalities. Nevertheless, there are often differences in how language processing is actualized (Andersen et al., 1993). An interesting was found during the interview when the subject consistently engaged in slow and repetitive touch exploration on each side of the raised image while describing the image. Touch exploration by students with acquired blindness serves as an input mechanism and aids in analyzing, understanding, and discerning features and shapes of the raised image. This phenomenon is supported by the notion that students with acquired blindness rely on their sense of touch to comprehend shapes and volumes of objects (Hötting & Röder, 2009). This activity represents one of the greatest compensatory mechanisms for the loss of visual capability, allowing external input to be obtained through touch exploration and hearing. Many studies have examined touch exploration in students with acquired blindness. In-depth research has shown that tactile acuity in students with acquired blindness is not only superior to that of sighted students (Alary et al., 2009; Fleming et al., 2016; Goldreich & Kanics, 2006), but it also allows them to perceive touch more rapidly (Ravisankar & Brundha, 2016). However, it is believed that weaknesses still exist in the tactile understanding of students with acquired blindness, which may influence the perception and interpretation of objects, particularly limitations in recognizing detailed aspects of objects not always accessible through touch.

Furthermore, the blind subject slowly and repeatedly explored the raised image, tactilely examined the Braille characters present in the mathematical task, and even tactilely counted the number of assistive tools to be used for reconstructing the raised images. This phenomenon was confirmed twice during the interview process, as follows "...reading the task, touching the raised image, answering/writing the task response on paper, touching the raised image of the rectangle, touching the assistive tools. Assembling and orienting the assistive tools, aligning their sides, forming a rectangular shape...". The tactile exploration performed by the blind student is subsequently processed by the visual cortical area in the brain (Cohen et al., 1997; Kujala et al., 2005; Sadato et al., 1996; Saville et al., 2015; Striem-Amit et al., 2012), and is further used to construct a representation of an object (A. Amedi et al., 2005; James et al., 2002; Sathian, 2005; Woods & Newell, 2004). The pictorial reconstruction is conducted by the blind student using assistive tools. The reconstruction process begins by placing each assistive tool studently, then connecting their ends to form a rectangle, with the fingers positioned at each rectangle corner.

Subsequently, corrections are made by tactilely assessing each side of the formed rectangle to adjust it to the geometric shape of a rectangle. The fingers are then slowly lifted from the assembled structure. The outcome of the reconstruction process is a somewhat imprecise rectangular shape at its corners (Refer to Figure 4). In the illustration, deficiencies in lines that reflect difficulties experienced by the blind student in accurately measuring line lengths are evident. This constraint is presumed to arise due to the lack of visual feedback typically experienced by the blind student.

Furthermore, this representation of a rectangle also demonstrates challenges in accurately depicting angles and perspectives. It reflects the difficulties faced by the blind student in producing illustrations and perspective in drawings. Generally, this rectangular representation illustrates that blind students have limitations in accurately depicting two-dimensional objects, particularly in line lengths, relationships between elements, angles, and perspective representation (Kamel & Landay, 2000). Another corroborating fact supporting the findings of this study is that a blind student can explore an object using touch, construct a mental representation, and produce a drawing. However, the accuracy of the produced drawing relies on the blind student's ability to construct, manipulate, and interpret the contents of the formed mental representation (Amir Amedi et al., 2008).

5. RECOMMENDATIONS AND IMPLICATIONS

This study analyzed the pictorial representation abilities of adventitiously blind students and found that they possess a fundamental capacity to generate pictorial representations of rectangular shapes; however, they exhibit limitations in accurately measuring line lengths, depicting angles, and conveying perspective. As a result of these observations, in order to achieve more optimal outcomes and objectives, we recommend that these students receive multisensory stimulation, the development of assistive tools, reinforcement of tactile skills, richer social interactions, and the creation of specialized learning materials to enhance their pictorial representation abilities.

6. LIMITATIONS

The research was conducted using a qualitative method, hence the research findings cannot be generalized. The outcomes generated are highly contingent upon the characteristics of the subjects, specific contexts, and situations under investigation, as well as being exploratory in nature.

7. CONCLUSION

Our study demonstrates that adventitiously blind students possess a fundamental ability to generate pictorial representations of rectangular shapes, albeit with limitations. Blind students rely on their tactile and auditory senses as substitutes for visual input in the process of understanding images. However, challenges exist in accurately measuring line lengths and accurately representing angles and perspectives. Nevertheless, they are capable of exploring objects through touch, constructing mental representations, and producing pictorial representations. The accuracy of these depictions depends on an student's ability to translate mental representations into more precise images. The implicit implication of our research findings suggests that the pictorial representations produced by adventitiously blind students are still incomplete. It is believed to arise from various factors, including deficiencies within the cognitive Neuroplasticity system, limitations in the tactile and auditory systems, as well as insufficient social interaction experienced by blind students.

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Author's Contributions

All authors have collaborated effectively to produce this research article with significant scientific quality and contribution. The first author designed the research, managed data collection and analysis. The second author assisted in the literature review and interpretation of results. The third author contributed to data verification and analysis.

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References

Abboud, S., Hanassy, S., Levy-tzedek, S. & Maidenbaum, S., 2014, 'EyeMusic : Introducing a " visual " colorful experience for the blind using auditory sensory substitution', 32, 247–257.

Alary, F., Duquette, M., Goldstein, R., Elaine Chapman, C., Voss, P., Buissonnière-Ariza, V. La & Lepore, F., 2009, 'Tactile Acuity in the Blind: A Closer Look Reveals Superiority Over the Sighted in Some But Not All Cutaneous Tasks', Neuropsychologia, 47(10), 2037–2043.

Amedi, A., Kriegstein, K. von, Atteveldt, N.M. van, Beauchamp, M.S. & Naumer, M.J., 2005, 'Functional Imaging of Human Crossmodal Identification and Object Recognition', Experimental Brain Research, 166(3–4), 559–571.

Amedi, A., Merabet, L.B., Camprodon, J., Bermpohl, F., Fox, S., Ronen, I., Kim, D.S. & Pascual-Leone, A., 2008, 'Neural and Behavioral Correlates of Drawing in an Early Blind Painter: A Case Study', Brain Research, 1242, 252–262.

Amedi, A., Raz, N., Pianka, P., Malach, R. & Zohary, E., 2003, 'Early "Visual" Cortex Activation Correlates with Superior Verbal Memory Performance in the Blind', Nature Neuroscience, 6, 758–766.

Andersen, E.S., Dunlea, A. & Kekelis, L., 1993, 'The Impact of Input: Language Acquisition in the Visually Impaired', First Language, 13, 23–49.

Andersen, E.S., Dunlea, A. & Kekelis, L.S., 1984, 'Blind Children's Language Resolving Some Differences', Journal of Child Language, 11(3), 645–664.

Boonen, A.J.H., Wesel, F. van, Jolles, J. & Schoot, M. van der, 2014, 'The role of visual representation type, spatial ability, and reading comprehension in word problem solving: An item-level analysis in elementary school children', International Journal of Educational Research, 68, 15–26.

Braun, A., 2016, 'The Speaker Identification Ability of Blind and Sighted Listeners: An Empirical Investigation', The sensory compensation hypothesis, pp. 1–159, Springer Fachmedien Wiesbaden, Wiesbaden.

Cohen, L.G., Celnik, P., Pascual-Leone, A., Corwell, B., Faiz, L., Dambrosia, J., Honda, M., Sadato, N., Gerloff, C., Dolores Catalá, M. & Hallett, M., 1997, 'Functional Relevance of Cross-modal Plasticity in Blind Humans', Nature, 389(6647), 180–183.

Creswell, J.W., 2012, Educational Research: Planning, Conducting, and Evaluating Quantitative and Qualitative Research Fourth Edition, 4th edn., Pearson, Boston.

Cunningham, S.I., Weiland, J.D., Bao, P. & Tjan, B.S., 2011, 'Visual Cortex Activation Induced by Tactile Stimulation in Late- Blind Students with Retinitis Pigmentosa', Proceedings of the Annual International Conference of the IEEE Engineering in Medicine and Biology Society, EMBS, 2841–2844.

DeWindt-King, A.M. & Goldin, G.A., 2003, 'Children ' s Visual Imagery : Aspects of Cognitive Representation in Solving Problems with Fractions 1', Mediterranean Journal For Reasearch in Mathematics Education, 2(April), 1–42.

Erickson, K.A. & Hatton, D., 2007, 'Literacy and Visual Impairment', Seminars in Speech and Language, 28(1), 58–68.

Eriksson, Y., 2013, 'Tactile Reading: Tactile Understanding', in R. Manduchi & S. Kurniawan (eds.), Assistive Technology for Blindness and Low Vision, p. 387, CRC Press Taylor & Francis Group.

Fleming, S.M., Massoni, S., Gajdos, T. & Vergnaud, J.-C., 2016, 'Metacognition about the past and future: quantifying common and Distinct Influences on Prospective and Retrospective Judgments of Self-Performance', Neuroscience of Consciousness, 2016(1), niw018.

Fortin, M., Voss, P., Lord, C., Lassonde, M., Pruessner, J., Saint-Amour, D., Rainville, C. & Lepore, F., 2008, 'Wayfinding in The Blind: Larger Hippocampal Volume and Supranormal Spatial Navigation', Brain, 131(11), 2995–3005.

Frasnelli, J., Collignon, O., Voss, P. & Lepore, F., 2011, Crossmodal Plasticity in Sensory Loss, 1st edn., vol. 191, Elsevier B.V.

Goldin, Gerald A., 1998, 'Representations and the psychology of mathematics education: Part II', The Journal of Mathematical Behavior, 17(2), 135.

Goldin, Gerald A, 1998, 'Representational systems, learning, and problem solving in mathematics', Journal of Mathematical Behavior, 17(2), 137–165.

Goldin, G.A., 2002, 'Representation in Mathematical Learning and Problem Solving', in L.D. (Queenslan. U. of T. English (ed.), Handbook Of International Research In Mathematics Education, p. 821, Lawrence Erlbaum Associates, Mahwah, New Jersey London.

Goldin, G.A. & Shteingold, N., 2001, 'Systems of Representations and the Development of Mathematical Concepts', in A.A.C. Corcio & Frances (eds.), The Roles of Representation in School Mathematics, p. 1, NCTM (National Council Of Teacher Of Mathematics).

Goldreich, D. & Kanics, I.M., 2003, 'Tactile Acuity is Enhanced in Blindness', Journal of Neuroscience, 23(8), 3439–3445.

Goldreich, D. & Kanics, I.M., 2006, 'Performance of Blind and Sighted Humans on a Tactile Grating Detection Task', Perception and Psychophysics, 68(8), 1363–1371.

Gougoux, F., Lepore, F., Lassonde, M., Voss, P., Zatorre, R.J. & Belin, P., 2004, 'Pitch Discrimination in the Early Blind People', Nature, 430(6997).

Graham, L., Berman, J. & Bellert, A., 2015, Sustainable Learning: Inclusive Practices for 21st Century Classrooms, Cambridge University Press, Sydney.

Hallahan, D.P. & Kauffman, J.M., 1988, Exceptional Children Introduction to Special Education Fourth Edition.

Hallahan, D.P., Kauffman, J.M. & Pullen, P.C., 2014, Exceptional Learners An Introduction to Special Education, Twelfth Ed, Pearson Education Limited Edinburgh.

Hollins, M., 1989, Understanding Blindness: An Integrative Approach, Taylor & Francis Group.

Hötting, K. & Röder, B., 2009, 'Auditory and Auditory-Tactile Processing in Congenitally blind Humans', Hearing Research, 258(1–2), 165–174.

James, T.W., Humphrey, G.K., Gati, J.S., Servos, P., Menon, R.S. & Goodale, M.A., 2002, 'Haptic Study of Three-dimensional Objects Activates Extrastriate Visual Areas', Neuropsychologia, 40(10), 1706–1714.

Janvier, C., Girardon, C. & Morand, J.C., 1993, 'Mathematical symbols and representations.', Research Ideas for The Cassroom: High School Mathematics, pp. 79–102, National Council of Teachers of Mathematics.

Kamel, H.M. & Landay, J.A., 2000, 'A Study of Blind Drawing Practice: Creating Graphical Information Without the Visual Channel', Proceedings of the ACM Conference on Assistive Technologies, ASSETS 2000, (November), 34–41.

Kohanova, I., 2006, Teaching Mathematics to Non-Sighted Students : With Specialization in Solid Geometry – PhD thesis, Comenius University Bratislava, Bratislava .

Kujala, T., Palva, M.J., Salonen, O., Alku, P., Huotilainen, M., Järvinen, A. & Näätänen, R., 2005, 'The Role of Blind Humans' Visual Cortex in Auditory Change Detection', Neuroscience Letters, 379(2), 127–131.

Kupers, R. & Ptito, M., 2014, 'Compensatory Plasticity and Cross-modal Reorganization Following Early Visual Deprivation', Neuroscience and Biobehavioral Reviews, 41, 36–52.

Lessard, N., Pare, M., Lepore, F. & Lassonde, M., 1998, 'Early-blindhuman Subjects Localize Sound Sources Better than Sighted Subjects', 395(September), 1–3.

Lowenfeld, B., 1971, Our Blind Children Growing and Learning with Them (3rd Edition), vol. 56.

Maidenbaum, S., Abboud, S. & Amedi, A., 2014, 'Sensory Substitution: Closing the Gap between Basic Research and Widespread Practical Visual Rehabilitation', Neuroscience and Biobehavioral Reviews, 41, 3–15.

Millar, S., 1975, 'Visual Experience or Translation Rules? Drawing the Human Figure by Blind and Sighted Children', Perception, 4(4), 363–371.

Monoyiou, A., Spagnolo, F., Elia, I. & Gagatsis, A., no date, 'Visual Representations in Mathematics Education'.

Neumann, F.T., 1971, 'Demonstrating the Relationship between Three-Dimensional Figures and Their Two-Dimensional Representations to Blind Students of Mathematics', Journal of Visual Impairment & Blindness, 65(4), 126–128.

Pieniak, M., Lachowicz-Tabaczek, K., Karwowski, M. & Oleszkiewicz, A., 2022, 'Sensory Compensation Beliefs Among Blind and Sighted Students', Scandinavian Journal of Psychology, 63(1), 72–82.

Poirier, C., Volder, A.G. De & Scheiber, C., 2007, 'What Neuroimaging Tells us about Sensory Substitution', Neuroscience and Biobehavioral Reviews, 31(7), 1064–1070.

Ptito, M., Matteau, I., Zhi Wang, A., Paulson, O.B., Siebner, H.R. & Kupers, R., 2012, 'Crossmodal Recruitment ofthe Ventral Visual Stream in Congenital Blindness', Neural Plasticity, 2012.

Radziun, D., Crucianelli, L., Korczyk, M., Szwed, M. & Ehrsson, H.H., 2023, 'The Perception of Affective and Discriminative Touch in Blind Students', Behavioural Brain Research, 444.

Ravisankar, A. & Brundha, M.P., 2016, 'Comparative Study of Touch Perception in Normal and Blind People', Journal of Pharmaceutical Sciences and Research, 8(11), 1285–1287.

Röder, B., Teder-Sälejärvi, W., Sterr, A., Rösler, F., Hillyard, S.A. & Neville, H.J., 1999, 'Improved Auditory Spatial Tuning in Blind Humans', Nature, 400(6740), 162–166.

Sadato, N., Pascual-Leone, A., Grafman, J., Ibañez, V., Deiber, M.P., Dold, G. & Hallett, M., 1996, Activation of the Primary Visual Cortex by Braille Reading in Blind Subjects, Nature, 380(6574), 526–528.

Sathian, K., 2005, 'Visual Cortical Activity during Tactile Perception in the Sighted and the Visually Deprived', Developmental Psychobiology, 46(3), 279–286.

Saville, C.W.N., Feige, B., Kluckert, C., Bender, S., Biscaldi, M., Berger, A., Fleischhaker, C., Henighausen, K. & Klein, C., 2015, 'Increased Reaction Time Variability in Attention-Deficit

Hyperactivity Disorder as a Response-related Phenomenon: Evidence from Single-trial Event-related Potentials', Journal of Child Psychology and Psychiatry, 56(7), 801–813.

Silva, P.R., Farias, T., Cascio, F., Santos, L. dos, Vinícius, P., Crespo, E., Ayres, C., Ayres, M., Marinho, V., Bastos, V.H., Ribeiro, P., Velasques, B., Orsini, M., Fiorelli, R., Freitas, M.R.G. de & Teixeira, S., 2018, 'Neuroplasticity in Visual Impairments', 10, 111–117.

Sorokowska, A. & Karwowski, M., 2017, 'No Sensory Compensation for Olfactory Memory: Differences between Blind and Sighted People', Frontiers in Psychology, 8(DEC), 1–10.

Striem-Amit, E., Dakwar, O., Reich, L. & Amedi, A., 2012, 'The Large-scale Organization of "visual" Streams Emerges without Visual Experience', Cerebral Cortex, 22(7), 1698–1709.

Tinti, C., Adenzato, M., Tamietto, M. & Cornoldi, C., 2007, 'Visual Experience is Not Necessary for Efficient Survey Spatial Cognition: Evidence from Blindness', Quarterly Journal of Experimental Psychology, 59(7), 1306–1328.

Toroj, M. & Szubielska, M., 2011, 'Prior visual experience , and perception and memory of shape in people with total blindness', The British Journal of Visual Impairment, 29 (1), 60–81.

Tran, T.M.P. & Pho, P.D., 2020, 'A Case Study of How Visually Impaired Learners Acquire Language', Ethical Lingua: Journal of Language Teaching and Literature, 7(1), 1–10.

Utomo & Muniroh, N., 2019, Pendidikan Anak dengan Hambatan Penglihatan, Pertama, vol. 53, Prodi. PJ JPOK FKIP ULM Press, Kota Banjarbaru, Kalimantan Selatan.

Wong, M., Gnanakumaran, V. & Goldreich, D., 2011, 'Tactile Spatial Acuity Enhancement in Blindness: Evidence for Experience-dependent Mechanisms', Journal of Neuroscience, 31(19), 7028–7037.

Woods, A.T. & Newell, F.N., 2004, 'Visual, Haptic and Cross-modal Recognition of Objects and Scenes', Journal of Physiology Paris, 98(1-3 SPEC. ISS.), 147–159.