COMPREHENSION OF 3D OBJECTS FROM 2D TACTILE DIAGRAMS

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INDIAN INSTITUTE OF TECHNOLOGY DELHI

Department of Design

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by

ANCHAL SHARMA

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This thesis is dedicated to my mother & father

Ms. Anuradha Sharma & Mr. Vinod Kumar Sharma

Certificate

This is to certify that the thesis entitled "Comprehension of 3D objects from 2D Tactile Diagrams" submitted by Ms Anchal Sharma to the Indian Institute of Technology Delhi, in fulfilment of the requirements for the award of the degree of Doctor of Philosophy, is a record of original research work carried out by her under our supervision. The contents of this thesis, in full or in part, have not been submitted to any other Institute or University for the award of any other degree or diploma.



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Finally, I dedicate this work to all learners with visual impairments, with the hope that it contributes in some way to building more inclusive educational pathways and expanding access to scientific discovery.

Abstract

This thesis addresses the critical challenge of designing effective tactile diagrams for people with visual impairment (PVI) by investigating how spatial object information is comprehended, represented, and recognized through touch. Existing tactile graphics often borrow visual design conventions which are often based on perspective and isometric projection, and do not align with the perceptual strategies of PVI, particularly those without visual memory. Spanning five empirical studies, this research combines qualitative and quantitative methods to explore intuitive tactile drawing strategies in congenitally blind children, recognition patterns across different representation styles, and the influence of diagram size on spatio-temporal integration.

One of the first studies of this thesis explores how congenitally blind children intuitively draw without prior training in visual representation. The objective is to understand how they internally encode spatial configurations and whether features such as genus and proportional differences of similar topological forms are reflected in their drawings. The work evaluates the alignment between verbal object descriptions and drawn outputs forming a baseline for understanding intuitive untrained tactile representation.

Secondly, four distinct tactile representation styles: lofting, surface development, orthographic, and isometric are studied for their effectiveness in conveying 3D geometric objects to blind, late blind, and blindfolded users. The goal is to assess which configurations best support recognition across different participant groups. The findings emphasize that tactile layouts preserving geometric primitives and surface connectivity are more effective for PVI than visual-centric projections, thereby challenging conventional representation practices. Third study carried out as

a part of this thesis focuses on determining which features or factors support successful object identification in conventional tactile graphics. Using a diverse set of tactile representations of commonly used everyday objects, the study involves exploration by blind participants to describe cues that aid recognition.

Next, two sets of studies are carried out to evaluate the role of diagram size in tactile recognition. Challenging the classic theory that 'Bigger is better' in tactile representation, two sets of data consisting of both discrete (dot-based) and continuous (outline-based) patterns are used in this study. The goal is to determine if there exists an optimal "Goldilocks" scale range that maximizes perceptual clarity while minimizing cognitive overload. This study carried out with three sets of participants, blind, late blind, and blindfolded has found that the Goldilocks exists for discrete dot patterns. However, the preference of sizes varies with different participant groups for line drawings.

Towards the end, empirically grounded recommendations for tactile representation *TacTales*, are proposed offering actionable insights for educators, designers, and assistive technology developers aiming to make STEM content more accessible to blind learners. Furthermore, it lays out important scientific avenues for investigation ahead.

सारांश

यह शोध-प्रबंध दृष्टिबाधित व्यक्तियों के लिए प्रभावी स्पर्श-आधारित आरेखों के अभिकल्पन की महत्वपूर्ण चुनौती को संबोधित करता है, और इस बात की जाँच करता है कि स्थानिक वस्तु-संबंधी जानकारी को स्पर्श के माध्यम से किस प्रकार समझा, निरूपित और पहचाना जाता है। वर्तमान में प्रचलित स्पर्श-आधारित आरेख प्रायः दृश्य-आधारित अभिकल्पन परंपराओं को अपनाते हैं, जो अक्सर परिप्रेक्ष्य और समदैशिक प्रक्षेपण पर आधारित होती हैं, और जो दृष्टिबाधित व्यक्तियों की अवधारणात्मक रणनीतियों से मेल नहीं खातीं, विशेष रूप से उन व्यक्तियों की रणनीतियों से जिनके पास दृश्य-स्मृति नहीं होती। पाँच अनुभवजन्य अध्ययनों में विस्तृत यह शोध, जन्मांध बच्चों में सहज स्पर्श-आधारित रेखाचित्रण रणनीतियों, विभिन्न निरूपण शैलियों में पहचान के प्रतिमानों, तथा स्थानिक-कालिक एकीकरण पर आरेख के आकार के प्रभाव का अन्वेषण करने हेतु गुणात्मक और मात्रात्मक विधियों का संयोजन करता है।

इस शोध-प्रबंध के आरंभिक अध्ययनों में से एक यह जाँचता है कि जन्मांध बच्चे दृश्य निरूपण के पूर्व प्रशिक्षण के बिना सहज रूप से किस प्रकार चित्र बनाते हैं। इसका उद्देश्य यह समझना है कि वे स्थानिक विन्यासों को आंतरिक रूप से किस प्रकार कूटबद्ध करते हैं, और क्या समान सांस्थितिक रूपों के जीनस तथा आनुपातिक अंतर जैसी विशेषताएँ उनके चित्रों में प्रतिबिंबित होती हैं। यह कार्य मौखिक वस्तु-वर्णनों और बनाए गए चित्रों के बीच के संरेखण का मूल्यांकन करता है, जिससे सहज एवं अप्रशिक्षित स्पर्श-आधारित निरूपण को समझने के लिए एक आधार-रेखा तैयार होती है।

दूसरे चरण में, चार भिन्न स्पर्श-आधारित निरूपण शैलियों, अर्थात् लॉफ़्टिंग, सतह विकास, लंबकोणीय और समदैशिक, का अध्ययन इस दृष्टि से किया गया कि वे त्रि-आयामी ज्यामितीय वस्तुओं को नेत्रहीन, पश्चकालिक नेत्रहीन और आँखों पर पट्टी बँधे उपयोगकर्ताओं तक पहुँचाने में कितनी प्रभावी हैं। इसका लक्ष्य यह आकलन करना है कि कौन-सा विन्यास विभिन्न प्रतिभागी समूहों में पहचान को सर्वोत्तम रूप से सहारा देता है। निष्कर्ष इस बात पर बल देते हैं कि ज्यामितीय मूल-तत्वों और सतह की संयोजकता को संरक्षित रखने वाले स्पर्श-आधारित विन्यास, दृष्टिबाधित व्यक्तियों के लिए दृश्य-केंद्रित प्रक्षेपणों की तुलना में अधिक प्रभावी होते हैं, और इस प्रकार ये पारंपरिक निरूपण प्रथाओं को चुनौती देते हैं।

इस शोध-प्रबंध के अंतर्गत किया गया तीसरा अध्ययन यह निर्धारित करने पर केंद्रित है कि पारंपरिक स्पर्श-आधारित आरेखों में कौन-सी विशेषताएँ या कारक सफल वस्तु-पहचान में सहायक होते हैं। दैनिक जीवन में सामान्यतः प्रयुक्त वस्तुओं के विविध स्पर्श-आधारित निरूपणों का उपयोग करते हुए, इस अध्ययन में नेत्रहीन प्रतिभागियों द्वारा अन्वेषण कराया गया, ताकि पहचान में सहायक संकेतों का वर्णन किया जा सके।

इसके पश्चात्, स्पर्श-आधारित पहचान में आरेख के आकार की भूमिका का मूल्यांकन करने के लिए अध्ययनों के दो समूह किए गए। स्पर्श-आधारित निरूपण में 'बड़ा अर्थात् बेहतर' के शास्त्रीय सिद्धांत को चुनौती देते हुए, इस अध्ययन में विविक्त अर्थात् बिंदु-आधारित तथा संतत अर्थात् रूपरेखा-आधारित, दोनों प्रकार के प्रतिमानों से युक्त दो आँकड़ा-समूहों का उपयोग किया गया। इसका लक्ष्य यह निर्धारित करना था कि क्या कोई इष्टतम 'गोल्डीलॉक्स' मापमान-परास विद्यमान है, जो अवधारणात्मक स्पष्टता को अधिकतम और संज्ञानात्मक भार को न्यूनतम करता है। नेत्रहीन, पश्चकालिक नेत्रहीन और आँखों पर पट्टी बँधे, इन तीन प्रतिभागी समूहों के साथ किए गए इस अध्ययन में पाया गया कि विविक्त बिंदु-प्रतिमानों के लिए गोल्डीलॉक्स परास विद्यमान है। तथापि, रेखाचित्रों के संदर्भ में आकारों की वरीयता विभिन्न प्रतिभागी समूहों के अनुसार भिन्न होती है।

अंत में, स्पर्श-आधारित निरूपण के लिए अनुभवजन्य रूप से आधारित अनुशंसाएँ, अर्थात् 'टैकटेल्स', प्रस्तावित की गई हैं, जो नेत्रहीन शिक्षार्थियों के लिए विज्ञान, प्रौद्योगिकी, अभियांत्रिकी और गणित संबंधी विषय-वस्तु को अधिक सुलभ बनाने के इच्छुक शिक्षकों, अभिकल्पकों और सहायक प्रौद्योगिकी विकासकर्ताओं को व्यावहारिक अंतर्दृष्टि प्रदान करती हैं। इसके अतिरिक्त, यह आगे के अन्वेषण के लिए महत्वपूर्ण वैज्ञानिक दिशाओं को भी रेखांकित करता है।

List of Figures

Figure 2.1 Tactile graphics example (Raised lines foundation, 2019) 8
Figure 2.2 Hand-made tactile diagrams in low-resource setting 9
Figure 2.3 Tactile Graphic creation using swell technology (source: American thermoform website) 10
Figure 2.4: Map of India using thermoforming (facility credits: Raised Lines foundation, Noida) 11
Figure 2.5: A geometric figure in a conventional tactile book 13
Figure 2.6 Haptic exploratory procedures by Lederman and Klatzky (1987) 17
Figure 2.7 Geons proposed by Biederman (1987) 22
Figure 3.1 : Set of familiar and novel objects used in the study 33
Figure 3.2 Depicting the process of exploring and drawing the geometric forms by participants 34
Figure 3.3 Descriptions of objects by participants categorized into 'Volumetric' vs 'Basic shapes' 44
Figure 3.4 Representing a solid cone in multiple views 46
Figure 3.5 Using lines to depict depth information of cylinders and cones 47
Figure 3.6 : Cross-Section representation of cylinder and a cone. 47
Figure 3.7 Hatch representation of surface/solid (cube, sphere and a cylinder) 47
Figure 4.1 The objects presented in the study 52
Figure 4.2 The two-dimensional representation styles of objects that are provided to the participants showed surface development, lofting, orthographic, and isometric styles. 52
Figure 4.3 The procedure of the exploration of tactile representations by the participants. 53
Figure 4.4 The identification of a bottle by a born-blind participant by exploring the tactile sketch shown on the right 64
Figure 5.1 Tactile shapes used for the study 68
Figure 5.2 Hand explorations with the tactile stimuli 70
Figure 5.3 Mean identification performance by group 71
Figure 5.4 Graph showing overall identification frequency of all stimuli 72
Figure 5.5 Comparison between prior 3D tactile experience and 2D familiarity frequency to object shape recognition 74
Figure 5.6 Dent of an apple in 3D form and 2D drawing. 76
Figure 5.7 Representation of objects (with minimal thickness) with high identification rates 77
Figure 5.8 Coordinated hand movement for symmetric objects during the exploratory process by various participants 80
Figure 6.1 Fifteen configurations of raised dot patterns (schematic) 88
Figure 6.2 : Stimuli of the five sizes of a dot pattern (from left: S1 smallest to S5 largest) 88
Figure 6.3 Stimuli set of 25 raised-line shapes representing common objects (schematic) 89

Figure 6.4 Example of one shape stimulus (“tree”) at sizes S1 through S5 (left to right). The physical size doubles with each step, from ~10 mm (S1) to ~160 mm (S5). 90
Figure 6.5 Experimental set-up and the participant exploring the tactile stimuli before drawing it. 92
Figure 6.6 Mean similarity scores by scale and participant group. Bar plot showing mean similarity scores (1 = not at all similar; 7 = very similar)..... 97
Figure 6.7 Scatter-plot showing errors in dot numerosity versus scales for each of the three groups. Numbers correspond to (cardinality of reference pattern - cardinality of recreated pattern). 100
Figure 6.8 Mean shape identification performance as a function of size (combined across groups). 102
Figure 6.9 Comparison of the Sighted group using vision(top) vs the Blindfolded sighted group(bottom)on dot pattern reconstructions..... 108

List of Tables

Table 3.1 Tactile drawings of known 3D objects (schematic representation [n=36]) 36
Table 3.2 : Tactile drawings of less-familiar 3D objects (schematic representation [n=36]) 37
Table 3.3 Drawings and descriptions by participants (examples of 6 participants and 7 objects) 39
Table 3.4 Various categories of descriptions and their frequencies [n=26] 42
Table 4.1 Recognition across different representation styles by different participants 55
Table 4.2 Recognition across different objects by participant groups 60
Table 5.1 Individual performances of the participants 71
Table 5.2 Stimuli descriptions and identifying features 73
Table 6.1 Dot pattern drawings produced by a late-blind participant (L4 & L12) after exploring three patterns: D8, D13, and D14. 94
Table 6.2 Drawings produced by a late-blind participant (L9 & L6) after exploring three shapes: Car, Cycle, and Pineapple 95
Table 6.3 : The strategy of exploration, category, and its respective frequency by the participant groups 101
Table 7.1 Tactales framework (provisional) 116

Table of Contents

Certificate v
Acknowledgments vi
Abstract ix
List of Figures xi
List of Tables xiii
Table of Contents xiv
1. Introduction 1
1.1 Background and Context 1
1.2 Research Motivation 2
1.3 Research Objectives 3
1.4 Research Approach 4
1.5 Organization of the Thesis 4
1.6 Significance of the research 6
2. Literature Review 7
2.1 Chapter overview 7
2.2 Tactile graphics 7
2.3 Techniques for developing tactile graphics 8
2.4 Limitations of Tactile graphics 11
2.5 Tactile Shape Perception 15
2.6 Tactile vs. Visual 17
2.7 Role of working memory and visual mediation 20
2.8 Perceptual theories of Vision: Relevant Theories 21
2.10 Factors and features influencing tactile identification 25
2.11 Gaps in Existing Research 28
2.12 Research Objectives 29
2.13 Methodology and Approach 30

3. Object comprehension and intuitive drawing strategies 31
3.1 Introduction 31
3.2 Methodology 32
3.3 Results 34
3.4 Discussion 47
3.5 Summary 48
4. Evaluating the interpretability of 3D solids by 2D sketches 50
4.1 Introduction 50
4.2 Methods 51
4.3 Data analysis 54
4.4 Results 55
4.5 Discussion 61
4.7 Summary 64
5. Object recognition from two-dimensional tactile graphics 66
5.1 Introduction 66
5.2 Methodology 67
5.3 Results 71
5.4 Discussion 82
5.5 Summary 84
6. Role of size in perceptibility of tactile graphics 85
6.1 Introduction 85
6.2 Research questions: 86
6.3 Methodology 86
6.4 Results 96
6.5 Discussion 106
6.6 Summary 110
7. Conclusions, Recommendations and Future Work 112
7.1 Summary 112
7.2 Conclusion of the thesis 113
7.3 Perceptual science to practical insights 114
7.4 Towards a framework for tactile object representation: *Tactales* 116

7.5 Contributions of the thesis 117
7.6 Implications 119
7.7 Limitations of the thesis 119
7.8 Future Research Ideas 122
References 125
Publications: 131
Glossary 133
Author Biography 134