Jurnal Teknologi

Full Paper

An Evaluation of Children's Structural Drawing Strategies

Narges Tabatabaey-Mashadi[a], Rubita Sudirman [a*], Puspa Inayat Khalid[a]

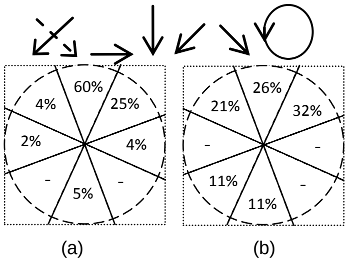
[a]*Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahrui, Johor, Malaysia*

*Corresponding author: rubita@fke.utm.my

Article history

Received :31 May 2012
Received in revised form :10 October 2012
Accepted :5 January 2013

Graphical abstract



Dominant structural pattern drawing strategies among pupils with comparison of circle drawing start position among (a) average and (b) below average writers.

Abstract

Inspecting children's structural drawing is developmentally and psychologically important. Today's digital availability of such data from electronic tablets, inspires automatic analysis; however, converting such data to an informative feature vector for further analysis and identification of related indicators, needs appropriate algorithms. This study presents simple, fast methods for detecting X, O and 4 basic lines' drawing strategies. The functionality of the algorithms is tested on an available database subtending the performances of 74 (6-7years) pupils. Results demonstrate typical behaviors such as counterclockwise popularity in circle drawing, and other tendencies in the population's structural pattern drawing's performance. Algorithms clearly reveal all different strategies used by participators. Consequently the suitability of the algorithms, in effectively detecting strategic features, is clarified. In addition, according to the data labels in database, some features are suggested to serve as attributes distinguishing handwriting ability.

Keywords: Sequential strategic features; structural drawing; handwriting; circle drawing; diagonal drawing; line drawing; handwriting standard

Abstrak

Memeriksa lukisan struktur kanak-kanak adalah perkembangan dan psikologi penting. Ketersediaan data itu daripada tablet elektronik digital hari ini, memberi inspirasi analisis automatik, namun, menukarkan data tersebut kepada vektor ciri bermaklumat untuk analisis selanjutnya dan pengenalan penunjuk berkaitan, memerlukan algoritma yang sesuai. Kajian ini membentangkan, kaedah mudah dan cepat untuk mengesan X, O dan strategi lukisan 4 baris asas. Fungsi algoritma diuji pada pangkalan data tersedia subtending persembahan 74 (6-7years) murid. Keputusan menunjukkan tingkah laku yang biasa seperti populariti lawan dalam lukisan bulatan, dan kecenderungan lain dalam prestasi corak lukisan struktur penduduk. Algoritma jelas mendedahkan semua strategi yang berbeza yang digunakan oleh peserta ujikaji. Akibatnya kesesuaian algoritma dalam mengesan ciri-ciri strategik telah dijelaskan. Di samping itu, bedasarkan label data dalam pangkalan data, beberapa ciri-ciri telah dicadangkan untuk membezakan keupayaan tulisan.

Kata kunci: *Sequential strategic features*; lukisan berstruktur; tulisan; lukisan bulatan; lukisan menegak; lukisan garisan; garispanduan tulisan

1.0 INTRODUCTION

Educationally, assessing beginners' perceptual and motor skills, that are best delivered in children's drawing and handwriting performance, are important especially from the perspective of developmental capabilities'. Practically, efficiently and effectively analyzing such performances among children requires automated screening systems. Modern technology has provided digitizing tablets to collect drawings/writings digitally; however interpretation and presentation of such data in an informative, short feature vector for automated analysis and identification of related indicators, requires proper algorithms. Drawing carries numerous information about a child behavior and his/her functionality;[1-4] researchers found talent, cognition and physiological indicators in drawing performance. For example clinically, spastic hemiparesis was studied for interlimb coupling using bimanual circle drawing;[5] Oriented line and shape drawing dynamics were observed various with handwriting levels;[6,7] or a neuropsychological study investigated temporal consistency with cerebellar function through structural circle drawing strategies;[8] Thus automatically detecting structural drawing strategies can contribute to better analysis of such data. This technical service may serve as a tool, assisting scientists scrutinizing different aspects of tasks.

Since drawing development starts before handwriting, and shape allographs base letter formations,[9] drawing strategies may influence letter sequence of strokes that was studied widely in handwriting analysis.[10] Most of the works produced outskirt online drawing/writing analyses (which are applied to online tablet data) focus on handwriting.[11,12] Drawing and handwriting share common sensory awareness and functionality, therefore various new aspects of drawing may be achieved by focusing on strategies and procedures rather than just handwriting basic constructors. Besides Remi *et al.* work which considers structural drawing strategy of the Meulenbroek's figure,[12] and Khalid *et al.* who report segment analysis of a triangle drawing among children with respect to handwriting,[13] other online attempts such as [6] concentrate on other timing features as velocity, acceleration, or tilt and pressure;[14] nevertheless sometimes the drawing analysis results in the deduction of static info (related to the appearance of the outcome rather than dynamic information); this is when studies use online data and the procedure as another source to detect static information superior than before. However, fractionating drawing procedure methods are significant in terms of understanding the mechanisms of graphic construction, and conceptual analysis related to neuropsychology.[15] There is also a stimulant whether it is possible to find strategic features of children's structural drawing performances that characterize their handwriting performance. Regardless of the few number of studies related to digitized handwriting quality assessment [11] and accordingly digitized drawing-handwriting relations, evidences suggest correlations. Recent research gives credit to drawing for recognizing children with handwriting difficulties.[7,13] Hence structural pattern drawing analysis is likely to contribute to decomposed analysis of handwriting performances.

This study aims to systematically model drawing performances, and deduce meaningful information about strategies of the performance. As the result, variety of strategies performed among children is revealed; and their comparison is facilitated. This manuscript intends to practically detect the strategies of common structural pattern drawing among pupils. Automatically running the system and being able to apply it via eHealth systems bring about the fair public services; and the benefit of accessing and collecting precious data from large children populations. Such data bear differences in strategies which may address different cognitive and physical behaviors in target populations, showing new insights to scientists and clinicians while assisting them. To implement an automated algorithm for detecting structural drawing strategies and analyzing them, first structural patterns are defined and their importance are discussed; then, algorithms are presented and examined on an available database to verify their functionality; to conclude, algorithms' performances are discussed subsequently.

1.1 Structural Patterns

The term *structural pattern* in this study is referred to simple basic patterns that base the fundamentals of children's drawing and handwriting. Simple patterns as circle, diagonal cross, and different line orientations are considered among such patterns; sometimes they are referred as elements of drawing.[3] These patterns are also commonly examined in psychological tests,[16] children development milestones,[17] and new handwriting standards.[18] Challenges involved in structural pattern drawings are related to children appreciation and construction of spatial configurations. It is believed that diagonal cross (╳) drawing can provide significant information about child's visual spatial understanding according to many turns and directions which is associated with.[19] Circle/O drawing has been considered in different psychological analysis; cultural differences,[20] disabilities and behavioral diversities have been observed with different circle drawing strategies.[21] Circle may be considered as the first product of natural motor activity while being a perceptually symmetrical and simple drawing.[3] Similarly, mastery in constructing lines of different orientations is the necessary ingredient for good drawing and handwriting.[7,22] In addition, children's line drawing serves as an indicator of their physical/anatomical ability; [8] or even indicating development and talent.[3] Horizontal, vertical, right oblique and left oblique line drawings are the typical line drawings tested by Beery VMI test.[16] How children practice these lines bears information about different aspects of children's execution; e.g. in terms of motor activity, when producing diagonals, crossing the midline of the body is hard while perceptually integrating the start-end points in a whole is also used in this task.[3]

Accordingly, more detailed analysis of such basic drawings may reveal new aspects of human behavior. Various fields benefit from in-depth analysis of structural pattern drawings including neuropsychology and brain mapping. [23] Finding a good algorithm to detect valuable known features from children's structural drawing performance while having the capability to explore beyond the known boundaries, is the key to such advantages. This study implements algorithms and extracts strategic features of the four basic lines, X and O drawings.

■2.0 STRATEGIC FEATURE EXTRACTION

The aim of the extraction method in this study is to dig out dynamic strategic features of the drawing easily and fast. The raw input data given to the algorithm consists of coordinates of the pen movement and the pressure acquired from children drawing performances on a digital tablet. By detecting the drawing region from pupil's pen movement (with detection of pen trajectories with non-zero pressures), the proposed algorithms for O, X, and four basic line drawings are discussed in the following subsections.

2.1 Circle Drawing Strategy

The important features in circle drawing analysis are starting point and wise directionality. To implement an algorithm capable of detecting the starting area, first the area of drawn circle is allocated according to Figure 1. The eight unequal sections are produced by dividing the 360^o drawing area to 45^o sectors related to the drawing region's central point as the origin. Sectors considered in a way which the 12, 3, 6, and 9 O'clock polar angle positions sat in the middle of their sections. With that, top, bottom, left, right and in between of these are clearly sectioned for state detection of the pen positions. In addition, by monitoring pen pressure, a ninth state is considered as *pen off* state for when the pen is lifted. To detect the sequential strategy, the movement is observed administering the state model with only recording the transitions among states. The recorded sequence of states then bears the start, end and wise directionality of the O drawing performance. Furthermore, the number of applied strokes becomes available from the number of *pen-off*s observed in the sequence. (A stroke is produced from a continuous pen movement in contact with the paper.) Finally circle drawing is summarized in a set of states, containing all subsequent transitions during the performance. A typical example of the sequence is [S1, S8, S7, S6, S5, S4, S3, S2, S1].

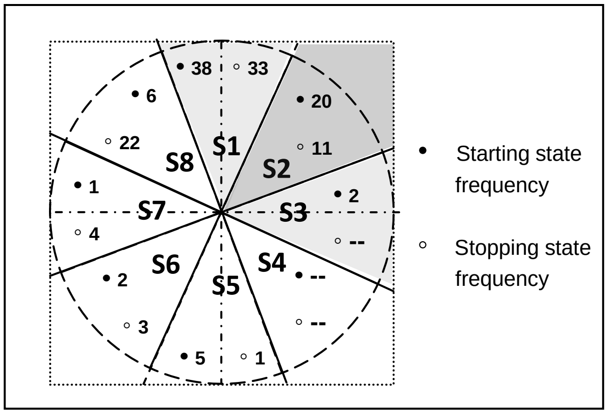


Figure 1 Circle state allocation (S1-S8); coloured regions represent S1-S3 state areas. Numbers represent state popularities at the start/end of the drawing (discussed in section 4)

2.2 ╳ Drawing Strategy

Similar to circle drawing, allocation of the drawn region is needed for extracting diagonal cross drawing strategy. In X drawing, focuses are on *when*, and *how* each diagonal of the cross are performed; e.g. either left oblique first and downward or etcetera. Accordingly, the X drawing region was allocated to four equal sections by dividing width and height of the drawing region into half. Consequently the four sections are the top right, top left, bottom right, and bottom left areas. Considering each section as a state plus a pen off state similar as in O drawing, the sequence of states is detected from the pen positions by observing the transitions; however this method records a lot of noisy transitions when applied to real X drawings; and so the strategies and their comparison becomes complex.

To illustrate the production of noisy transitions Figure 2 shows a pupil's X drawing performance and allocated regions; since the drawn X pattern is not ideal (and the center of X is not exactly positioned in the center of the pen trajectory area), the transition from each corner to the other does not take place by passing the exact center; rather it transfers through one of the other three regions before reaching the target corner. As in Figure 2 the first movement from S1 to S2 passes S3; or in the next step when S4 is the target corner to be reached from S3 the trajectory deviated to S1 before reaching the target. This phenomenon produces noisy transitions in the sequence regarding rough performance related to static features and not linked with dynamic drawing strategy of our interest. To overcome the noise then, another method for recording the states' sequence is proposed; it is based on the reality that X drawing is composed of straight line drawing strokes. Hence it is only necessary to keep record of the beginning and ending states of each line stroke. Nonetheless, the method still recognizes the number of strokes used in drawing. Consequently a sequence of start-end states of the strokes, in a decussate way, is formed for X drawing performance; in which subsequent couples are related to same stroke. Therefore the detected sequence for the performance illustrated in Figure 2 would be [S1, S2, S3, S4] instead of the noisy sequence [S1, S3, S2, S0, S3, S1, S4].

2.3 Basic Oriented Line Drawing Strategy

Each participant in this study performed the four basic oriented line drawings in one test overlay. Thus the strategy of this drawing also considered the extra information of all four drawings with relation to one another (i.e. which line was drawn first, etc.). The overlay, later shown in Figure 3, presupposes a separate empty box for each line. Subsequently to detect each line the algorithm divides the drawing region into equal sections and by considering the position of each drawn stroke, it relates it to one of the 4 lines. According to directional trajectories in sub areas, the strategy of the related line strokes performed is detected. To watch number of strokes in each line drawing, pen offs are observed. Onward, the sequence records each stroke performance by a code -relating it to one of the four basic lines-followed by another code relating it to the direction in that sub-area; the latter code is related to each line whether it was drawn rightward/downward or vice versa for horizontal/vertical lines and similarly upward or downward for oblique lines. All stroke codes are subsequently ordered as they occurred. Extracted sequence includes number of strokes for each line, as well as the direction for each stroke performance.

3.0 THE DATABASE

Worthiness of the presented algorithm is shown by applying it to a database and discussing the information which becomes available. The used database contains the raw data originally collected during a prior research on relating quantitative outcome measures of children's drawing to handwriting difficulties (i.e. velocity and pressure).[7] This small available database is used to show the capability and functionality of the algorithms in detecting children's strategies.

First grade children who attended a normal primary school in Skudai were screened by a questionnaire;[24] and 143 (6–7 years old) were classified to two groups of average and below average writers regarding the focus of that study. To avoid subjectivity of teacher's scores on questionnaire, only 74 right-handed samples (55 avg. & 19 below avg.) with scores faraway from mean value were selected for drawing tests.

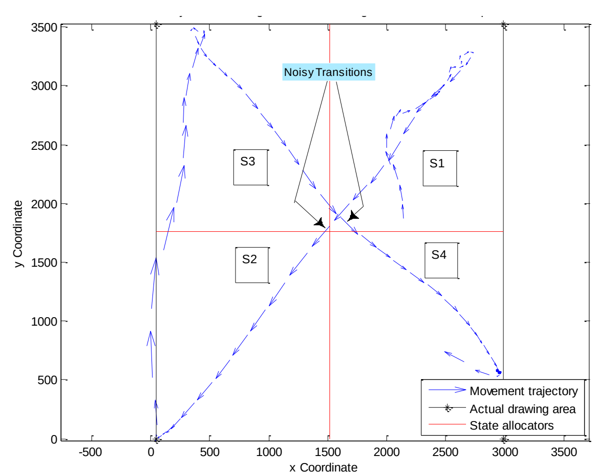


Figure 2 State allocation for actual X drawing of a pupil and illustration of noisy transitions

To digitally acquire children drawing performances, pupils were asked one by one to draw on an A4 paper on top of a WACOM GD0912U graphic tablet. Pen coordinates, pressure, and tilts were sampled and recorded a hundredth of a second. Participants drew four basic lines in one overlay and a circle and X cross patterns each in a separate overlay. In the model, patterns were drawn in a box and another similar empty box was provided for pupil to reproduce the drawing. The four basic line overlay is illustrated in Figure 3.

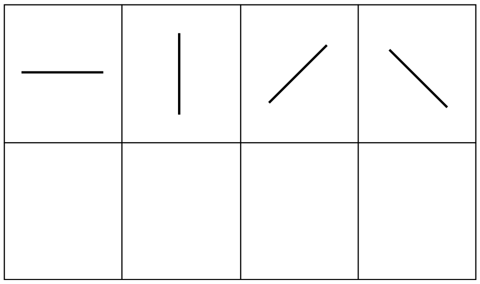


Figure 3 The overlay for basic oriented line drawing; pupils draw the top row patterns in empty boxes below them

4.0 RESULTS & DISCUSSIONS

Analysing the explained database, all pupils' different favoured strategies in the sample population were detected for X, O, and line drawing performances. Except two participants, the rest of pupils used two strokes in drawing the diagonal cross which is an ideal choice. Similar circle parameter analysis reveals that only one pupil drew it with more than a single stroke.

Notice that the aim of the proposed algorithm is not to detect static information about the pattern drawing such as neatness; since those prospects are related to offline analysis of drawing/handwriting (with no difference whether they are calculated from online dynamic data or offline images of the manuscript). However, here the study looks for the *strategy* of the drawing performance; which is extracted from the dynamic sequential data provided by the digital tablet. Unlike prior research, current study focus on detecting qualitative features i.e. sequential strategic features of the drawing performance rather than quantitative.

Available database prevents us to show statistical significant relations between the two groups' individual extracted features due to small number of samples in each cell of the contingency table; however demographic results from structural patterns drawings sometimes suggest relations between those features and handwriting ability. Further investigations on larger databases is required since this study's statistical descriptive analysis indicates considerable attribute differences (as for starting state in circle drawing, later discussed) which present criteria for recognizing risky children for handwriting ability. Before presenting the results, the authors like to emphasize that findings are related to first grade students who are starting handwriting and not illiterate children; so the outcome probably is biased to learned instructions and practiced handwriting rules, and therefore cannot be generalized as pure propensities of children. The results for each pattern are presented in the following subsections.

4.1 Circle Drawing

Strategic sequential circle drawing vector exposed that counterclockwise (CCW) directionality is much more popular among the pupils. Only 17.7% (i.e. 13 in 74) drew clockwise (CW). Counterclockwise preferences in school children and adults are well recognized.[25] That consequence may also be driven from the study that showed CCW directionality is associated with less hand–pen contact force synergy than the clockwise.[2] Prior studies also reported highest drawing speeds with CCW rotating patterns.[8] Counterclockwise priority is prominent in adults as well; right handed participants and 33% of left handed contributors in a study, started O drawing near top and drew CCW;[15] the rest of their left handed participants started near 10 O'clock position and moved CW.

Regarding the start and stop point analysis of circle drawing, back to Figure 1, the tendencies are shown by frequencies. The majority of students (51.4%) preferred starting at top (S1 or 12 O'clock position) and ending there (44.6%). The second most popular starting position is about 1 to 2'Oclock (S2 or Northeast area); conversely the next used ending state is S8, which is quite controversial regarding the few pupils preferring to start with it. For better interpretation of this phenomenon task's Start-End states' statistics were pulled out simultaneously. Variety of their used combinations among pupils' O drawings detected and more popular ones are presented in Table 1. The table also considers wise directionality. Apparently, pupils either end in the same state that they start the drawing, or they end in the start's adjacent states. Other than that was witnessed in only 8.1% (6/74) of pupils; while considering pupils within their groups, the unusual feature was witnessed with 15.8% of below average and 5.5% of average writers. The connotation that more than one state distance between starting and ending states are more likely observed with below average group is an interpretation of the observations; however due to the limited number of data in contingency table cells, the study is unable to report statistically significant difference among the two groups regarding this feature.

Table 1 Various Start-Stop & wise combinations used in O drawing

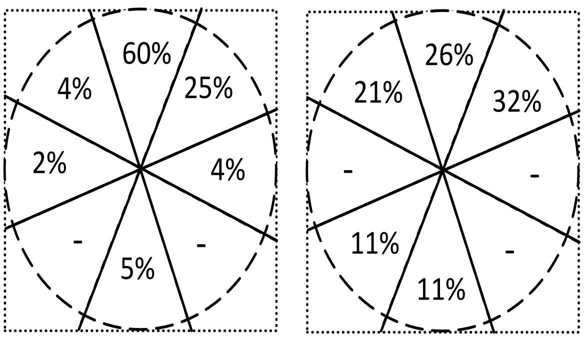
Start-Stop strategy	Average group		Below average group		CCW freq.	CW freq.	Total freq.
	CCW	CW	CCW	CW			
S1 - S1	15	2	2	0	17	2	19
S1 - S8	12	0	2	0	14		14
S2 - S1	9	0	4	0	13		13
S2 - S2	3	0	1	0	4		4
S5 - S6	0	2	0	1		3	3
S8 - S8	2	0	1	2	3	2	5
S1 - S2	1	2	1	0	2	2	4
Others with 3>frequencies					8	4	12

The pupil's O drawing auxiliary strategic info are available and detachable from the sequence; e.g. considering the direction with start (Table 2), reveals that all children who started O at S5 (6'Oclock) continued CW; while among the 3 top states (S8, S1 & S2) only 10.3% (6/58) starters performed CW. These outcomes are consistent with typical start-rotation principle.[26] Table 2 shows the population's Start-Wise perform.

As explained in section 4, here the aim of using this small available database is to show the functionality of the algorithms and present overall preferences in structural drawing among the 6-7 years sample population; however by observing the starts in each categorized group -in terms of descriptive analysis- a considerable difference between the two groups is apparent (Figure 4). The two groups seem to differently favor starting at top 12 O'clock position and top-right (1 to 2'Oclock). Overall, the circle drawing start and progress findings are seem to contrast with the easy and difficult writing rules; the rules point a difficult task when it starts in the upper right and continues CCW;[27] though a considerable amount of pupils (20/74) started at S2 -which is top right- and all performed CCW (Table 2) similar as in start-rotation theory.[26]

Table 2 Pupils' O drawing Start-Wise frequencies

Start State Wise		S1	S2	S3	S4	S5	S6	S7	S8
Average group	CCW	29	14	2	0	0	0	0	2
	CW	4	0	0	0	3	0	1	0
Below-average	CCW	5	6	0	0	0	1	0	2
	CW	0	0	0	0	2	1	0	2
CW		4	0	0	0	5	1	1	2
CCW		34	20	2	0	0	1	0	4



(a) (b)

Figure 4 Preferred starting state popularities in % for circle drawing in pupils with (a) average and (b) below average handwritings

4.2 ╳ Drawing

Applied X drawing strategies are listed in Table 3 with their popularity among samples. Among all different possibilities of drawing an X, only two of them are most liked; and besides another two, none of the remaining four two-stroke strategies are used. Crossing involves the use of spatial artistic configuration skills,[19] being associated with a number of turns and directions, its performance likely related to hemispherical psychology; so it illustrates perceptual worthy info about child's visual spatial form judgment; plus balancing motor sensory and perception.

According to the outcome (Table 3), it is palpable that drawing the left oblique of X downward is dominant; no matter in which stroke it was drawn: first/second/third. (Separate oblique line drawings will be discussed further on.) It is also apparent that the majority prefer to start with right oblique (58.1%) rather than left. Generally the first two strategies indicate one style of drawing only with reversed order of strokes performed; same goes for the next two strategies after that in Table 3. In the 3rd and 4th strategies, pupils favoured right oblique drawing upward while adhering to left-to-right directionality implicitly (13.5%). However, the overall downward movement is dominant among the pupils (86.5%).

Table 3 Pupils' frequencies of X drawing strategies

Strategy [a]	Frequency
	41
	21
	7
	3
Others with three # of strokes	2

[a] Solid arrow represents the 1st & dashed represents 2nd stroke drawn

In extracting the X drawing strategy, assuming additional states, such as considering nine subsections, would make simple strategies look complicated and blurs the information; and will not benefit noise reduction either; so the choice of this research was to record the start and end of respective strokes in a feature vector using a four state model. The sequences of *other 3-stroke* strategies in Table 3 were: [S1, S1, S1, S2, S3, S4] & [S1, S2, S3, S4, S2, S2]; which with respect to state allocations in Figure 2, they indicate that the former done S1-S2 diagonal in two strokes, while performing the first strategy style. The latter state sequence reveals that the used style is the first one, but another stroke was drawn in the end within S2 area, either accidentally or as a justification. Nevertheless the algorithm offers the required drawing features.

4.3 Basic Line Drawing

Analysis show that all the pupils performed each line in a single stroke except two which the extra strokes detected for them are related to slight pen touches in a very short time, producing undersized strokes that are more related to inaccurate performance of the child rather than suggesting his/her dominant style. Considering the order of drawing, only one student performed the lines starting from the right most to the left (4th strategy Table 4); others done the overlay, line by line from left to right. (Table 4 represents performed strategies.) Conversely that same student performed the horizontal line rightward and the left oblique downward; nevertheless the pupil was a member of the below average group which his behavior is questioned for difficulties. Then again, the third line strategy from Table 4 generally follows the right to left movement in drawing line strokes rather than left to right. This strategy is used by one student and is the only performance which drew the left oblique upward.

As recognized in literature, vertical lines are given priority and are easier for children to draw.[3,28,29] Everyone performed the vertical line downward. Excluding the student with right to left drawing stroke tendency in third strategy, all others performed the horizontal line rightward; and the left oblique line downward. The same way which was witnessed in X drawing strategy for left oblique diagonal. The heterogeneous strategy observed within the population was the right oblique line drawing. Only 29.7% (22/74) of the participants drew this oblique line upward rather than downward. This behavior was observed with X drawing; and had been reported in [13] for triangle drawing in at least 27% (46/170) of children as well.

This performance seems to be related to the way children adhere the general left to right writing movement; i.e. some give primacy to rightward movement over top-bottom; otherwise saying, that is the trade of between downward and rightward tendencies of the graphic rule [28] whereas most children prior the downward movement. However difficult motor task of crossing the midline of the body, involved in oblique line drawings,[3] may affect child's choice as well.

Table 4 The general strategies for basic lines in the population

Basic lines drawing strategy	Frequencies
→ ↓ ↙ ↘	50
→ ↓ ↗ ↘	22
← ↓ ↙ ↖	1
↘ ↙ ↓ →	1

■5.0 CONCLUSION

What is discussed shows that the algorithms presented for extracting X, O, and basic line drawing strategies neatly detect creditable features of structural pattern drawing which are of interest in different psychological and clinical societies; the whole process being automatically applied to the digital data obtained from a tablet, promotes its capability of being embedded into e-health and telemedicine systems. Additionally, abstracting pupils' drawing performance in a short feature vector concludes collecting records of large different sample populations; which foresees future hand drawn categorization and its scrutiny.

Though the pupils are classified with average and below average handwritings in the database, the limited number of data avoids deducing statistical inference conclusions from the descriptive results; however the algorithms are robust in detecting the strategies and extracting perceptual and practical information about structural drawings. Consequently descriptive analysis proposed some structural drawing strategic features to discriminate pupils with below average handwritings from average; such as the state difference between starting and ending states in circle drawing, and the start state itself. Subsequently these with other features should be investigated in larger reliable databases for evidence and confirmation.

Technically strategies are considered important in psychology and neuropsychology in terms of providing new insights to typical children/human performances; hence offered stepwise methods of drawings analyses, can help neuropsychologists and brain mappers to examine in-depth details of human behavior performances and anatomy.

Acknowledgement

This paper is a part of a publication series on Research and Development in Signal, Image and Sensors in Biomedical Engineering Applications. The researcher would like to express the most gratitude to Malaysian Ministry of Higher Education & Universiti Teknnologi Malaysia for supporting this study under Vote Q.J130000.7123.00J07. We are also indebted to our research Biomedical Instrumentation and Electronics research group who has worked together in this research study.

References

[1] A. Vinter, V. Marot. 2007. *Dev. Psychol.* 43(1):94–110.
[2] J. K. Shim, A. W. Hooke, Y.-S. Kim, J. Park, S. Karol, Y. H. Kim. 2010. *Journal of Biomechanics.* 43(12): 2249–2253.
[3] C. Milbrath. 1998. From Line to Representation. *Patterns of Artistic Development in Children: Comparative Studies of Talent*: Cambridge University Press.
[4] G. S. Braswell, K. S. Rosengren, S. L. Pierroutsakos. 2007. *Task Constraints on Preschool Children's Grip Configurations During Drawing*.
[5] M. J. M. Volman, A. Wijnroks, A. Vermeer. 2002. *Acta Psychologica.* 110(2-3): 339–356.
[6] M. C. Fairhurst, T. Linnell, S. Glenat, R. M. Guest, L. Heutte, T. Paquet. 2008. *Behavior Research Methods.* 40(1): 290–303.
[7] P. I. Khalid, J. Yunus, R. Adnan. 2010. *Research in Developmental Disabilities.* 31(1): 256–262.
[8] J. Bo. 2006. *Continuous versus Discontinuous Drawing: Possible Cerebellar Involvement in the Development of Temporal Consistency*: Neuroscience and Cognitive Science, University of Maryland.
[9] M. Sarfraz. 2005. *Computer-Aided Intelligent Recognition Techniques and Applications.* West Sussex, England: John Wiley & Sons Ltd.
[10] S. Izadi, J. Sadri, F. Solimanpour, C. Y. Suen. 2006. SACH'06 proceedings College Park, MD, USA. 22–35.
[11] R. Sudirman, N. Tabatabaey-Mashadi, I. Ariffin. 2011. 1st International Conference on Informatics and Computational Intelligence proceedings Bandung, Indonesia. 49–54.
[12] C. Rémi, C. Frélicot, P. Courtellemont. 2002. *Pattern Recognition.* 35(5): 1059–1069.
[13] P. I. Khalid, J. Yunus, R. Adnan, M. Harun, R. Sudirman, N. H. Mahmood. 2010. *Research in Developmental Disabilities.* 31(6):1685–1693.
[14] Y. Liang, R. Guest, M. Fairhurst, J. Potter. 2007. *Pattern Analysis & Applications.* 10(4): 361–374.
[15] P. van Sommers. 1989. *Cognitive Neuropsychology.* 6(2):117–164.
[16] K. E. Beery, N. A. Buktenica, N. A. Beery. 2004. *Beery-Buktenica Developmental Test of Visual-Motor Integration*
[17] Child-Development-Network. 2003. Child Development Milestones – 5 years. Queensland Government, Queensland Health.
[18] J. Z. Olsen. 2009. Handwriting Standards *Kindergarten Through Grade Four*. Handwriting Without Tears.
[19] G. Goldstein, S. R. Beers, M. Hersen. 2004. *Comprehensive Handbook of Psychological Assesment: Intellectual and Neuropsychological Assessment.* New Jersey: John Wiley & Sons.
[20] M. Taguchi. 2010. *Psychological Reports.* 107(1): 329–335.
[21] M. J. Furlong. 1981. *Journal of Clinical Child Psychology.* 10(3):165–167.
[22] H. M. Gillespie. 2003. *Component handwriting skills among early elementary children with average and below average printing ability*, Northwestern University.
[23] M. S. Cohen. accessed 2012. Brain Mapping. http://www.brainmapping.org/.
[24] S. Rosenblum. 2008. *American Journal of Occupational Therapy.* 62(3): 298–307.
[25] T. Hans-Leo. 1996. Handwriting movement control. In: H. Herbert, W. K. Steven, eds. *Handbook of Perception and Action*: Academic Press.
[26] R. G. J. Meulenbroek, A. Vinter, P. Mounoud. 1993. *British Journal of Developmental Psychology.* 11(3): 307–320.
[27] A. Lagarrigue, M. Longcamp, J.-L. Nespoulous, J.-L. Velay. 2011. 15th IGS Conference proceedings Cancun, Mexico. 209–212.
[28] A. J. W. M. Thomassen, H. J. C. M. Tibosch. 1991. A Quantitative Model of Graphic Production. In: J. Requin, G. E. Stelmach, eds. *Tutorials in Motor Neuroscience.* New York, US: Springer, Kluwer Academic/Plenum Publishers.
[29] M. L. Simner, C. G. Leedham, A. J. W. M. Thomassen. 1996. *Handwriting and Drawing Research: Basic and Applied Issues.* Amsterdam: IOS Press.