DigiPressPad: An Automated Tool for Quantifying and Improving One's Graphic Skill

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ABSTRACT

Graphic skill essential for good quality handwritten content can be quantified through attributes, e.g., graphic force and graphic speed using pressure-sensitive tablets. Though powerful, such solutions are expensive and without automated feedback. Feedback can help one to adopt self-corrective measures to improve graphic skill. Thus, there exists need for tools to quantify graphic quality, graphic force and graphic speed and offer feedback. Here, we have developed an automated tool to quantify one's graphic skill and to offer individualized feedback. Given that there exist differences in the graphic skill of Typically Developing (TD) children and those with Autism (ASD), we used this tool for 6 pairs of TD children and those with ASD. Preliminary results indicate the potential of our tool in capturing differences and improvement in graphic skills of participant groups. The automated tool can act as a complementary tool in the hands of teachers and caregivers.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Interaction devices; Human computer interaction (HCI); Empirical studies in HCI; • **Social and professional topics** → Professional topics; Computing education; Student assessment.

KEYWORDS

Automated Feedback, Graphic Skill, Quantification, Improvement

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1 INTRODUCTION

Graphic skill which encompasses the ability to handwrite content and/or draw images is frequently needed by children to do academic tasks [1]. The ability to successfully execute graphic tasks can affect one's academic performance [2]. In earlier days, graphic tasks used to be executed on paper that could be stored for future reference. With technological innovations and children becoming technology savvy [3], there has been a shift from the use of pen-and-paper to digital platforms (e.g., tablets) for execution of graphic tasks. One's ability to execute graphic tasks can be quantified in terms of various metrices such as graphic force and graphic speed.

One's graphic speed can be related to one's ability to regulate hand movements during graphic execution [4]. It is important to estimate one's graphic speed since deviation from one's comfortable speed of graphic execution can affect the quality of graphic output [5]. Though off-the-shelf pressure tablets are powerful in quantifying one's graphic speed, such tablets are expensive and restricted to Lab-based settings. Thus, there exists a need to come up with alternate tools that can go beyond lab-based settings.

Again, one's graphic force, i.e., force exerted by pen-tip on a surface during graphic execution can have an underlying linkage with his/her graphic speed [6]. The graphic force can affect the intensity of imprint [7] that in turn can affect overall presentation, i.e., quality of handwritten content [5]. Thus, it is important to quantify the graphic force exerted during a graphic execution. Such quantification can in turn be helpful in providing feedback to improve one's graphic force that in turn can contribute to improved quality of graphic output. Given the importance of monitoring one's graphic force, researchers have used stack of sheets separated by carbon papers [5] in conventional settings to get an estimate of one's graphic force. To remove subjectivity from such measurements, researchers have used devices while quantifying and categorizing graphic force into weak (i.e., less than 1.4 N), normal (i.e., 1.4 N to 4.25 N) and strong (i.e., greater than 4.25 N) force ranges [8]. However, such devices do not provide real-time feedback on one's graphic force. Thus, there exists a need to come up with alternate tools that can quantify one's graphic force and offer automated feedback which can be useful for adopting self-corrective measures (if required) for creating presentable graphic output.

One's ability to accurately reproduce a written/drawn content has been shown to be an indicator of his/her graphic performance [9]. In fact, for ensuring good quality of one's graphic output (affected by one's use of graphic force and graphic speed), it is crucial to quantify the quality of graphic output. In conventional practice, one can judge the quality of graphic output through visual inspection [10] while comparing the graphic output in terms of its similarity with a reference template that can suffer from subjectivity [10]. With technology-assisted solutions, one can use similarity measure such as that proposed by Perner et al. [11] to present a quantitative estimate of similarity/dissimilarity of the created graphic output with a reference template to the user as automated feedback. Such estimates on quality of the graphic output along with quantification of other attributes such as graphic force and graphic speed can help explore the underlying causes behind the variations in the graphic output of children irrespective of them being Typically Developing (TD) or with Autism (ASD).

Given that there exist differences in graphic skill of TD children and those with ASD [4], [12], [13], it is important to use tools that can quantify one's graphic force, graphic speed and quality of graphic output while offering automated feedback (useful for adopting self-corrective measures) contributing to improvement in one's graphic skill. Thus, our research questions were (i) does there exist any qualitative difference in the graphic output between TD children and those with ASD? (ii) does use of graphic force and graphic speed during graphic execution vary between TD children and those with ASD which in turn can help differentiate their graphic skill? and (iii) does use of a digital tool quantifying one's graphic force and graphic speed and offering individualized feedback can contribute to the improvement in one's graphic skill? To address these research questions, our objectives were three-fold, namely, (i) design an automated digital tool offering individualized feedback and having the potential to quantify one's graphic performance in terms of quality of graphic output along with one's use of graphic force and graphic speed during graphic execution, (ii) investigate the potential of the developed tool in quantifying graphic skills of TD children and those with ASD and (iii) understand the potential of the developed tool in improving graphic skills of TD children and those with ASD. The rest of the paper is organized as follows. Section II describes our System Design. The details of Experiment and Methodology used are discussed in Section III. An overview of preliminary Results obtained is in Section IV followed by Conclusion and directions for Future Work.

2 SYSTEM DESIGN

Our automated tool (Figure 1) comprised of (i) DigiPressPad interfaced with (ii) Computing Unit. The DigiPressPad Unit consisted of a (a) digital screen, (b) force-sensing pen and (c) microcontroller-based Data Acquisition (DAQ) unit. The Computing Unit housed (a) a Feature Extraction routine and (b) an Automated Feedback Generator and was used for data storage. The digital screen was used to acquire the 2D (x, y) coordinates of point of contact of the pen-tip. The force-sensing pen was used to measure graphic force exerted by the writer. The 2D (x, y) coordinates and the graphic force acquired by DAQ unit were routed (via a USB cable) and stored in the Computing Unit along with time stamping. Subsequently, the

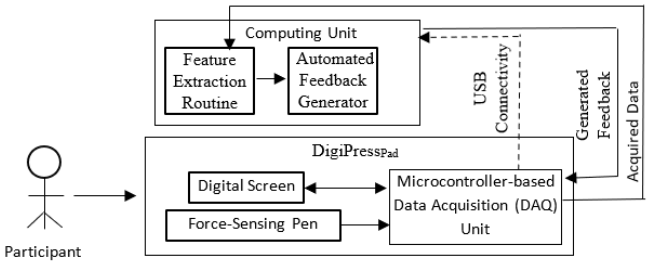


Figure 1: Bird's Eye View of DigiPressPad System

Feature Extraction routine running in the Computing Unit was used to compute the graphic attributes. Subsequently, these extracted attributes (i.e., features) were passed through an Automated Feedback Generator that offered individualized feedback presented on the digital screen. In the sections below we offer a brief description of each module.

2.1 DigiPressPad Unit

The DigiPressPad Unit comprised of a resistive touch-sensitive digital screen, force-sensing pen and a microcontroller-based DAQ unit. The digital screen worked in both input and output mode. In input mode, the digital screen was used to record the 2D (x, y) coordinates of the point of contact of the pen-tip on the screen. In output mode, it was used to give a real-time visual presentation of one's handwritten content along with displaying individualized feedback. The force-sensing pen was a commonly used ball-point pen augmented with a Force Sensitive Resistor (FSR) to acquire data (on a scale of 0-1023; Section 2.1.2) on graphic force. Data from the force-sensing pen and digital screen were routed to the Computing Unit via a USB-enabled DAQ unit.

2.1.1 Digital Screen of DigiPressPad Unit. The digital screen was 2.4" in size (diagonal). The data on 2D (x, y) coordinate of pen-tip touching the digital screen (acquired using DAQ unit; Section 2.1.3)

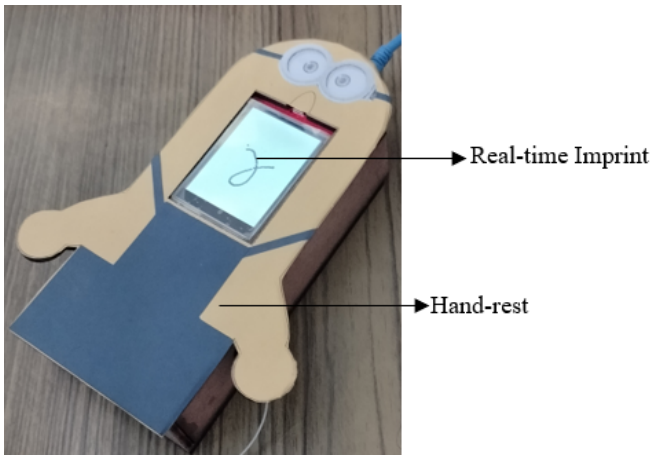


Figure 2: Real-time Imprint on Digital Screen

was used to recreate one's handwritten content. Each 2D (x, y) coordinate pair of pen-tip touching the digital screen was represented as black colored dot of diameter 0.5 mm in real-time. The size of the black colored dot was chosen as an initial approximation while ensuring visibility of the written content. The digital screen was mounted on a hand-rest of size 14 cm x 8.5 cm (l x w) so as to make the writing process comfortable. While designing the hand-rest, we wanted to ensure that it looks attractive to children. Thus, we chose to give it in the shape of a popular cartoon character (Figure 2).

2.1.2 Force-Sensing Pen of DigiPressPad Unit. A Force Sensitive Resistor (FSR; SEN-09673) with force sensitivity ranging from 0.1-10N and active diameter of 0.16" was used to design the force-sensing pen. Given that axial pen force while writing ranges from 1.86 to 2.81 Newton (N) [14] in children, the FSR was calibrated over a range from 0.98N to 9.81N. The data from FSR connected to a voltage divider circuit (powered by a regulated 5V source) was acquired by the DAQ Unit (Section 2.1.3) and sampled using a 10-bit Analog to Digital converter. For calibration of the FSR, known force was exerted on the FSR from 0.98N to 9.81N in steps of 0.98N and the corresponding digital output was recorded. This process was repeated 3 times which indicated that the FSR output was repeatable and was linearly (R^2=0.98) related to the applied force.

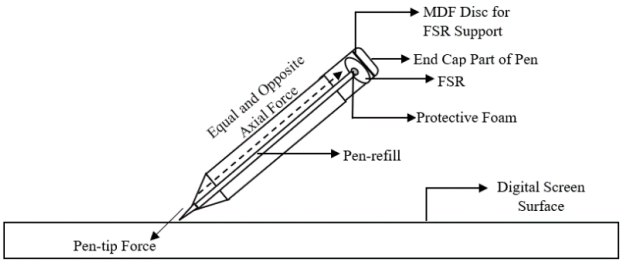


Figure 3: Component Details of Force-Sensing Pen

To get an estimate of one's graphic force, a ball-point pen (commonly used by children for writing in their schools) was augmented with the calibrated FSR. The end cap part of the pen housed a MDF sheet disc acting as a support for the FSR and a protective foam (of thickness 0.5 mm) as seen in Figure 3. The FSR was concealed using the cutout of a popular cartoon character. The purpose of concealing the FSR was to avoid it being a distraction during the execution of the task. While pen-tip touched the digital screen, the end of the pen-refill pushed against the FSR thereby offering force on the FSR via intermediate foam layer. The data (0-5V) from the FSR was acquired by the DAQ Unit.

2.1.3 Data Acquisition Unit of DigiPressPad. The Data Acquisition (DAQ; Figure 4) unit consisted of a microcontroller (Arduino Uno) that received power using a regulated 5V supply.

This was used to acquire data from the FSR of the force-sensing pen and 2D (x, y) coordinates of pen-tip touching the digital screen

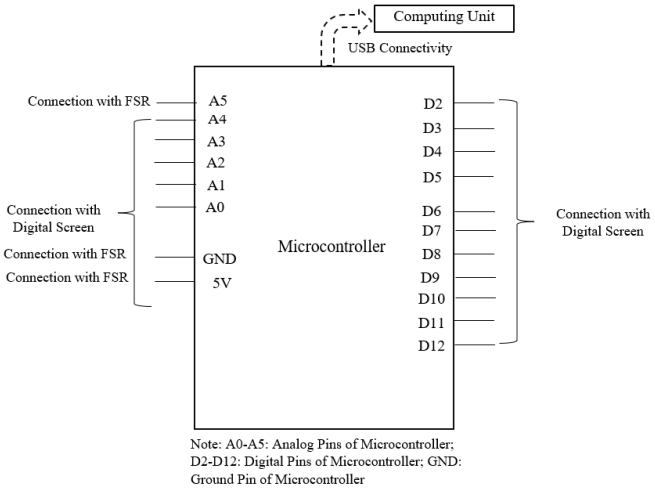


Figure 4: Data Acquisition Unit

in real-time. These data were sampled using a 10-bit Analog to Digital converter at ~40 samples/second and transmitted to the Computing Unit via a USB cable at a baud rate of 115.2 Kbits/sec. The acquired data was stored in a .csv file and used by the Feature Extraction Routine (Section 2.2.1). The DAQ unit was mounted at the back side of the hand-rest (Figure 2).

2.2 Computing Unit

The computing unit was used to (i) store data acquired using the microcontroller-based DAQ unit (Section 2.1.3), (ii) compute graphic attributes (extracted using Feature Extraction Routine (Section 2.2.1)) while one executed a graphic task and (iii) present individualized feedback (generated by Automated Feedback Generator (Section 2.2.2)) on the digital screen of DigiPressPad via the DAQ unit (Section 2.1.3) at the end of each task. The graphic task needed one to write digits '1'- '9' in one of the three languages, namely English, Gujarati or Hindi (Section 3.3).

2.2.1 Feature Extraction Routine. The Feature Extraction Routine was used to compute various graphic attributes, i.e., features, such as similarity index, graphic force and graphic speed.

Computation of Similarity Index. For quantifying the quality of graphic output, our Feature Extraction Routine computed Similarity Index using algorithm described by Perner et al. [11] (Figure 5) wherein the handwritten content was first scaled and oriented with respect to the template (for each of English, Gujarati or Hindi) image of digits '1'- '9' to be written. This was followed by superimposition of scaled and reoriented handwritten image on template image. Subsequently, our Feature Extraction Routine was used to calculate percentage error/dissimilarity in terms of pixel-based average Euclidean distance between the reference template and handwritten content. Finally, %Similarity Index of handwritten content was computed using Eq. 1.

$$\%Similarity\ Index = 100 - \%Error\ (Dissimilarity) \quad (1)$$

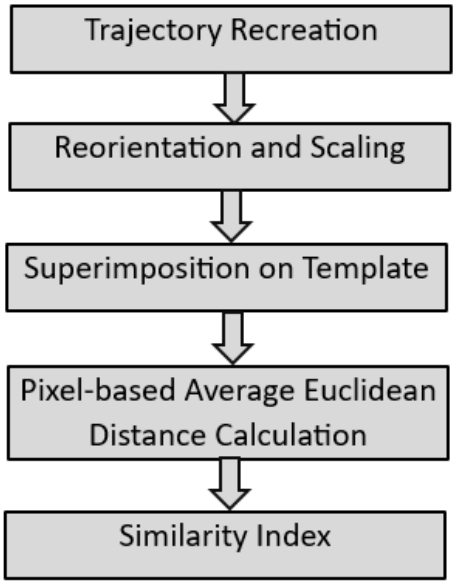


Figure 5: Computation of Similarity Index

Computation of Graphic Force. The Feature Extraction Routine was used to compute the average graphic force for each of the digits '1'- '9' by using Eq. 2).

$$GF_{Avg} = \frac{\sum_{i=1}^{n} GF_i}{n} \quad (2)$$

Where, GF_{Avg} is the average graphic force, GF_i is the graphic force at the i^{th} data point and n is the total number of data points.

Computation of Graphic Speed. The Feature Extraction Routine was used to compute one's graphic speed by taking the first derivative of the coordinate pair displacement of the pen-tip on the surface of the digital screen with respect to time [15] using the Eq. 3).

$$GS_{Avg} = \frac{\sum_{i=1}^{n} \sqrt{(x_{i+1} - x_i)^2 + (y_{i+1} - y_i)^2}}{t} \quad (3)$$

Where, GS_{Avg} is the average graphic speed, (x_i, y_i) and (x_{i+1}, y_{i+1}) are the 2D coordinates of the i^{th} and $(i+1)^{th}$ data point, n is the total number of data point and t is the total time taken.

2.2.2 Automated Feedback Generator. The Automated Feedback Generator residing in the Computing Unit was used to offer individualized feedback based on the computed attributes. Here, we have considered the Similarity Index (Section 2.2.1.1) and the graphic force (Section 2.2.1.2) for the individualized feedback. The reason behind this was to understand whether feedback on one's graphic force and Similarity Index can contribute to offering improvement in the area of controlled and regulated hand movement (involved during a graphic task) defining graphic speed without explicit mention on modifying graphic speed. In fact, the graphic speed is crucial given that there exists an underlying linkage of one's graphic speed with graphic force [6] and the Similarity Index [16].

With regard to individualized feedback on the Similarity Index, the Automated Feedback Generator categorized the computed attribute into 5 sub-categories (based on inputs from school teachers) as shown in Table 1. Again, with regard to graphic force, the Automated Feedback Generator categorized the computed attribute into 3 sub-categories (similar to that in another study [8]; Table 1). The feedback was presented as text on the digital screen of DigiPressPad via the DAQ unit using a Python-based script.

3 EXPERIMENT AND METHODOLOGY

3.1 Participants

A total of 12 participants (6 Typically Developing individuals ($Group_{TD}$ henceforth) and 6 individuals with Autism (ASD) ($Group_{ASD}$ henceforth) took part in our study (Table 2).

All participants belonging to $Group_{TD}$ were recruited through nearby local regular schools based on teachers' recommendation. All the participants belonging to $Group_{ASD}$ were recruited from a nearby mental health institute based on the therapist's recommendation. We also administered the Social Responsiveness Scale (SRS) [17] and Social Communication Questionnaire (SCQ) [18] for participants belonging to both the groups. All the participants in $Group_{TD}$ were below the cut-off for both SRS and SCQ scores while, all the participants belonging to $Group_{ASD}$ had SRS and SCQ scores above the clinical cut-off.

3.2 Experimental Setup

The setup (Figure 6) comprised of (i) DigiPressPad (Section 2.1), (ii) Computing Unit (Section 2.2) connected to the DigiPressPad via USB cable, (iii) template board, (iv) table and (iv) chair.

The DigiPressPad was placed on table top and facing a template board displaying numbers '1' to '9' in the language of choice.

Table 1: Feedback on (a) Similarity Index and (b) Graphic Force

Percentage Similarity Index	Feedback
Similarity Index >=95%	Excellent
80 >= Similarity Index < 95	Very Good
65 >= Similarity Index < 80	Good
50 >= Similarity Index < 65	Well Done
Similarity Index < 50	Fair
(a)	

Graphic Force Range	Feedback
Graphic Force < 1.4 N	Weak
1.4 N >= Graphic Force <= 4.25 N	Normal
Graphic Force > 4.25N	Strong
	(b)

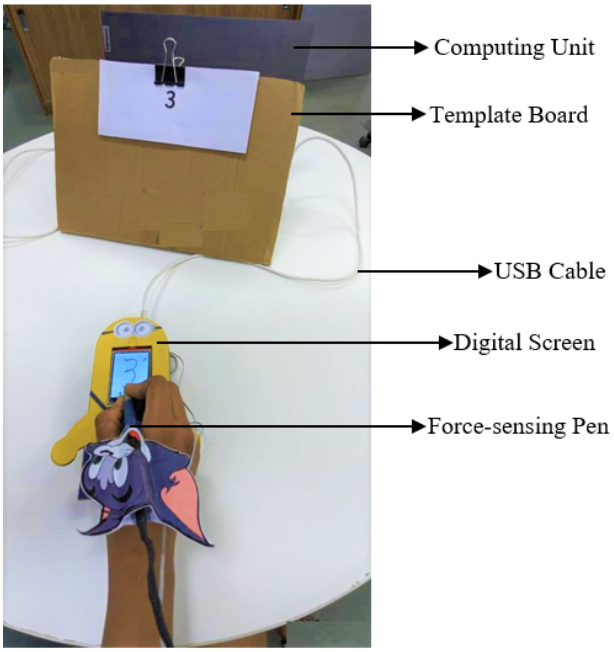


Figure 6: Experimental Setup

3.3 Tasks and Procedure

Completion of tasks required a commitment of ~7 minutes from each participant. As soon as a participant entered the study room, the experimenter introduced herself and the participant was asked to sit comfortably on a chair. Then the experimenter showed the experimental setup (Figure 6) comprising of the DigiPressPad and the template board. After this, the experimenter explained the task to the participant. The task consisted of 9 sub-tasks wherein each subtask required one to write digits '1'- '9' sequentially in one of the three languages, namely English, Gujarati or Hindi (Figure 7 (a)-(c)).

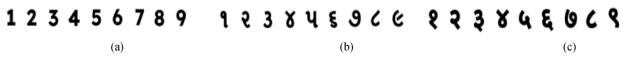


Figure 7: Digit Writing Task (a) in English (b) in Gujarati and (c) in Hindi

The idea was to select a language most preferred by an individual so as to not offer any additional difficulty due to unfamiliarity with task language. Also, the participant was told that he/she was free to ask for breaks in between the task (if needed) and that he/she was free to discontinue from the study in case of any discomfort. The participant was offered the force-sensing pen and was asked to use the DigiPressPad to be accustomed in using our setup. Once the participant expressed that he/she was ready to start the task, the experimenter displayed number on the template board (in participant's preferred language). The study was conducted following Institute Ethics (IEC/UL/2021/001).

3.4 Statistical Technique Used

We wanted to understand the potential of our tool in quantifying one's graphic skill in terms of computed graphic attributes (Section 2.2.1). We normalized each of the graphic attribute across both participant groups using Max Normalization [19]. Given limited sample size, we carried out independent sample comparison using non-parametric Mann-Whitney U Test [20]. Also, to get an estimate of effect size, we computed Cohen's d [21].

3.5 Correlation Technique Used

We wanted to understand whether our developed tool can quantify underlying linkages between the attributes of graphic skill. For this, we used Pearson's Correlation [22].

3.6 Computation of Percentage Change

We wanted to understand the potential of our tool to contribute to improvement in graphic skill quantified in terms of various attributes within each participant group. Given that the task comprised of 9 small sub-tasks with each sub-task comprising of writing of a single digit, and that the Feedback Generator offered feedback at the end of each sub-task, we computed percentage change in graphic attributes within each participant group between the respective first and last sub-tasks using Eq. 4).

$$\%Change = \frac{Value\ in\ last\ subtask - Value\ in\ first\ subtask}{Value\ in\ first\ subtask} \text{ x } 100 \quad (4)$$

Table 2: Participant Characteristics

ID	Gender	Age (Years)	SRS (1)	SCQ(2)	ID	Gender	Age(Years)	SRS(1)	SCQ(2)
		$Group_{TD}$					$Group_{ASD}$		
TD1	M	6	42	1	ASD1	M	6	80	20
TD2	M	7	42	2	ASD2	M	6	64	17
TD3	M	6	42	7	ASD3	M	7	67	17
TD4	F	6	48	5	ASD4	M	6	66	18
TD5	M	6	43	1	ASD5	M	6	78	16
TD6	M	7	42	1	ASD6	M	6	64	20
Mean		6.3	43.1	2.8			6.1	69.8	18
(S.D)		(0.5)	(2.4)	(2.5)			(0.4)	(7.2)	(1.6)

Note: ID: Participant ID, (1): cut-off for SRS = 59; (2): cut-off for SCQ = 15

4 RESULTS

Given the importance of reproducing good quality handwritten content (quantified in terms of Similarity Index) and the importance of investigating the features associated with one's graphic execution, we wanted to understand the potential of our tool to quantify one's graphic skills in terms of computed graphic attributes, i.e., Similarity Index, graphic force and graphic speed in two groups of participants ($Group_{TD}$ and $Group_{ASD}$). Also, we wanted to understand the potential of our tool in improving one's graphic skills. In addition, we collected participants' views regarding the ease of use of our tool.

4.1 Users' View on the Ease of Using the DigiPressPad System

After each participant finished the task execution (with all the participants being able to write all the digits '1' to '9' in their preferred language), the experimenter conducted an exit survey to understand the users' view on the ease of using the tool. The participants verbally responded to the questions asked by the experimenter. Specifically, we wanted to understand the users' views on the ease of (i) writing on the digital screen of DigiPressPad and (ii) using the force-sensing pen (while executing the task). Also, we wanted to know whether the participants were interested to use our tool in future. All the participants expressed that they enjoyed using DigiPressPad. When asked about their impression on writing on the digital screen, majority of them mentioned that they found it natural since they were habituated to writing their online assignments on tablet screens for the last couple of years. The participants mentioned that the pen seemed familiar to them and it was thus easy for them to write using it. Given that there was no noticeable lag between the instant one used the pen to create a mark on the screen of DigiPressPad and the display of handwritten imprint on the screen, some of the participants tried to use the pen to scribble lines on their palms to know how the imprint looked on their palms. On asking, they reported that they felt that the pen was an ink pen that one can use to write on a sheet of paper. Also, all of them reported that the hand-rest of DigiPressPad was comfortable to them. In addition, the participants asked for future possibilities of using DigiPressPad.

4.2 Investigating the Potential of the DigiPressPad System to Quantify Graphic Skills

To understand the potential of the developed tool to quantify one's graphic skill, we analyzed the computed graphic attributes, such as similarity index (Section 2.2.1.1), graphic force (Section 2.2.1.2) and graphic speed (Section 2.2.1.3) for both $Group_{TD}$ and $Group_{ASD}$.

4.2.1 Similarity Index of $Group_{TD}$ and $Group_{ASD}$. Given that graphic skills vary among individuals, we wanted to understand whether our tool can evaluate one's graphic output quantified in terms of Similarity Index (Section 2.2.1.1) for each of the handwritten digit for both $Group_{TD}$ and $Group_{ASD}$.

Our results (Figure 8) show that the group average similarity index was nearly similar for the two participant groups with no statistical difference as expected given that all participants were familiar to writing all the digits as a part of their academic curriculum. To summarize, our tool was able to quantify the qualitative aspect of handwritten content (irrespective of the other attributes of handwriting that might differ between the two participant groups) in terms of a metric, i.e., similarity index thereby addressing our first research question.

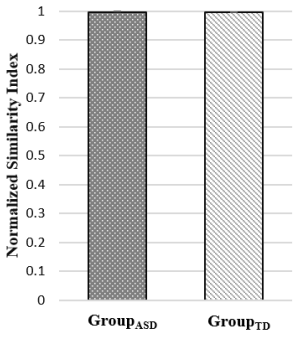


Figure 8: Comparative Group Analysis for Similarity Index (with error bars representing Standard Error)

4.2.2 Graphic Force of $Group_{TD}$ and $Group_{ASD}$. Notwithstanding the fact that both the participant groups on an average had nearly same Similarity Index and given that literature indicates that individuals with ASD often use weaker graphic force [23], we wanted to understand whether our tool can capture any difference in graphic force between the two participant groups.

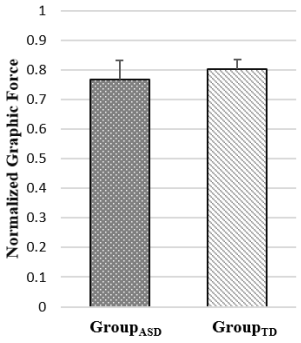
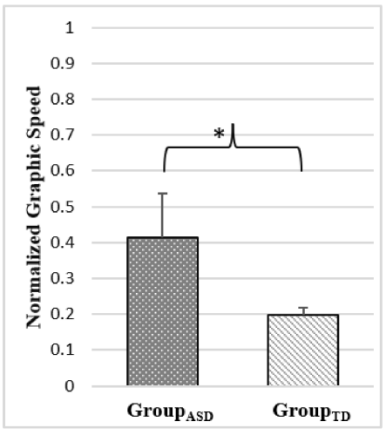


Figure 9: Comparative Group Analysis for Graphic Force (with error bars representing Standard Error)

The Figure 9 shows the normalized group average graphic force for $Group_{TD}$ and $Group_{ASD}$ for the digit writing task. It can be seen that the graphic force for $Group_{TD}$ was greater ($\Delta\% = 4.47\%$) than that for $Group_{ASD}$ though the difference was not found to be statistically significant (p-value>0.05; Cohen's d = 0.28).

4.2.3 Graphic Speed of $Group_{TD}$ and $Group_{ASD}$. Given that there often exists an underlying linkage between the use of specific graphic force and graphic speed [6], we wanted to understand whether our tool can quantify such a linkage in terms of quantifying the graphic skill through the graphic force and graphic

speed. For this, first, we wanted to understand whether our tool can capture any difference in the graphic speed between the two participant groups. The Figure 10 shows the normalized group average graphic speed (Section 2.2.1.3) for $Group_{TD}$ and $Group_{ASD}$ for the digit writing task. It can be seen from Figure 10 that the normalized average graphic speed (evaluated by our tool) for $Group_{ASD}$ was found to be statistically (p-value<0.05; Cohen's d = 0.98) greater ($\Delta\%$ = 109.27%) than that for $Group_{TD}$. Also, the normalized average graphic speed of the participants was found to be negatively correlated (Pearson's Correlation indicating medium strength) with the graphic force. This observation throws light on the underlying linkage between the two graphic attributes that helps explain the reduced ability of $Group_{ASD}$ in controlling and regulating their hand movements during the graphic execution [4] thereby causing them to demonstrate higher graphic speed.



Note: * indicates p-value<0.05

Figure 10: Comparative Group Analysis of Average Graphic Speed (with error bars representing Standard Error)

In short, the DigiPressPad was able to capture differences between $Group_{TD}$ and $Group_{ASD}$ in the use of graphic force and graphic speed during graphic execution thereby addressing our second research question.

4.3 Investigating the Potential of the DigiPressPad System to Improve one's Graphic Skill

We wanted to understand whether the feedback (given explicitly on Similarity Index and graphic force) offered by the Automated Feedback Generator can have potential to contribute to improvement in one's graphic skill quantified in terms of Similarity Index and graphic force. Additionally, though our tool did not offer explicit feedback on one's graphic speed, we wanted to explore the contribution of our tool on one's graphic speed given underlying linkage between the graphic attributes. Since the task comprised of 9 small sub-tasks with each sub-task comprising of writing of a single digit, and that the Feedback Generator offered feedback at the end of each sub-task, we wanted to investigate whether there was any change in the graphic attributes within each participant group between the respective first and the last sub-tasks (Section 3.3).

4.3.1 Change in Similarity Index between first and last sub-tasks within each of $Group_{TD}$ and $Group_{ASD}$. The Figure 11 shows the normalized percentage change ($\Delta\%$) in Similarity Index between the last and the first sub-tasks for each participant group (i.e., $Group_{TD}$ and $Group_{ASD}$).

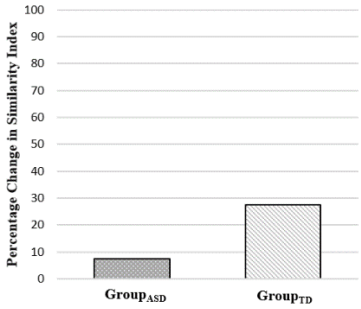


Figure 11: Percentage Change in Similarity Index

It can be seen from Figure 11, that there was an increase in the Similarity Index for each of $Group_{ASD}$ and $Group_{TD}$ (though the improvement was less for $Group_{ASD}$ than that for $Group_{TD}$) inferring improvement in graphic skills.

4.3.2 Change in Graphic Force between first and last sub-tasks within each of $Group_{TD}$ and $Group_{ASD}$. The Figure 12 shows the normalized percentage change ($\Delta\%$) in graphic force between the last and the first sub-tasks for each participant group (i.e., $Group_{TD}$ and $Group_{ASD}$). It can be seen from Figure 12, that for $Group_{ASD}$, there was an improvement in graphic force for most of participants wherein the graphic force improved from Weak to Normal (Table 1) in 4 (out of 6) participants and from Strong to Normal in 1 (out of 6) participant leaving behind 1 participant who retained his Normal graphic force.

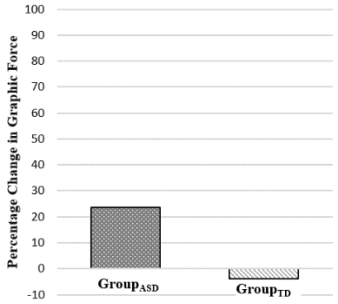


Figure 12: Percentage Change in Graphic Force

For $Group_{TD}$, the overall change in the graphic force was different from that of $Group_{ASD}$. Such difference can be attributed to the changes in the use of graphic force from Strong to Normal in 3 (out of 6) participants, from Weak to Normal in 2 (out of 6) participants with 1 participant retaining her Normal graphic force.

4.3.3 Change in Graphic Speed between first and last sub-tasks within each of $Group_{TD}$ and $Group_{ASD}$. Having found that use of our tool brought in at least some improvement in Similarity Index and graphic force in each of the participant groups, we wanted to understand whether there was change in the graphic speed since ability to control and regulate one's hand movement is crucial in producing good graphic output [4] that can be related to use of individualized graphic force [6].

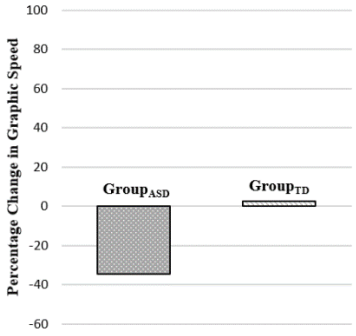


Figure 13: Percentage Change in Graphic Speed

The Figure 13 shows normalized percentage change ($\Delta\%$) in graphic speed between the last and first sub-tasks for each of $Group_{ASD}$ and $Group_{TD}$. It can be seen from the Figure 13, that overall, there was a decrease in the graphic speed for $Group_{ASD}$ with the decrement being considerably more than the amount of increment for $Group_{TD}$.

In short, given the preliminary findings, the DigiPressPad was found to have potential to contribute to improvement in one's graphic skill thereby addressing our third research question.

5 CONCLUSION

We have developed an automated tool that can quantify one's graphic skill in terms of quality of graphic output, graphic force and speed while offering individualized feedback. Preliminary results of our study with 6 pairs of TD children and those with ASD indicate that our tool was able to quantify the graphic skill of the two participant groups by capturing their differences in graphic force and speed. Also, the quality of graphic output improved along with change (first-to-last task) in graphic force and speed for both the groups. Though promising, our proof-of-concept study had limited sample size and thus we do not intend to claim its potential to contribute to improvement in one's graphic skill. In future, we plan to conduct a study with a larger sample size. Also, we plan to investigate other attributes such as air-time, number of pen-lifts, etc. Our current task included writing of digits '1'- '9'. However, the developed tool can be used for drawing of shapes, writing of letters/words. Nonetheless, our current results indicate that such an automated tool can have applications in assessment of one's graphic performance while assisting in improvement of one's graphic skill. Thus, such a tool can find application in schools, therapy centers, homes, etc. and serve as a complementary tool in the hands of teachers, therapists and caregivers working with children.

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