Children Adapt Drawing Actions to Their Own Motor Variability

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ABSTRACT

Children like to draw, but how easy is it for them to draw on a touch screen device? More specifically, how do children adapt the way that they draw to the device, to their own limitations and to the motivational context for action? To answer this question we conducted empirical studies on children's drawing to examine how they adapt drawing actions to their own motor variability and to extrinsic motivations (rewards). Our study consisted of drawing tasks that tested the application of a movement planning model based on statistical decision theory. The idea was to see how children act as ideal drawing planners when choosing tracing movement trajectories on touch surfaces. We derived predictions of the hypothesis from children drawing on a touch surface with regions carrying reward or penalties. The model predicts shifts in subject's drawing contact point in response to changes of reward and penalty structures within the drawing environment and changes to subject's own motor uncertainty during rapid drawing movement. The results of the study show that children adapt drawing actions by shifting their mean points of drawing contact in response to the proximity of penalty regions relative to target area.

Author Keywords

Children's drawing; drawing feedback; reward signals; movement planning; optimality; visuomotor strategy; motor variability; statistical decision theory.

ACM Classification Keywords

H.5.2. Information Interfaces and Presentation (e.g. HCI): User Interfaces-Input devices and strategies,Theory and methods;

INTRODUCTION

Children like to draw, but how easy is it for them to draw on a touch screen device? More specifically, how do children adapt the way that they draw to the device and to their own limitations? Recent work has shown that while children seem to like using tablets they have specific difficulties. For example, they have a tendency to miss a greater proportion of onscreen targets compared to adults [1, 2] and they make unintentional touches with trailing fingers and thumbs [6]. A scientific understanding of how children draw might help inform design of tablets that facilitate children's drawing.

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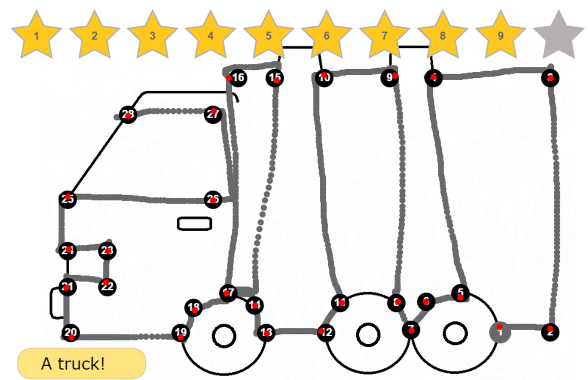

Figure 1. Drawing task with reward function of least distant error. This drawing need to go through a series of dots to get a perfect score and were measured upon the minimal distance of the drawing lines with the dots.

The problems that children experience with tablets could possibly be due to the fact that they have less experience with technology or less well developed sensorimotor coordination. Although some of this evidence may introduce perceptual and motor difficulties for drawing on tablets, they still arguably offer a more flexible drawing tool than paper and pencil. Drawing is still a task that may increasingly be done by children on a tablet rather than on paper, reflecting a broader digitization of both child and adult activities. However there have been very few studies of how they do so. Following [7], we report a study investigating childrens' hand motor control from drawing activity using touch surface interaction.

To explain the emergence of children's drawing strategies on touch-screen surface might be informed by understanding the psychology of how drawing is enabled by an adaptive cognitive system. An adaptive cognitive systems approach to human-computer interaction has been proposed by Payne and Howes (2013) [8]. The components of the system include motor output, imagery, memory, meaning, perception . These components constrain the strategy adopted making drawing a complex task that involves planning in both perceptual motor and cognitive skills. In order to understand children's planning and drawing skills, we developed a drawing task that embedded drawing goals and drawing feedback. Our work lies in understanding strategies given limits in the device and in the perceptual and motor control system.

The modeling approach that we take is grounded in Bayesian decision theory [11] looking into reward factors that could motivate children to adapt their drawing actions to draw better. While motivation is partly an important element in children's drawing, it is not unreasonable to suppose that their perception of the quality of what they draw is influenced by their assessment of a drawing fitness for these purposes. Such assessment could be perceived more as a support for encouragement to engage in drawing for longer [3]. This suggests that drawing tasks, used in studies, could benefit from extrinsic motivation such as rewards as drawing feedback. This is sometimes achieved socially, while having children experience drawing in an interesting and challenging environment, sometimes it is achieved by a computer system giving more stars for higher quality drawings. At the end of this paper, we will discuss the implications of the empirical findings for decision theoretic framework emphasizing reward signals in children's drawing.

STUDY 1

The first study concerned the accuracy of contact points and drawing line segments to perform a complete drawing figure. The drawing task was built upon a series of dots that formed a shape where children were required to connect these dots according to the order of the number. We named the drawing task as *Join-the-Dots* mimicking the conventional way of joining the dots on paper but with drawing feedback. The manipulation of a reward system in the drawing task measured the accuracy of the contact points and segments of line drawing throughout. The accuracy of the contact point was calculated based on the weighted function of least squared errors where the drawing line need to go through a series of dots to get a perfect score. These contact points within the drawing lines were measured upon the minimal distance to the numbered dots. The drawing lines on the other hand were measured against the shape of the drawing, which was measured with the sum-squared error, giving more stars for the right shape even if the distance of contact points were off. The reward was manipulated as an independent variable where high reward gave easy access to ten stars and low reward made difficult to attain the ten stars. The objective was to examine how children behave regarding the type of reward they received with assumption that children are motivated to draw more accurately given high reward than low reward .

Method

Apparatus

The experimental setup used was an iPad Air tablet device of 10.1-inch wide screen that was connected to an Apple MacBook-Pro 13-inch laptop through a USB cable. The drawing tool that was developed using HTML5 and JavaScript was loaded to the tablet device using web Safari via cellular data or WIFI network that were available in the area. Subjects either used their fingertips or pen stylus to perform the drawing task and were given flexibility to sit at their own convenient pace. All input data from drawing task were transferred automatically to the laptop at the end of the session.

Stimuli and Experimental Design

We developed two drawing applications with similar tasks but different reward function. The first had a reward function based on the accuracy of the contact point and the second a reward function was based on the shape of the line drawing. The experiment was a between participants design with two independenet variables: reward manipulation(*low* and *high*) and mode input(*pen stylus* or *fingertips*). There were 4 experimental groups; *High Reward* with *Pen*(*A1B1*), *Low Reward* with *Pen*(*A1B2*), *High Reward* with *Fingertips*(*A2B1*) and *Low Reward* with *Fingertips*(*A2B2*). It was a one data point per participant, a two-by-two analysis of whether a subject was affected by the pen or fingertips and high or low star ratings. The experiment lasted about 40 minutes to 1 hour per participant.

Procedure

The drawing software started with a main page followed by a simple instruction page. When the *Start Now* button was tapped, the first drawing task was loaded. The *Join-the-dots* drawing had mainly around 15 to 30 dots for each task. The dots had a black circle background with a bold white font number. Every first dot was bigger in size than the rest and with a grey background to make it stand out. The input drawing strokes were in grey and participants were instructed that they should follow the order number of the dots. When the strokes passed every dot, a small red dot from the strokes would appear marking the nearest stroke dot to the task dot. The drawing time was recorded from once the participant first touched the screen until the end of the touch near the final dot. The screen would then freeze and the number of stars would be displayed. The stars were in yellow and were numbered. One example of drawing task is illustrated in Figure 1)A yellow box with circular edge and a text inside naming the drawing would appear at the bottom-left of the screen. An arrow button would appear on the bottom-right of the screen to tap for next page which lead to rest page. Here, subjects could choose to pause for rest or tap to the *Next Drawing* button for the next drawing task. Altogether there were 20 drawing tasks, a mix of vehicles and animals, with intermittent rest page in-between the task. After all 20 drawings were completed, a page that showed each score for every drawing task and an overall score was displayed.

Subjects and Instructions

There were 34 participants comprising of 15 boys and 19 girls, all ranging from age 5 to 11 years old. All parents had given their informed consent to allow their children to participate in the study. Children gave their informed consent verbally and in writing prior to the experiment. Subjects were briefly told how the task should be completed. They were then asked whether they had any experience with a tablet. Those who did not have any experience were given the tablet to familiarize themselves for about ten minutes. After that, they did a warm-up session of joining the dots task on paper using a pen. This is to ensure that subjects were familiar with number ordered from 1 to 50. Once they completed the task on paper, they were assigned to one of four groups. The group assignment was based on the order of participants. The first subject went to group 1, *A1B1*; second subject to group 2, *A1B2*; third subject to group 3, *A2B1*; fourth subject to group 4, *A2B2*; fifth subject back to group 1 and the pattern continued. All were unaware of the hypotheses under test. When subjects completed the task, they were given a form to fill in their background information, time spending of drawing on paper and tablet and user satisfaction on the drawing tool. At the end of the sessions, they were given a small bag of gifts as token of appreciation.

Data Analysis

In this study we wanted to identify the effect of whether feedback with high reward function motivates children to draw more accurately than drawing with low reward function. We also wished to examine the effect of whether the pen stylus could reduce errors due to trailing fingers and increase precision and quality. Therefore, we recorded the drawing time, score, number of penlifts, speed and user satisfaction. In the analysis, we examined the accuracy of drawings from the least distant error function, retain shape function and the balance between both factors. We also looked into the drawing mode of using fingertips or pen stylus and whether it could affect their drawing strategies or scoring.

Result

The mode of drawing using finger or stylus did not differ significantly in either condition nor in distant errors or shape errors. However there was a main effect of reward condition in least distant error with $F(1,29)=4.712$, $n=33$ and $p=0.038$ but no main effect occurred on reward shape error. We measured the balance between the two reward function to find the accuracy of the drawings and found out that the mode of drawing (finger or stylus) did not affected the accuracy of drawing. Regardless at which condition the subjects were in, they were getting about the same number of stars. In fact their performance was at ceiling. From our observations during the experiment, participants tried their best to complete the drawing task at high accuracy at their own convenient pace. Even if the reward is set to be harder, the children were already doing as well as possible. The task could be improved by putting a constraint to the drawing environment. One possible way is to put time limits and the other could be imposing a reward and penalty effects to the drawing. Given this two possibilities could induce a rapid drawing movement task. This was one of the motivations of study 2.

STUDY 2

This study focused on the understanding how children adapted drawing to the proximity of penalty regions, when under time pressure. The dots in the previous task were all black dots. What happen if there was a red dot nearby and touching a red dot loses some points? How would a child-user avoid the red dot and at the same time trying to achieve a higher score? This task is a natural variant of Trommershauser et al.(2003) work. Again, as with study 1, the aim was to understand how children adapt strategies for using a tablet to reward factors.

Model Strategy of Drawing Movement

In Bayesian decision theory, the visual-motor strategy relies upon the goal of the movement, the planned duration, the possibility of visual feedback during movement, previous training and intrinsic uncertainty in the motor system [11]. If the movement exceeds the time limit, a high penalty will be incurred. If the penalty region is reached, negative or zero points will be awarded. Since the movement needs to be rapid, the end point of the movement may touch the penalty region. When a high penalty region is placed next to a small target region (see example in Figure 2), adults are known to alter the motor plan. In particular they shift their aim point so as to avoid the penalty region. In response to changes in the reward and penalty structure of the environment and with changes in the subject's motor variability, the theory predicts specific shifts in a subject's mean movement end point [11].

A visual motor strategy is a sequence of motor commands involving intermediate goals in space and time. The outcome of drawing movement planning consisted of a visual motor strategy, S, where S is selected based on the mean end point of drawing movements within a given time limit. For any time t, the drawing movement trajectory, $\tau(t)$ is a result of a contact point fingertip position in time and 2-dimensional drawing space with $\tau{:}t \to [x(t), y(t)]$. Once the motor strategy is executed, it imposes a probability density, $P(\tau|s)$ that is a possible drawing movement trajectories on a 2-dimensional drawing space. This probability density $P(\tau|s)$ of drawing movement is likely affected by the interactivity of drawing task itself concerning the goal of drawing and visual drawing feedback; experiences from performing the drawing trials and intrinsic uncertainty embedded in the motor system [11]. The drawing task environment contains regions that carry a penalty or reward point that was explicitly known to the subject. [11] used the term gain, G_i, $i = 0,...,N$ to refer to both rewards and penalties point incurred from different regions, R_i, $i = 0,...,N$. The optimal of visual-motor strategy S occurred when subject maximizes the expected gain $\Gamma(S)$ on any drawing trials.

Selecting the Optimal Drawing Movement in Regions of Expected Gain

In a drawing task, a participant is required to draw a line from a starting point towards a target region within a time limit. On every trial, there is a penalty region placed near to the target region in different proximities. The penalty region is located either next to the target region or overlapping to the target region. Each drawing trial that completed within the time limit has four possible outcomes (The value of reward and penalty is represented as gains, G):

- The non-overlapping target is hit. If region R_0 is hit, subject receives a high reward of G_0 stars ($R_0 > 0$).

- The non-overlapping penalty region is hit. If region R_1 is hit, subject receives a penalty of low reward as G_1 stars ($G_1 > 0$).

- The overlapping target and penalty region is hit. If region R_2 is hit, subject receives a medium reward of G_2 stars ($G_2 > 0$).

- The outside region is hit. If region R_3 is hit, subject does not received any reward ($G_3 = 0$)

Late responses incur the same penalty as G_3; where no stars are given. The possible visual-motor strategies S is denoted by the resulting mean end point (x,y) of contact point on the touch screen; denoted as the *aim point* of the subject. In order to predict the optimal aim point of drawing movement, the drawing end point should maximize the expected gain function. Thereof, we look into the end points that hit all possibility regions within the time limit.

$$\begin{aligned} L(x, y) = G_0 P(R_0 \mid x, y) + G_1 P(R_1 \mid x, y) \\ + G_2 P(R_2 \mid x, y) + G_3 P(R_3 \mid x, y) \end{aligned} \tag{1}$$

We can ignore the constant G_3, outside region.

$$\begin{aligned} L(x, y) = G_0 P(R_0 \mid x, y) + G_1 P(R_1 \mid x, y) \\ + G_2 P(R_2 \mid x, y) \end{aligned} \tag{2}$$

Method

Apparatus

The experimental setup was the same as in experiment 1. We named the second drawing application as *Draw-A-Line*. In the second experiment, subjects only use their fingertips to perform the drawing task.

Stimuli and Experimental Design

The experiment comprised of 2 sessions; a 10-15min first session of calibration and a 30-40min second session of main drawing task. Since we were dealing with young children , we made the first session of the experiment a calibration procedure to find the best target size that would fit a child's ability to work on touch screen using their finger-tips. There were 7 drawing tasks for one block of trial but without a penalty region. Each block of trial represented one target size starting with target size 4 as the mid-size of all other 7 target sizes available. There would be a randomized of 7 drawing tasks in different angle and location (either to the left or to the right side of the screen). The session ended only when the target size fit the criterion of a specified error rate. These were performed using psychometric function with a cumulative Gaussian Distribution. The stimulus configuration for the main drawing task consisted of a target region and a penalty region with the size outcome coming from the calibration procedure. The target region was semi-circular black shading. The penalty region was also semi-circular of bright red shading with little transparency so that the overlapping area with the target region would be readily visible. Both the target and penalty regions had a bright yellow edge on the inner of the circumference semi-circular shape as indication entrance of the drawing line. A small circle with grey shading had radii of 30 pixels/7.94mm marked the starting point of the drawing. The small circle had a radii distance to the semi-circular of target and penalty regions by 580 pixels/153.46mm. The target and penalty region were randomly located either to the left or right of the starting point on the screen. They were located perpendicular to the small grey circle. Both of these regions had angle ranging from 155 to 205 degree when located at the left side of the screen and 340 to 360 degrees or 0 to 20 degrees when located at the right side of the screen.

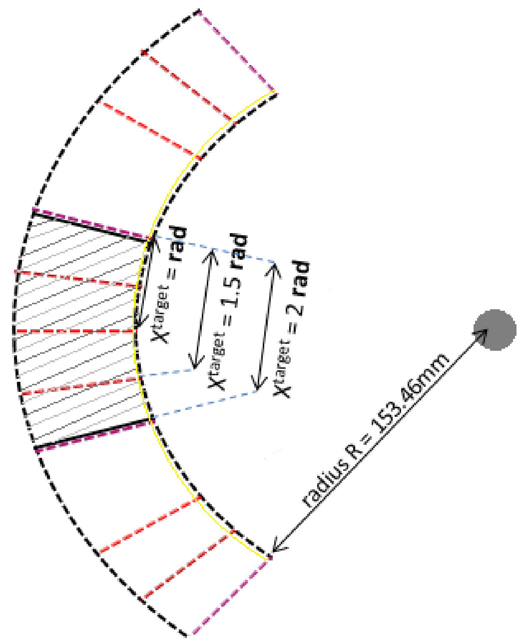

Figure 2. Layout of the stimuli in experiment of study 2. The six dashed regions indicate the six different positions at which the penalty region could appear.

The rest of the other angles do not fit the screen area. The target and penalty regions appeared simultaneously, on a white background. The penalty region had three possible magnitudes of displacements placed next to the target region at the location of above or below the target region as seen on screen. As shown in Figure 3, there were six stimulus configurations displayed on the left or right side of the starting point. Only one configuration was displayed on a particular trial. At random interval, this stimulus configuration were placed on either side of the screen making one block of trial comprised of 12 drawing task altogether.

In the second session, prior to the main task, participants performed a block of trials consisted of 12 drawing task as the practice session. All the task in the practice session consisted of 12 stimulus configuration mentioned earlier. These were to ensure subjects were familiar with every possible situation of drawing tasks during the practice session. Immediately after the practice session, there were 19 blocks of trials. Each trial carried 12 drawing tasks. Participants were encouraged to finish all the block trials but were also given a choice to stop at either 12th or 15th block of trial if exhausted. This was so children enjoyed the drawing task and were willing to complete all the sessions by themselves. Thereof, the drawing data was readily recorded after each block of 12, 15 and 18 trials.

Procedure

The stimulus display for all penalty conditions is illustrated in Figure 3. The small grey circle was the starting point of drawing. If a participant draws on an area other than the starting

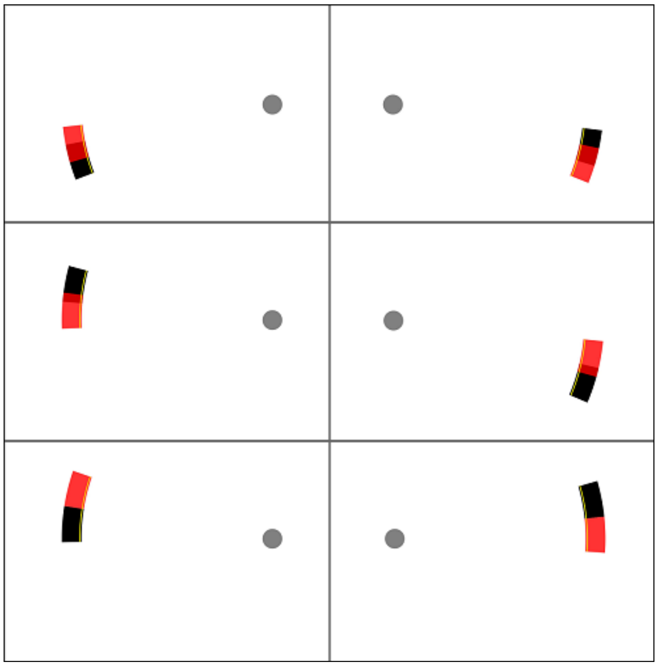

Figure 3. Displacement of penalty conditions

point, there would be no drawing marks. Once the drawing strokes passed through the starting point region, the drawing time began. The response time was recorded from when the line stroke passed through the circumference of the small grey circle. Only when the line strokes passed through the yellow line or surpassed the radius R would the drawing time end. Immediately after, the number of stars would be shown. The stars were displayed in the middle of the layout screen, removing the current drawing task layout off the screen.

In the calibration session, a score of 5 yellow stars was given if drawing strokes hit the target region within time. There were no penalty regions included. Hitting outside the target region or after the time limit of 500ms would show a blank of 5 grey stars. After each block of trials, the score were accumulated and computed as 7 stars for full score. Once the ideal size of the target region was captured, the session ended and the next task instruction was shown. Subjects were encouraged to take a short break before entering the second session. The second session was the main task of the experiment which was similar to the previous session but with penalty regions included and with a fixed target size. Starting with the practice session, subjects were required to draw a line towards the target region avoiding penalty region within the time given. If the drawing strokes successfully touched the area of non-overlapping reward region in time, 6 stars would be displayed. If it touched within the area of the non-overlapping penalty region, only 1 yellow star would be displayed with 5 blank grey stars. If the drawing stroke touched the overlapping region of the target and penalty areas, 3 yellow stars would be awarded with 3 blank grey stars . The main session followed after the practice session with a short break interval occurred after every 12 drawing task marked as 1 block of trials. The data was recorded during the whole session excluding the practice session.

Subjects and Instructions

20 children participated in the experiment, comprising of 15 boys and 5 girls ranging from age of 5 to 11 years old. All parents and children had given their informed consent to participate in the experiment similar to how experiment 1 was conducted. Subjects were informed the payoffs and penalties for each penalty displacements. All were unaware of the hypotheses under tests. Subjects underwent two sessions which were the calibration session and the main drawing task experiment. Since this was a repetative drawing task, some of the children did not complete all trials but decided to stop at trial 12 and 15. All participants data were included in the analysis irrespective of trials completed. At the end of the sessions, subjects received a small gift as a token of appreciation for their participation.

Data Analysis

In the first session of the experiment, we recorded the target size and score for every trial. While in the second session, we recorded the reaction time, drawing time, end point (x,y) that hit the circumference area at the end of the radius distance from the starting point and the score for every trial.

Target Size

We first looked at whether there was a relationship between the target size and the age of children. We did not find a significant correlation between the two; $r = 0.291$, $n = 20$ and $p = 0.213$. Age was not found to be correlated with target size.

Reaction Time and Drawing Time

We tested whether reaction time and drawing time differed significantly in any given condition but found no effects. This suggested that the drawing time limit of 500ms was short enough for subject to respond consistently. Trials in which the drawing strokes exceed the drawing time limit of 500ms were excluded from the analysis.

Penalty Distance

There were 228 data points per participant who completed the 19 blocks of trials. One block of trials consisted of 12 drawing tasks with six stimulus configurations had interaction in one direction(Right-to-Left) and the other six had interaction in the opposite direction(Left-to-Right). The endpoint positions (x^p_{ij}, y^p_{ij}) were recorded relative to the center of the green target region for each penalty-distance $i(i = 1,2,3)$, displacement condition $j(j = 1,...,6)$, and trial $p(p = 1,...,n_{ij})$. The penalty distance represented close (1), medium (2) and large (3) distance; the displacement condition represented the location of penalty region which was either to the left or right side of target region (above and below the target region as seen on screen). The example of six positions of red penalty region according to target size four (chosen due to its middle size), $x_{red,i}$ = -3.6, -1.8, 0, 0, 1.8 and 3.6 degrees and $y_{red,i} = 0$ (i = 1...6). Each target size have different penalty coordinates according to its size. The mean end point for each subject and each condition X_{ij} and Y_{ij} were averaged across replications p

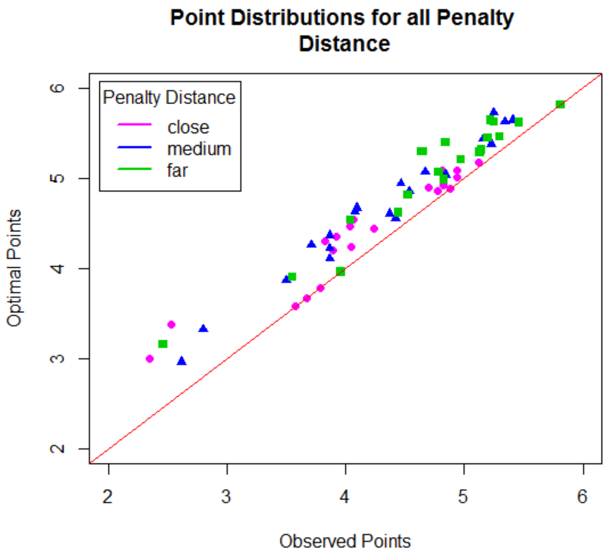

Figure 4. The observed and optimal points of all penalty distance for all subjects.

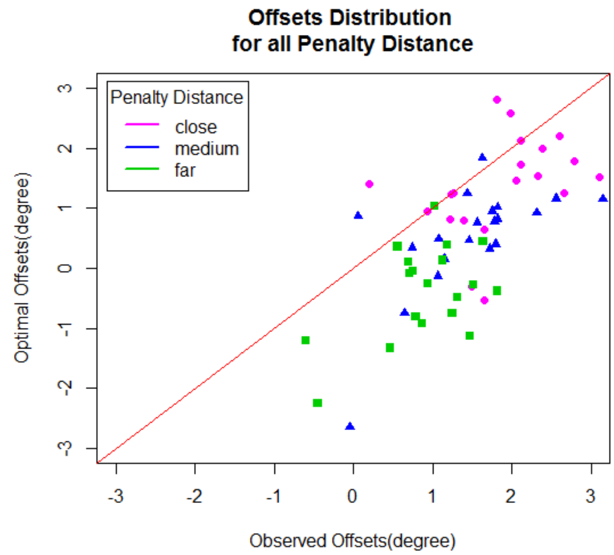

Figure 5. The observed and optimal offsets of all penalty distance for all subjects.

$= 1,...,n_{ij}$. A value of $|x_i| > 0$ indicated that the recorded endpoint was on the right side of the target center. Trials of the drawing task that were not within the time limit were omitted from the analysis. The aiming point is the mean distribution of all end points per participant. To see if there was a shift in aiming point according to different penalty distance (close, medium, large), a one-way repeated measures ANOVA was conducted. We also looked into the interaction of the drawing strokes movement between the Right-to-Left(RL) and Left-to-Right(LR) directions and found that these two did not have an effect.

Predictions of Optimal Aim Point

Equation 2 is used to predict the optimal aim point for different penalty distances. The model predicts a shift of optimal aiming point in horizontal direction perpendicular to the small grey circle of the starting point. The equation is use to calculate the prediction of the maximum expected gain for all subjects in all penalty distance condition. If there was no penalty region, the optimal aim point (X_{ij}^{opt}, Y_{ij}^{opt}) should be the center of the target region, (X_j^{target}, Y_j^{target}) with ($X_{ij}^{opt} = X_j^{target}$, $Y_{ij}^{opt} = Y_j^{target}$). The optimal aim point (X_{ij}^{opt}, Y_{ij}^{opt}) shifted further away from the center of the target region when the condition has a penalty region.

To find out whether there was a difference between subject's performance and the optimal performance we determined the optimal offset given subject's individual motor variance as shown in figure 6. The highest point in each figure marked the optimal performance while subject's performance was marked in blue dashed line. We calculated the endpoint relative to the target center: $|x_{ij}|$=X_{ij} - X_j^{target} for each subject in all conditions.

Score

To find each subjects' score compared to optimal performance, we computed the mean and variance distribution of optimal performance predicted by the model. We perform computer simulations for every penalty distance condition of close distance, medium distance and far distance for each subject individually. To compute the score, we used an estimate of the subject's motor variance to simulate around 50 trials in each condition. This estimation was to see whether subjects' performance was significantly different from the optimal. We then found the efficiency of the comparison between subjects' performance to optimal performance. We defined efficiency as the observed point as a percentage of optimal point. The observed point is the actual average score a subject achieved while the optimal point is the maximum expected gain for that subject. The maximum expected gain take into account the possibilities of the motor variance to aim at the penalty region, overlapped region, outside region and on the target within the given time. The efficiency was also computed for each subject in each condition. From there, we computed the average efficiency for all subjects within all conditions to see whether subject's overall performance correlated with the optimal performance predictions.

RESULT

Performance Comparison

We examined subjects' performance in drawing movement to see whether there was a gap from optimal performance. There was a main effect in observed and optimal performance for all penalty conditions with observed having $F(2,38)=32.901$, $n=20$ and $p<0.001$ and optimal having $F(1,19)=106.318$, $n=20$ and $p<0.001$. There was no interaction effect between the two showing that the two were not distinguish to one another. Figure 4 also shows that there was a strong positive correlation between the observed points and optimal points

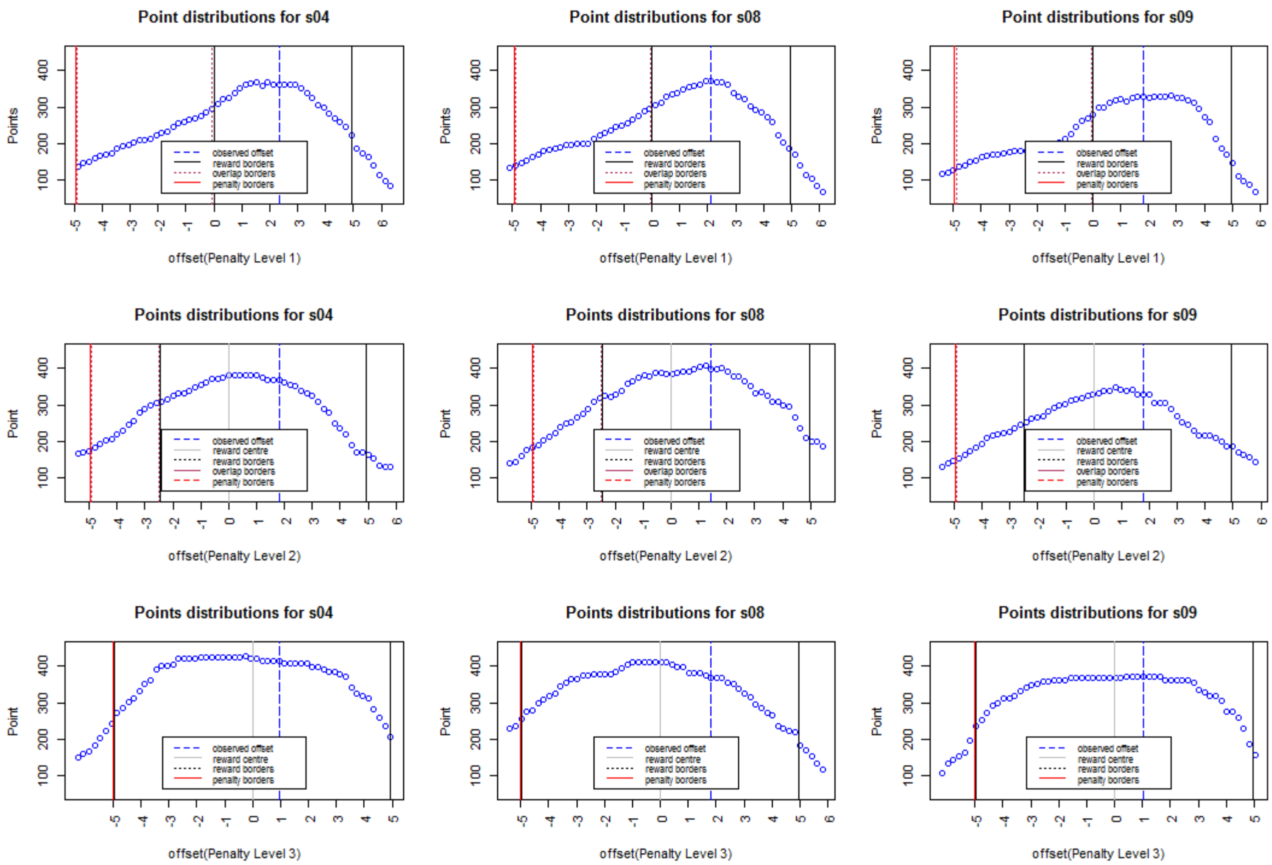

Figure 6. A direct comparison of observed aim points with the experimental data for subject s04, s08 and s09. The data points from these subjects were using the same target size one. The columns represent the subjects and the rows represent the penalty conditions with penalty distance 1 as close distance, penalty distance 2 as medium distance and penalty distance 3 as far distance.

for all penalty conditions, $n = 20$ $p < 0.0001$ with close distance; $r = 0.983$, medium distance; $r = 0.991$ and far distance; $r = 0.986$. This suggests that the optimal strategy is a good predictor of participant performance. All the points shown in the graph are above the diagonal lines as they could not go further than the optimal points. The efficiency of subjects' performance was 93% which deviate less than 7% compared to optimal performance.

Effect of penalty displacements

Subjects altered their aiming point away from the penalty area accordance to the model prediction. This is shown in figure 5 where aim points in pink showed larger shift, aim points in blue showed moderate shift and aim points in green showed the least shift respectively to the distance of penalty regions. Our result is in agreement to the predictions and was statistically significant by Wilks' Lambda = 0.1, $F(2,18) = 81.226$ and $p < .0005$ with multivariate partial eta squared = 0.90. We can conclude that subjects shifted their aiming point more when the penalty region was placed close to target region and shifted less when the penalty region was far from target region. We also tested this separately in both direction of interaction; one in Right-to-Left condition and the other in Left-to-Right condition. Both conditions showed similar effect even when the interactions were in the opposite direction.

Optimal and Observed Aim Points

As shown in figure 5, we plotted the observed and optimal aim points for all subjects in the three penalty conditions. Most of the aim points in the graph are below the diagonal line due to the distant of observed aim points larger than the distant of optimal aim points respective to the penalty region. The optimal aim points were not far away from the penalty region as predicted because of its value having positive number than the background. To know whether subjects observed aim points were almost optimal or not, we looked into the relationships between the two variables. The graph has shown a strong positive correlation between the optimal offsets and observed offsets for all subjects in all conditions with $n = 20$, $p < 0.0001$; close distance $r = 0.96$, medium distance $r = 0.985$ and far distance $r = 0.964$. This relationship shows that subjects aiming point were close to the optimal aim points.

To understand how we obtained the observed and optimal aim points for each subject, we had shown an example illustration of our data at figure 6. We make a direct comparison of the prediction values x_{opt} in this figure. The drawing movement endpoints are distributed around this mean end point according to a bivariate Gaussian distribution. We simulated the experimental data for every subject in every penalty conditions of close, medium and far. We used equation 2 to find the aim points for every offset of margin 0.2. We tracked the aim points starting from the observed aim points offset and move to the left and right side of the offsets to gain the subsequent values from other offsets. We then put colored lines to mark the bars for all the boundary regions; reward regions, overlapped regions, penalty regions and outside regions. The grey bar indicates the centre of the reward region and the dashed blue bar marked subject's aim point, which is the observed aim point. Every aim point had a point score which maximized the expected gain from all the possibilities region. The highest plot point is the optimal aim point. The optimal aim points have the highest score. Most of the observed aim points are not far away from the optimal aim points. This can be seen by looking at the length distance between the observed aim points with the highest aim points in each figure shown at figure 6. This indicates that subjects are making optimal adaptation. But how can we know whether subjects were truly making optimal adaptation? Perhaps subjects were aiming what was left at the middle of the target if the case they were adapting less. Would this suggest that subjects were aiming at the centre of non-overlapping reward region, rather than optimising?

To investigate this issue further, we made an additional test to cater subjects' aiming points relative to the centre of non-overlapping target region. We plotted the optimal aiming points versus observed aim points for all the penalty distances of close, medium and far as shown in figure 7. As we can see from this figure, the scatter-plots do not resolve around the centre of non-overlapping reward region but rather shifted towards the background. To find the relationship of observed and optimal aim points for all penalty conditions for each subject, we computed the mean of observed and optimal aim points in all conditions per subject to get the correlations from the pooled data. We found that there is a significant difference in the medium positive correlation between the mean observed and optimal aim points with $r = 0.460$, $n = 20$ and $p = 0.041$. In response to the question: *Isn't just that subjects were aiming at the centre?*, Our analysis, displayed in figure 7, shows that this is not a good explanation. Optimal adaptation is better.

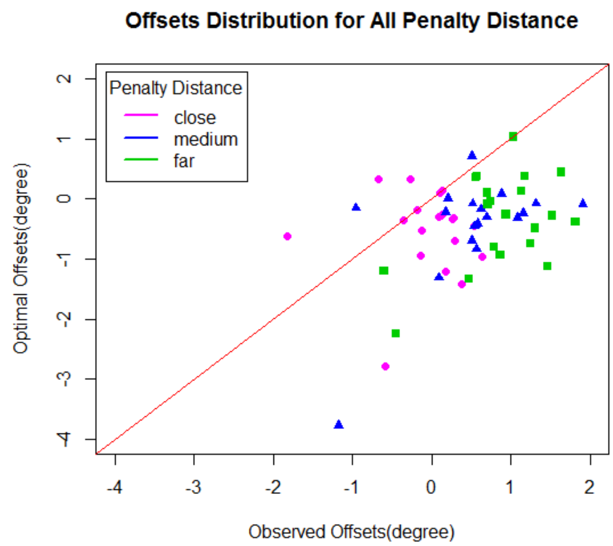

Figure 7. The observed and optimal offsets relative to the centre of non-overlapping reward region

GENERAL DISCUSSION

Recent work has shown that children have difficulty using tablets compared to adults and this includes when drawing. The aim of the work reported above was to further the scientific understanding of children's drawing strategies. The result of the first study showed were inconclusive but did show that child users of tablets were motivated to draw as well as possible to achieve as many stars as they could when drawing. Given that there were very few errors in maintaining the contact point and retaining the shape of the drawing, most of them achieved high scores in both of the reward manipulation conditions. The results of the second study suggested that children are able to adjust how they aim to the motivating reward signals (stars) and to their own motor performance variability. The results, also suggest the viability an exciting new way to model children's interaction with technology that derives from the Bayesian decision theoretic approach of Trommershauser (2003) [11] in motor planning. We used this model to understand children's drawing strategies given limits and reward feedback. In the Bayesian approach the aim is adjusted so as to maximize the motivating reward (stars) given the penalty region placing nearby the reward region in different proximities. This approach has been used before to predict adult performance in ballistic movement tasks but not to predict children moving finger along a tablet surface. Previous studies suggested that adult choose near-optimal strategies when planning speed movement under risk [4, 5, 9–11]. The results of our second study extend these results to children. The child users in our study shifted their aiming points away from the centre of reward region when there was a penalty region nearby. When penalty region placed closest to target region, the largest shifts occurred while smallest shifts occurred when penalty region located at the least close distance. The overall subjects' performance was correlated with the optimal rate suggesting that children were making near optimal adaptation. Therefore, we can conclude that children adapt drawing actions to subjective rewards, their own cognition and motor limitations and to the limitations of tablets and tablets software.

The Bayesian theoretical framing of this work opens up a number of research opportunities in children's drawing. One possible area is on extending from the simple task that we used to full join-the-dots task. When there is more than one target in a single drawing task, how do children normally plan to draw? Another possibility is that the work could extended to different kinds of drawing besides join-the-dots. Perhaps to free form drawing where the goal is to achieve the right drawing shape or picture. Is it possible that such tasks can be understood through the lens of Bayesian decision theory? Another possibility might be to study how drawing could be used as a platform for a mother and a child to engage with each other. How could different reward signals affect childrens' behaviour and motivate their drawing performance? Given the same theoretical framework, we believe that we can learn to understand better on how children adapt the way that they draw to the device, to their own limitations and to the motivational context for action applied to other research areas within the drawing domain.

CONCLUSION

Our work reviewed the theoretical and empirical perspective of children's drawing, derived, in part, from the cognitive psychology of human movement control. It consisted of an empirical investigation of the extent to which a decision theoretic framework can account for these skills. The experimental hypotheses of children's drawing task were motivated by a decision theoretic perspective on planning for drawing in which costs of interaction are balanced against the gain implicit in a rewarding drawing. As decision theory can apply to conditions of certainty, risk, or uncertainty, the idea was to understand how children adapt strategies to the risks and perceived costs of drawing errors, slips and mistakes. The work reported here shows how it is possible that a child's strategies for drawing on a tablet can be understood as a Bayesian adaptation to movement variability, motivation and the limitations of the device surface. This perspective may offer a promising means of understanding children's drawing strategies.

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