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Research article

Development of a Novel Approach to the Assessment of Eye-Hand Coordination

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ABSTRACT

Background: Current methods to measure Eye-hand coordination (EHC) have been widely applied in research and practical fields. However, some aspects of the methods, such as subjectivity, high price, portability, and high appraisal contribute to difficulties in EHC testing.

New methods: The test was developed on an Apple iPad® and involves tracing up to 13 shapes with a stylus pen. The time taken to complete each trace and the spatial accuracy of the tracing is automatically recorded. The difficulty level for each shape was evaluated theoretically based on the complexity and length of outline. Ten adults aged 31.5±7.8 years and five children aged 9.4±1.1 years with normal vision participated.

Results: In adults, the time taken to trace and number of errors significantly decreased from the first to the second attempt ($p<0.05$) but not thereafter, suggesting a learning effect with repeatability after a practice attempt. Time taken and number of errors in children were both higher in monocular than binocular viewing conditions ($p=0.02$ and $p<0.01$, respectively) while adults' performance was similar in both viewing conditions.

Comparison with existing methods: Existing EHC tests are subjective in clinics and require higher skills and cost in research, and measure gross EHC. The novel test has been developed to address some of the limitations.

Conclusions: The test is engaging for children and adults and is an objective method with potential for the assessment of fine EHC, suited to clinic-based and research use in ophthalmic and brain trauma settings.

Key words: eye-hand coordination, computer-based, development, repeatability, objective

1. Introduction

Eye-hand coordination (EHC) refers to the ability to produce goal-oriented hand actions that are guided by visual information from the eyes. Good coordination between the sensory visual system and the musculoskeletal system is required for efficient and effective human function during interaction with the nearby environment. For this reason, the assessment of EHC presents itself as being an informative method of understanding the functional processes that underlie goal-oriented behaviours such as reaching, grasping, and/or positioning of objects. Typically EHC assessment methods involve tasks such as the placement of objects in holes or on threads (O'Connor et al., 2010) and although these may be engaging to some extent, they may require subjective assessment by the examiner. On the other hand, EHC can be measured precisely and objectively using a system of biomarkers and cameras (e.g. Grant et al. 2007), but this method does not lend itself easily to clinical application.

Assessment of EHC has long been undertaken by researchers to understand the functional basis of visually guided behaviours (Loftus et al., 2004; Mazyn et al., 2004; Melmoth and Grant, 2006). One early method for measuring EHC was developed by Moore (1937) and measured the time taken to place marbles in holes. Subsequently, the test was further developed by introducing colour matching in 'The Moore Eye-Hand Coordination and Color-Matching Test (Moore, 1950) in which subjects were instructed to match coloured marbles with colour-coded holes as quickly as possible. 'The Purdue Pegboard' is another test based on the number of pegs inserted into holes in a given time period that was used by Gardner and Broman (1979) to compare EHC in school children with learning disabilities against those with normal development. They found that the former group performed more poorly on this task. A further test, the Grooved Pegboard test measures the time taken to insert 25 pegs into grooved holes, and has been found to be repeatable (Ruff and Parker, 1993). These methods may be confounded by subjective factors such as experimenter bias (since time measurement methods were either not stated or involved experimenter control) and by the use of gross hand/arm movements which require not only EHC but also control of the arm. More sophisticated methods of EHC assessment involve the use of biomarkers and allow precise measurement of the various phases of hand movement during tasks such as reaching and grasping. Such methods are objective but require laborious analysis and are not feasible for use in clinical practice. Furthermore, the tasks involved in existing methods are repetitive, with no variation in format, and may be minimally engaging for young children or others with low attention span. However, recently new trials using a programmable tablet device investigated the integrated human motor control of dominant and non-dominant hands using the Kinematic Assessment Tool software during configurable visual-spatial tasks (Culmer et al., 2009). Further afield from EHC, in the domain of human balance studies, progress has been made in devising electronic game-based measurement of human function that secures better certainty of measurement (Bartlett et al., 2014)

It has been demonstrated that visually guided movements are adversely affected by visual deficits that reduce ability to perceive depth (Grant et al., 2007; Suttle et al., 2011; Webber et al., 2008). Subjects with reduced or absent stereopsis show poor ability to complete visual-motor tasks, such as bead-threading (O'Connor et al., 2010) or grasping tasks (Melmoth et al., 2009) compared with subjects who have normal visual function. This link with stereopsis suggests the need for a carefully designed and clinically applicable and objective assessment of EHC without stereo-cues.

In the present study, a computer-based test of EHC was developed to address some of the limitations of existing EHC tests. In particular, this novel application was designed to be engaging and to allow objective assessment of the number of errors and time taken for completion of an EHC task that has no demands on stereopsis and that involves fine motor control. The test involves participants tracing complex shapes of common objects (Figure 1) with a stylus on a portable computer screen. In order to engage young and old participants, the test was presented as a game on a tablet system. Such a system's advantage is that it is cost effective, provides precision in measurement and is a very portable system that lends itself well to clinical testing. The goal of this study was to develop the methods underlying this new EHC test (named the "Lee-Ryan Eye-Hand Coordination Test") and to assess its effectiveness in terms of its repeatability and accuracy.

2. Methods

2.1 Development and Design

An iPad® (Apple Inc, Cupertino, California, US, 1st version; Display: 9.7 inch (diagonal) LED-backlit glossy widescreen multi-touch display with IPS technology; Resolution: 1024-by-768-pixel at 132 pixels per inch (ppi); iOS 5.1.1) and a stylus pen (Pogo Sketch®, Winitel Australia; 0.2 x 0.4 x 4.8 inches; 17g) were employed as the hardware for this device (Figure 1). The iPad® was chosen due to advantages such as an ergonomic system, easy portability, high resolution, reasonable price and popularity. The custom Unity 3D game engine software (Unity Technologies, San Francisco) was utilized by author M.R. to draw shapes in colour (yellow, orange, red, white, blue, green or violet) with paths of varied complexity on a black background (Figure 2) and with functionally to measure time taken and accuracy. The stylus has a rounded end, however only the central core registers with the iPad.

Insert Figure 1 about here

The game software reads the stylus position (referencing to the centre of the stylus touch zone) at approximation 25 frames per second from the time the user first touches the starting point (the pink cherry on the milkshake) until they reach the end of the straw. Each straw is made up of 200 to 600 control points depending on its length. The game keeps track of the current active control point on each frame. If the stylus moves, the control point is advanced, so long as the stylus does not move outside the straw. If the stylus does move more than a required distance from the straw, a soft failure sound is played and the control point does not advance. The game logs the time, stylus position and active control point for each frame. From this the total time taken for each trial and how many errors have been made can be calculated.

Thirteen shapes were designed. This number was arbitrary, and was driven by the desire to offer a range of shapes that are likely to appeal to participants of different age, interest and/or gender and which vary in their shape complexity. The shapes were: Rabbit, Snail, Seal, Elephant, Duck, Cat, Octopus, Dragonfly, Whale, Fairy, Unicorn, Dragon and the word 'Slurp' (see Figure 2). These shapes were chosen because these have appeal to both genders, young and old. The word 'Slurp' was appropriate because each shape was presented as part of a picture that included an image of a milk shake with a straw leading out of the drink to form the shape. As the shape was traced, 'milk' was drawn up out of the shake into the straw by the participant to empty the glass. This design was intended to optimize interest and attention in children during the tracing task and to be akin to the tablet games commonly played by their peers. Furthermore, the tablet-based tracing task was chosen because it is similar to other pen and paper treatment modalities employed in cases of amblyopia (e.g. chiroscopic tracing) and lends itself to the development of a better understanding of tracing as a developmental tool.

Insert Figure 2 about here

The software displays two measurements that comprise the total time taken to trace the shape and the total number of errors made during the trace as a measure of tracing accuracy. Firstly, the time taken to trace is recorded from when the stylus first contacts the pink 'cherry' at the top of the glass until the stylus reaches the end of the shape (time taken to complete the trace). Secondly, the software tracks spatial location of the stylus with respect to the shape as a means of tracking accuracy (the number of errors). The 'straw' constituting the outline of the shape to be traced is approximately 5mm wide on the display, as shown in Figure 3. When the centre of the stylus deviates from the centre of this region by half of this value, an error is counted by the computer system.

Insert Figure 3 about here

2.2 Participants

The study was approved by the University of New South Wales Human Research Ethics Committee. Based on the Declaration of Helsinki, each participant or parent gave signed, informed consent to participate after explanation of the nature and possible consequences of the study. Children gave verbal assent.

Ten adults aged 31.5 ± 7.8 years (6 males and 4 females) and five children aged 9.4 ± 1.1 years (4 males and 1 female) were recruited by advertisement. All participants underwent basic vision screening tests for monocular visual acuities (Snellen chart), refractive error (retinoscopy), accommodation (push-up test), ocular alignment (cover test), colour vision (Ishihara test), ocular dominance (the hole-in-the-card (Dolman method)), stereopsis (Randot stereotest) and ocular health (history and direct ophthalmoscopy). Participants with hyperopic refractive error or manifest strabismus were excluded to minimize the influence, if any, of accommodative instability, or abnormal binocularity. All participants were found to have normal visual function.

2.3 Procedure and Scoring

The iPad® was set flat on a table top and the participant was seated. The participant's task was to trace the shape with the stylus pen using their self-selected preferred hand (in all cases this was the right hand). Full refractive correction was worn if needed. Note that no participants required special correction for this near viewing distance. Before beginning the tracing task, participants were instructed to “Do your best to trace the line as fast as you can, because the number of mistakes you make and the time you take will be saved by the computer. Hold the pen upright as you trace.” Tracing was conducted both in monocular (dominant eye; the fellow eye covered with an opaque occluder) and binocular viewing conditions. All participants were instructed and visually monitored during tracing as to whether the pen was tilted significantly and that they maintained an approximately constant viewing distance from the iPad® screen while sitting in a natural position. Each participant was told that rest breaks could be taken whenever required between shape traces. With regards the possibility of rehearsing the task, it is possible that a period of viewing time might permit planning the task ahead and hence affect performance. Participants were not given a specific period of time to appraise their task, but all were started within five seconds of the new shape being revealed.

Adults. To verify repeatability of the test, undertaking the test refers here to tracing all 13 (or 7, see below) of the shapes. Adults performed the test three times at 7 to 10 day intervals tracing 13 shapes at the 1st and 2nd visits, but only 7 shapes at the 3rd visit. The reduction in the number of shapes at the 3rd visit for adults was based on feedback from the earlier visits from all adult participants regarding the challenge of completing all thirteen shapes within a session (see Section 2.4). The shapes used in the (7 shapes) version of the test were the Rabbit, Snail, Elephant, Duck, Octopus, Dragonfly and Dragon, as these represented a wide range of difficulty levels (see Table 1). For Test-retest reliability of the Lee-Ryan EHC Test, data from adults was analysed for a potential learning effect and for repeatability by comparing time taken and number of errors at testing days 1, 2 and 3. Measures for each participant at each test were (i) duration (in seconds) and (ii) the spatial error score (the number of occasions the stylus went outside the edges of the shape’s outline).

Children. As access to child participants for repetitive testing was limited during the early phase of testing of this EHC test, a simple pilot study was conducted. Children completed the test on only two occasions by tracing only the 7 shapes used for the adults at their 3rd test.

The complexity of the object to be traced could influence the degree of EHC required and was therefore analyzed mathematically. Complexity was measured by calculating the mean angle for each shape. To do this, the shape was considered as a series of points connected by straight lines. Each point defining the beginning and end of these straight line segments can be represented by Cartesian x and y coordinates on the iPad® screen. For each adjacent pair of points on the shape, the angle was found between the line connecting the points and the horizontal (x) and the vertical (y) axes of the iPad®. Each angle was normalized to the maximum angle in the shape (Angle/Maximum angle). The mean of normalized angles was calculated for the whole shape. This objective method for calculating complexity was based on the work of Field and Hess (1993). The product of the shape's complexity (the mean angle) and length was used as an indication of a shape's difficulty: 'Difficulty = Complexity x Length'. 'Difficulty' thus facilitated analysis of performance when shapes of equal complexity might be present but with different lengths, thus independently influencing time taken.

2.4 Feedback to Inform Design

After completing the first tracing test, each participant was asked informally whether they enjoyed the task and to explain what they enjoyed or did not enjoy about it. In addition, when participants volunteered comments during the task these comments were recorded by the examiner. Feedback was recorded as an indication of the extent to which participants found the method engaging, and to inform future design and development of the device beyond this study.

2.5 Data Analysis

Repeatability was assessed in adults and to a limited extent in children. Comparison was made between three tests in adults and two tests in children. Data from only the same 7 shapes were used in both adults and children. Since the data were found not to be normally distributed, these comparisons were made within participants across monocular and binocular conditions and across repeated tests using a Wilcoxon signed rank test. Bonferroni correction was applied to multiple comparisons. Data analyses used 'Diffculty' of the animal shape as the base, as explained above.

3. Results

All participants were observed to comply completely at all times with the request to hold the pen upright (i.e. to within ~20°) and all continued to the end of every task without removing the pen off the tablet.

In response to the three questions asked on preference of the Lee-Ryan EHC Test after completion of the test, nine of the ten adults responded that they did enjoy the tracing task. In response to "What did you enjoy about it" they referred to the gaming nature of the task ("it was like a game"), its simplicity ("it was simple and easy to follow"), its novelty ("it is something new I haven't done this before") and interest value ("interesting and exciting with various colours", "interesting shapes"). The one adult who did not enjoy the task much stated that it was too time consuming. Based on this comment, for the 3rd test each adult was given a task that included only 7 of the 13 shapes across a range of different levels of difficulty and hence statistical analyses for the group were confined to data relating to only these particular 7 shapes.

The objective measures of difficulty of each shape, based on measures of complexity and length are shown in Table 1. The Dragon and 'Slurp' shapes are the most difficult tests, while the Duck and Rabbit shapes are the least difficult.

Insert Table 1 about here

Adult Participants

Viewing conditions, whether monocular or binocular did not affect adult performance regarding either time or accuracy.

Insert Figure 4 about here

The differences in time taken to trace each shape between the first and second attempts and then second and third attempts for adults are shown in Figure 4, ranked in order of degree of difficulty. For each shape, the time taken significantly improved ($p<0.05$) between the first and second attempts monocularly and binocularly, seemingly reflecting a practice or learning effect. However, results from the second and third tests showed no significant difference ($p>0.05$), suggesting that the test is repeatable after sufficient practice.

Insert Table 2 about here

To further explore repeatability in adults, data from 2nd and 3rd testings are shown in Table 2. The aspects of time taken and the number of errors under both monocular and binocular viewing conditions show significant correlations (Pearson's correlation) between two repeated tests ($p<0.01$). Especially, in time taken strong correlations are shown under two viewing conditions, suggesting that repeatability of "time taken" and "number of errors" is acceptable under both monocular and binocular conditions.

Importantly, time taken to trace should not be considered in isolation as it is likely to co-vary with accuracy. Figure 5 shows a correlation between time taken to trace shapes and the average number of errors across 2nd and 3rd trials for monocular and binocular testing in adult participants. Surprisingly, there was a significant *positive* correlation (Pearson's correlation: $p<0.01$) between time and number of errors, indicating that participants who took longer to complete a trace also made more errors.

Insert Figure 5 about here

Child Participants

All of the five children said that they did enjoy taking the test. Their comments were all similar to each other and included: "characters are funny and colourful" and "it was difficult but fun like video games".

Contrary to the finding in adults, the viewing condition, i.e. whether monocular or binocular, affected the children's performance on the tracing task. The time taken was somewhat slower and the number of errors was higher in monocular than in binocular viewing conditions ($p=0.02$ and $p<0.01$, respectively) (Figure 6). On the other hand, there was a significant ($p<0.05$) improvement in the time taken between the first and second attempts at the test under both monocular and binocular viewing conditions as found in adults.

Insert Figure 6 about here

4. Discussion

The Lee-Ryan EHC Test is a reliable and engaging portable objective method to assess the efficiency and accuracy of EHC in a manner that better isolates the interaction of central vision inputs into the peripheral execution of purposeful fine motor movements of the hand.

The criticisms concerning experimenter bias and subjectivity in older simpler types of EHC tests that relate to factors such as the use of a stopwatch to time task completion or making subjective observations of the accuracy of task completion have been minimized. In addition, the Lee-Ryan EHC Test achieves much of what the more highly complex and expensive video-techniques achieve because time and spatial accuracy is recorded automatically by this computerized system. Due to the computerized design of the game, the task and the embedded pictures can be modified and upgraded relatively easily, facilitating further development of this novel assessment instrument to expand the range of designs targeted particular user group.

Although this test does use only one type of EHC task (tracing), a range of designs and difficulty levels are incorporated, so that the test can be applicable to individuals across a range of ages and developmental levels. The pictures for tracing have proved to appeal to different users, male and females, and to those with different interests. Participant feedback also suggests that the use of colours in the L-R EHC Test has enhanced the appeal of the task. An advantage of using a black background rather than one of some other colours is that for colour deficient observers there can be no confusion over the presence of the target to be traced, which might occur were the two colours each to lie on the one colour confusion axis.

The monocular-binocular difference in children in the present study could be regarded as surprising as within the iPad® there were no depth cues in the visual stimulus which as outlined earlier, eliminates one key functional difference between monocular and binocular viewing conditions. However, participants did need to locate the stylus tip on the target line during tracing, and this positioning task is likely to be an easier task in binocular viewing. In adults, there was no difference between performance in monocular and binocular viewing, indicating that performance was less affected by binocularity in adults than in children. Differences between children and adults in an EHC task have also appeared in other studies when various factors such as visual feedback and visuomotor control were found to be insufficient in children (Kuhtz-Buschbeck et al., 1998). Pryde and Roy (1998) also demonstrated that children aged 9 -10 years spent more time on the kinematics of reaching and grasping due to immature integration of the visual systems compared to adults. The only binocular advantage found in children was that the number of errors and time taken were statistically lower under binocular than monocular viewing. These differences suggest that child participants under monocular viewing condition may have felt more difficulty in order to complete the task in a timely fashion. This difference of EHC between adults and children under two different viewing conditions would need to be investigated further, as obviously a limitation of this study was the small number of children available at the time.

The Lee-Ryan EHC Test was found to be repeatable in the adult participants. However, time and accuracy consistency came only after completion of a first test that consisted of 13 traces. This suggests that practice is important in order to minimize a learning effect and to ensure repeatability. Although a practice session that included all 13 traces was used here, this would be time consuming in clinical practice. Therefore, it would be worthy to explore whether the practice session can be reduced to fewer than 13 traces. This is particularly given the case of one subject who did not improve between the 1st and 2nd monocular trials and even slowed dramatically during the 2nd binocular trial (all 13 trace-tasks), suggesting a possible fatigue effect. Whether the repeatability found in adults also exists in children needs to be explored further.

While the new device described here is an improvement on other EHC tests in some respects, such as removing confounding contributions from gross arm musculature, it could be argued that previous tests are better in some ways. For example, tests such as 'the Moore Eye-Hand Coordination and Color-Matching Test' and 'the Purdue Pegboard test' involve placing items into holes, which are tasks that use depth perception. The new device seemingly tests EHC only in two dimensions, not the third (depth) dimension. It could also be argued, however, that the hand holding the stylus and the stylus itself resting against the iPad®, and the proprioceptive feedback with the hand/stylus touching the device create a stabilized form of the visual scenery through stereopsis. Related to visualisation of the third dimension, there has been an explosion of technological advances in 3D visual displays and measurement, such as 3D displays and detectors (e.g. Microsoft Kinect) in recent years. Technology in this format may be useful in further development of this device.

Although the device has no means of controlling viewing distance, test distance was monitored by observation and reminders to the participants. Participants with uncorrected hyperopia were excluded from the study in an attempt to minimise any impact of accommodative instability. Such instability may be linked with varied visibility of the line being traced. Participants with large phorias and the potential for tropia were excluded in this study. Despite this, a tropia may have emerged after extended near viewing for some participants and could have involved diplopia or suppression in binocular viewing. In the former case, tracing would become a more complex task and presumably have taken longer, and in the latter, it would have become a monocular task.

All participants chose to use their right hand to hold the stylus and trace the pictures. None switched hands during tracing. All pictures were presented with the 'milk shake' part of the image on the left hand side of the screen and the straw leading from this to form the picture to trace to the right of the screen. This design allows right-handed users to easily view the ‘milk’ in the ‘straw’ as they trace, since the hand is at the leading part of the straw. For left-handed tracers, the hand would cover the milk being drawn up into the straw. This is a limitation which has recently been addressed in further development of the device so that in future the test can be oriented appropriately for left- or right-handed use.

Participants who took longer to complete the test also made more errors. This is surprising, since errors would be expected to be more numerous when completing the test more quickly. This result indicates that there was not a clear trade-off between time and accuracy, and that in at least some of the participants, accuracy was not compensated for by taking more time. This correlation issue should be considered again with an increased number of participants. One possible reason for this finding may relate to participants using continuous feedback during tracing (Proteau et al., 1987). To minimize their error and complete the task some might seek visual feedback more often, which adds to time taken. Furthermore, this behaviour could disturb their tracing and make it more erratic, thus contributing to more errors. Another reason for longer times being associated with increased numbers of errors is that the sound cue indicating an error has been made could be distracting and add further to the time taken to complete the task.

With regards possible uses of the Lee-Ryan EHC Test, although EHC has been found to be abnormal in children and adults with amblyopia, (Grant et al., 2007; Grant and Moseley, 2011; Suttle et al., 2011; Webber et al., 2008) it is not known yet whether EHC approaches or even reaches normal when amblyopia is successfully treated (as based on measures of improved visual acuity). Subject to validation in participants with normal vision and with amblyopia, the Lee-Ryan EHC Test may be applied to the measurement of EHC before, during and after amblyopia treatment to investigate this question. In further studies of the disorder of EHC in amblyopia, it should be possible to use the Lee-Ryan EHC Test to objectively and quickly analyse spatial error in terms of deviation of the ordinates x and y in order to better understand whether there is a particular spatial bias in this condition for given individuals.

In addition, outside the ophthalmic field the Lee-Ryan EHC Test particularly lends itself well to the assessment of abnormal behaviour arising from brain damage. For example, a recent study investigated EHC in stroke survivors by requiring them to point their finger at a moving target (Gao et al., 2010). Using this procedure the authors noted that stroke patients showed lower EHC abilities in terms of poorer reaction time and accuracy when using the affected hand. However, sensory-motor coordination disorders are not necessarily acquired as a result of disease or trauma. Children with developmental coordination disorder (Rodger et al., 2003; Wilmut et al., 2006) or with autism (Dawson and Watling, 2000) exhibit impaired eye-hand coordination. With many years ahead of them, interventions are provided for these children so as to improve these aspects of daily function. Naturally, rapid accurate assessment of pre and post status would be advantageous. Further use of the Lee-Ryan EHC Test is in the area of assessment relating to sports vision. Given the obvious the benefits of the Lee-Ryan EHC Test in providing an accurate and quick measure of EHC, this test lends itself well to both future studies that demand a reliable measure of EHC ability and as an indirect measure of the outcomes of therapies for a range of children and adults across a range of health disciplines.

In summary, the application described here for use on a tablet device can objectively, quickly and simply provide a measure of EHC, and therefore has the potential for both clinical and research applications. It may be particularly useful for the measurement of EHC in children, as it is designed to offer engaging stimuli and tasks using a digital medium that is highly acceptable to their peers. In the absence of a gold standard test for EHC and following further validation with an increased number of participants, the test will offer potential contributions for research into amblyopia, developmental disorders, sports vision and into the recovery from injury or stroke through analysis of the interaction of vision and the peripheral nervous system.

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Figure Legends

Figure 1: The iPad® with a shape partially traced and the stylus used for tracing.

Figure 2: The thirteen different shapes used in the Lee-Ryan EHC Test (Snail, Rabbit, Whale, Seal, Duck, Elephant, Dragonfly, Octopus, Fairy, Unicorn, Cat, Dragon and 'Slurp').

Figure 3: Details of the structure and size of the line in the Duck shape.

Figure 4: A comparison of differences in time taken between 1st and 2nd testings and 2nd and 3rd testings to trace 7 of the 13 shapes under monocular and binocular viewing conditions in normal adults, ordered according to degree of difficulty. (M=monocular, B=binocular) Error bars represent 95% confidence intervals.

Figure 5: Mean time taken to trace each shape (across 2nd and 3rd trials) as a function of mean number of errors in adults (Monocular: $r=0.77$; Binocular: $r=0.72$).

Figure 6: The distribution of the number of errors (A) ($p<0.01$) and time taken (B) ($p=0.02$) across the seven animal shapes for children during their 2nd round of testing under monocular and binocular viewing conditions. The respective linear regression lines for viewing condition are also shown.

Table Legends

Table 1: Length, complexity and level of difficulty for the 13 shapes.

Table 2: The repeatability of the Lee-Ryan EHC Test for time taken and the number of errors between the 2nd and 3rd testings, monocularly and binocularly.

Difficulty / Shapes	**Length**	**Complexity (angle)**	**Difficulty value**	**Assigned level of difficulty**
Dragon	1	0.983	0.983	1 (Hardest)
'Slurp'	0.827	1	0.827	2
Octopus	0.802	0.946	0.759	3
Fairy	0.681	0.954	0.65	4
Elephant	0.61	0.942	0.575	5
Cat	0.602	0.897	0.54	6
Dragonfly	0.541	0.997	0.54	7
Seal	0.54	0.943	0.51	8
Unicorn	0.542	0.907	0.491	9
Whale	0.528	0.89	0.47	10
Snail	0.426	0.953	0.405	11
Duck	0.424	0.876	0.371	12
Rabbit	0.351	0.816	0.287	13 (Easiest)

(Note: the values cited in the Length, Complexity and Difficulty columns represent normalized values)

Table 1

Between 2^{nd} and 3^{rd} test	Pearson's correlation coefficient (r)	p value
Time taken (monocularly)	0.910	<0.001
Time taken (binocularly)	0.852	<0.001
The number of errors (monocularly)	0.770	<0.001
The number of errors (binocularly)	0.596	<0.001

Table 2

Figure 1

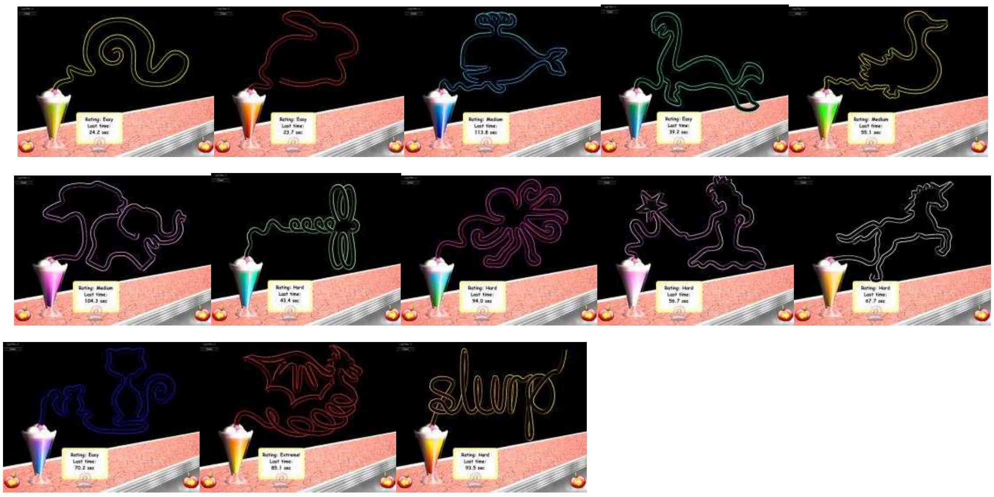


Figure 2

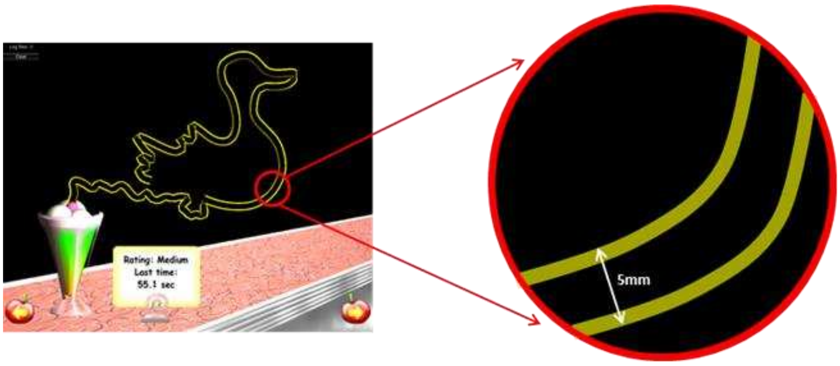
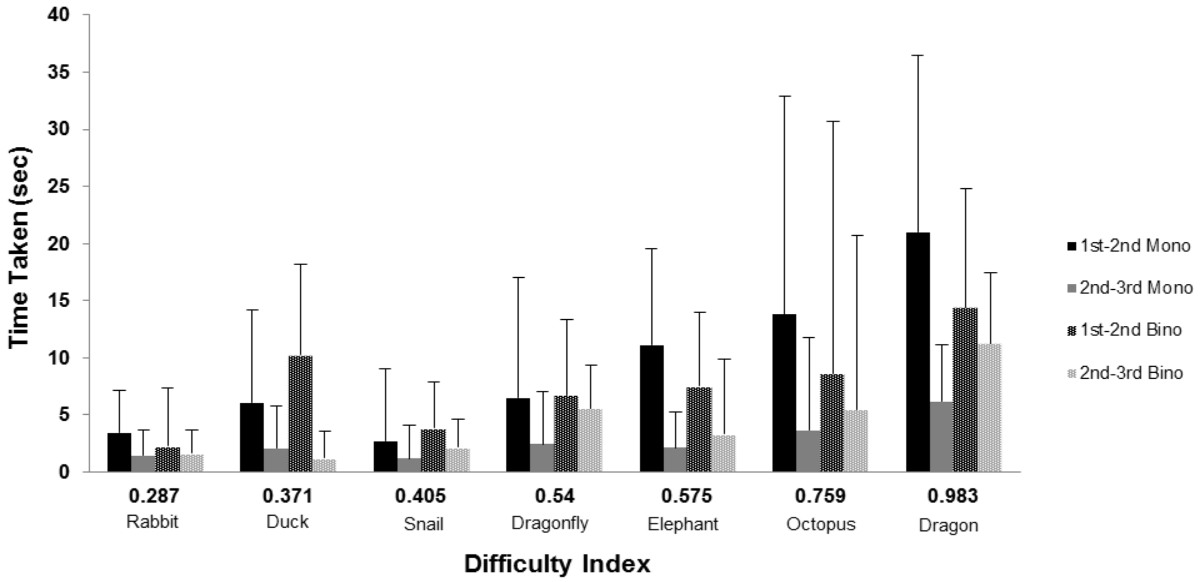
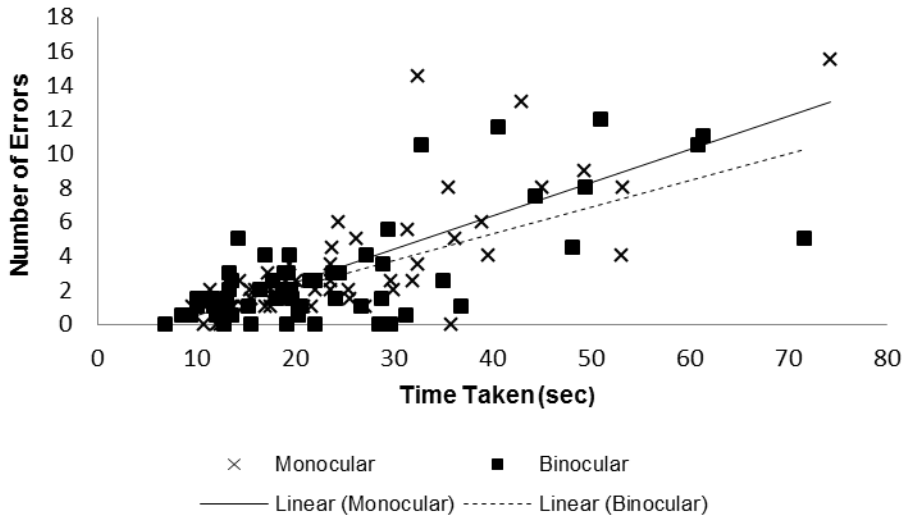


Figure 3



40
35
30
25
20
15
10
5
0
Time Taken (sec)
1st-2nd Mono
2nd-3rd Mono
1st-2nd Bino
2nd-3rd Bino
0.287
Rabbit
0.371
Duck
0.405
Snail
0.54
Dragonfly
0.575
Elephant
0.759
Octopus
0.983
Dragon
Difficulty Index

Figure 4



Number of Errors
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
50
60
70
80
Time Taken (sec)
Monocular
Binocular
Linear (Monocular)
Linear (Binocular)

Figure 5

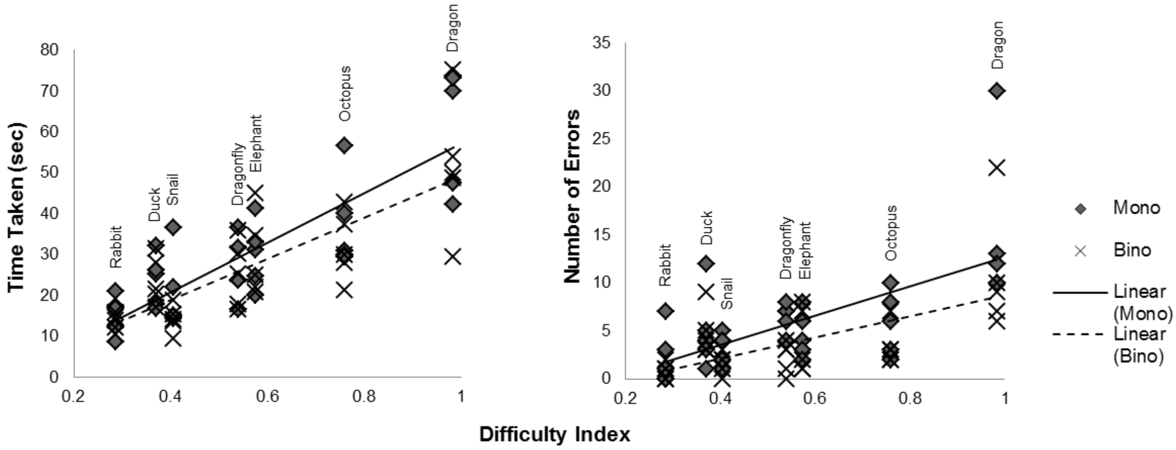

Time Taken (sec)
Number of Errors
Difficulty Index
Rabbit
Duck
Snail
Dragonfly
Elephant
Octopus
Dragon
Mono
Bino
Linear (Mono)
Linear (Bino)

Figure 6