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Original Paper

The Developmental Changes in Cube Copying Abilities of Japanese Children with Typical Development

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Abstract

Purpose: *The purpose of this study was to analyze the developmental changes in Necker cube copying and isometric perspective cube copying abilities of Japanese children of typical development.*

Methods and Results: *[Study-1] A total of 40 individuals aged 5-18 years participated in Study-1. The Necker cube copying task was administered, and scores were assigned based on the method developed by Yorimitsu et al. (2013). The results showed that the scores increased significantly for children in the 8-9 years age group ($p < 0.01$).[Study-2] A total of 32 individuals aged 6-10 years participated in Study-2. The isometric perspective cube copying task was administered, and scores were assigned based on the method developed by Otomo (2009). The results showed that the scores increased significantly for children in the 7-8 years age group ($p < 0.05$).*

Conclusions: *Japanese children of typical development were able to perform the Necker cube copying task from approximately nine years of age. The same participants were able to perform the isometric perspective cube copying task from approximately eight years of age.*

Keywords

cube copying task, Necker cube, isometric perspective cube, Japanese children, typical development

1. Introduction

The cube copying task is a non-verbal test to assess visual cognitive ability and constructional ability, using two types of stimuli: Necker cube drawings and isometric perspective cube drawings (Kato et al., 1988; Hirabayashi et al., 1992; Haruhara, 2006; Otomo, 2009; Yorimitsu et al., 2013; Watanabe et al., 2013).

In recent years, the cube copying task has been adopted for use in assessing children, including those with intellectual disabilities (Kubota, 1965; Tanabe, 1985) and developmental dyslexia (Haruhara, 2006; Otomo, 2009). For example, Kubota (1965) and Tanabe (1985) examined the relationship between the ability to copy drawings of isometric perspective cubes and mental age, in children with intellectual disabilities. Haruhara (2006) proposed the Necker cube copying task as a method for evaluating visual cognitive ability in individuals with developmental dyslexia, which is a core learning disorder. Otomo (2009) investigated the relationship between kanji writing scores and scores in the Necker cube copying task, in children aged 6-9 years who attended a regular school. This study was undertaken to validate the Necker cube copying task as a visual cognitive task.

As for the age at which it becomes possible to use a cube copying test, studies in the U.K. have reported that the Necker cube can be drawn by children from the age of 12 years and 8 months. This was discovered in a Developmental Test of Visual-Motor Integration (VMI), which helps to assess the extent to which individuals can integrate their visual and motor abilities (Keith et al., 2010). In Japan, however, there has been no detailed examination of objective data with children as participants. The age at which it is possible to copy Necker cube and isometric perspective cube drawings remains unknown.

The purpose of this study was to analyze developmental changes in the Necker cube copying and isometric perspective cube copying abilities of Japanese children of typical development.

2. Methods

2.1 Study-1

2.1.1 Participants (Table 1)

The participants comprised 40 children aged 5-18 years, with no history of brain injury. All participants had scores higher than -1.5 SD from the mean in Raven's Coloured Progressive Matrices (RCPM) (Raven, 1976). This shows that their general intelligence was within the normal range.

Table 1. Demographic Characteristics of the Participants (Study-1)

	5 years old	6 years old	7 years old	8 years old	9 years old	10 years old	11 years old or older
men	1	4	4	5	3	1	2
women	1	2	4	2	3	4	4
total	2	6	8	7	6	5	6

The "11 years old or older" age group consisted of six individuals: one who was 11 years old, two who were 13, one who was 15, one who was 16, and one who was 18 years old.

2.1.2 Procedure (Table 2)

Participants were asked to copy a Necker cube drawing, with each side having a length of 5.2 cm (Otomo, 2009). No time limit was imposed. The method developed by Yorimitsu et al. (2013) was followed for the scoring process. This method is simple, and has high reliability and validity. In this method, there are 10 scoring areas worth one point each. This maximum possible score is 10 points. The scoring of all participants' work was performed by three researchers, in order to minimize errors.

Table 2. Scoring Criteria for the Necker Cube Copying Task (Yorimitsu et al., 2013)

	Scoring Items (one point each: total 10 points)
①	There are eight vertices that split into three lines at the corners of the cube. There must be three line segments. Additionally, there should be no contact between a straight line and a perpendicular line, or between two line segments that form a straight line and a perpendicular line.
②	Line segments intersect orthogonally in two places.
③	The direction of each of the 12 line segments is appropriate.
④	There are diagonal lines representing depth. The diagonal lines representing depth must be tilted at 20-70 degrees, using the base as a reference line.
⑤	The top, bottom, left, and right surfaces are parallelograms which are congruent (relative sizes within 1.5 times that of the original). The relative lengths of opposing lines are within a factor of 1.5 and are congruent.
⑥	Both front and back surfaces are squares (relative sizes within a factor of 1.5). The relative lengths of the four edges are within a factor of 1.5.
⑦	There are four vertical lines. The tilt of the vertical lines is within ± 10 degrees of the vertical.
⑧	There are four horizontal lines. The tilt of the horizontal lines is within ± 10 degrees of the horizontal.
⑨	There are four diagonal lines which represent depth. They must be tilted at 20-70 degrees, using the base as a reference line.
⑩	There are either vertical or horizontal lines. The tilt of the horizontal/vertical lines are within ± 10 degrees of the horizontal/vertical.

2.1.3 Analysis

In Study-1 there was an insufficient number of participants by age. As such, changes in scores from the Necker cube copying task, scored as per Yorimitsu et al. (2013), were analyzed by applying a one-way analysis of variance on four groups: the groups of participants aged 5-6 years (n = 8), 7-8 years (n = 15), 9-10 years (n = 11), and 11 years old or older (n = 6). In cases where the main effect was found to be significant under the one-way analysis of variance, Tukey's HSD multiple comparison test was performed as a post-test.

2.2 Study-2

2.2.1 Participants (Table 3)

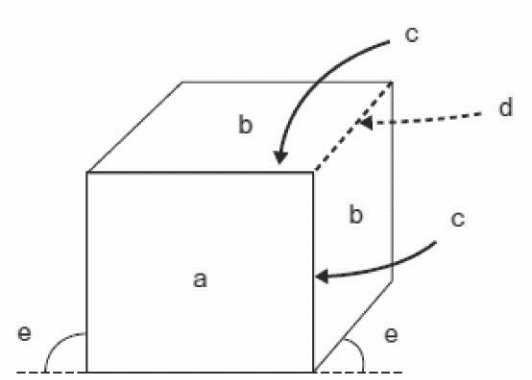
The participants comprised 32 children aged 6-10 years, with no history of brain injury. All participants had scores higher than -1.5 SD from the mean in RCPM (Raven, 1976). This showed that their general intelligence was within the normal range.

Table 3. Demographic Characteristics of the Participants (Study-2)

	6 years old	7 years old	8 years old	9 years old	10 years old
men	4	3	2	3	1
women	3	3	5	3	5
total	7	6	7	6	6

2.2.2 Procedure (Figure 1 and Table 4)

Participants were asked to copy an isometric perspective cube drawing, with each side having a length of 5.2 cm (Otomo, 2009). No time limit was imposed. Scoring was carried out following the method developed by Otomo (2009). This method has 15 scoring areas for surface construction and line direction, with each area worth one point. The maximum possible score is 15 points. The scoring of all participants' work was performed by three researchers, in order to minimize errors.



Fiture 1. Scoring Criteria Sections (Otomo, 2009)

Table 4. Scoring Criteria for the Isometric Perspective Cube Copying Task (Otomo, 2009)

	Scoring Items (total 15 points)
①	There is a square drawn for the front surface (Figure 1a; one point). It is acceptable even if it is not completely closed.
②	There are squares drawn for the top and side surfaces (Figure 1b; one point each, total two points). If there are two surfaces on either the left and right or top and bottom of the front surface square, only one shall be counted and given points. An excess in the number of surfaces required results in the subtraction of one point.
③	The front and top surfaces and front and side surfaces have common line segments (Figure 1c; one point each, total two points).
④	The top and side surfaces have a common line segment (Figure 1d; one point). The two vertices of each surface share joining line segments.
⑤	The direction of each of the nine line segments is correct (Figure 1e; one point each, total nine points). The tilt of horizontal/vertical lines is within ± 10 degrees from the horizontal/vertical. Diagonal lines representing depth must be tilted at 20-70 degrees, using the base as a reference.

2.2.3 Analysis

Changes in scores in the isometric perspective cube copying task, scored in accordance with Otomo (2009), were analyzed by applying a one-way analysis of variance to five groups: six-year-olds (n = 7), seven-year-olds (n = 6), eight-year-olds (n = 7), nine-year-olds (n = 6), and 10-year-olds (n = 6). In cases where the main effect was found to be significant under the one-way analysis of variance, Tukey's HSD multiple comparison test was performed as a post-test.

2.3 Informed Consent and Ethical Considerations

Informed consent for participation was obtained from both the participating child and the child's parent or guardian. After giving an outline of the study, the tests were administered only if both child and parent or guardian gave their approval. Participants were also told that they could drop out of the study at any time. They were informed that they would suffer no disadvantages by doing so. This research was conducted after obtaining approval from the Mejiro University Research Ethics Committee (Issue Number 15-010).

3. Results

3.1 Study-1; Results of the Necker Cube Copying Task (Figure 2)

The scores from the four groups (ages 5-6 years, 7-8 years, 9-10 years, and 11 years or older) in the Necker cube copying test were compared, and a significant difference was observed ($F(3, 36) = 18.794$, $p < 0.000$, $\eta^2 = 0.61$). Multiple comparison testing (Tukey's HSD method) revealed a significant difference between the 5-6 years and 9-10 years age groups ($p < 0.000$, $r = 0.73$), between the 5-6 years and 11 years or older age groups ($p < 0.000$, $r = 0.92$), between the 7-8 years and 9-10 years age groups ($p < 0.000$, $r = 0.64$), and between the 7-8 years and 11 years or older age groups ($p < 0.000$, $r = 0.82$).

3.2 Study-2; Results of the Isometric Perspective Cube Copying Task (Figure 3)

Scores from the five groups (six-year-olds, seven-year-olds, eight-year-olds, nine-year-olds, and 10-year-olds) in the isometric perspective cube copying test were compared, and a significant difference was observed ($F(4, 27) = 11.454$, $p < 0.000$, $\eta^2 = 0.63$). Multiple comparison testing (Tukey's HSD method) revealed a significant difference between the six-year-old and eight-year-old age groups ($p = 0.002$, $r = 0.76$), between the six-year-old and nine-year-old age groups ($p = 0.003$, $r = 0.71$), between the six-year-old and 10-year-old age groups ($p < 0.000$, $r = 0.88$), between the seven-year-old and eight-year-old age groups ($p = 0.009$, $r = 0.76$), between the seven-year-old and nine-year-old age groups ($p = 0.016$, $r = 0.71$), and between the seven-year-old and 10-year-old age groups ($p = 0.001$, $r = 0.91$).

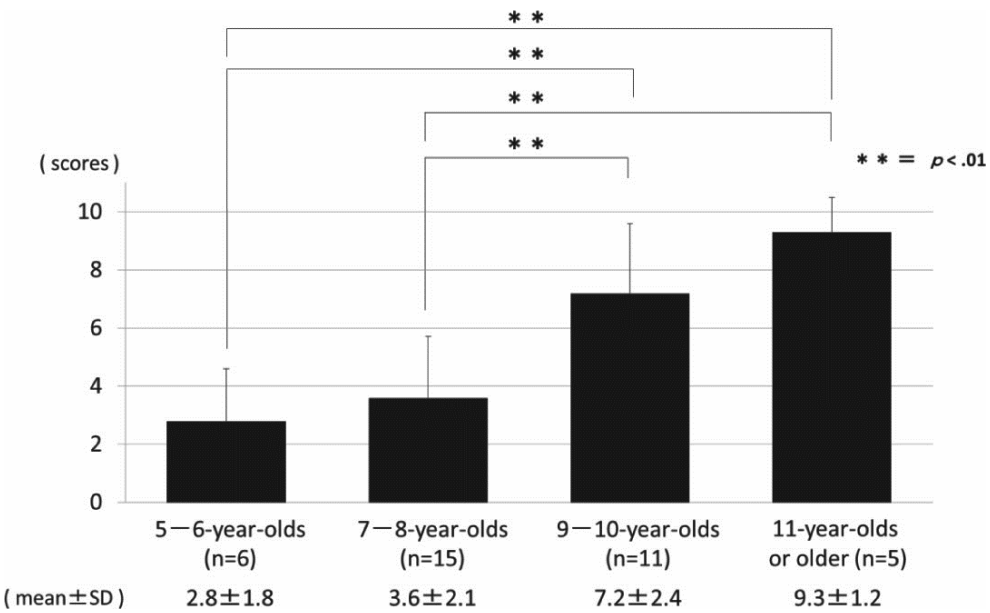


Figure 2. Results of the Necker Cube Copying Task

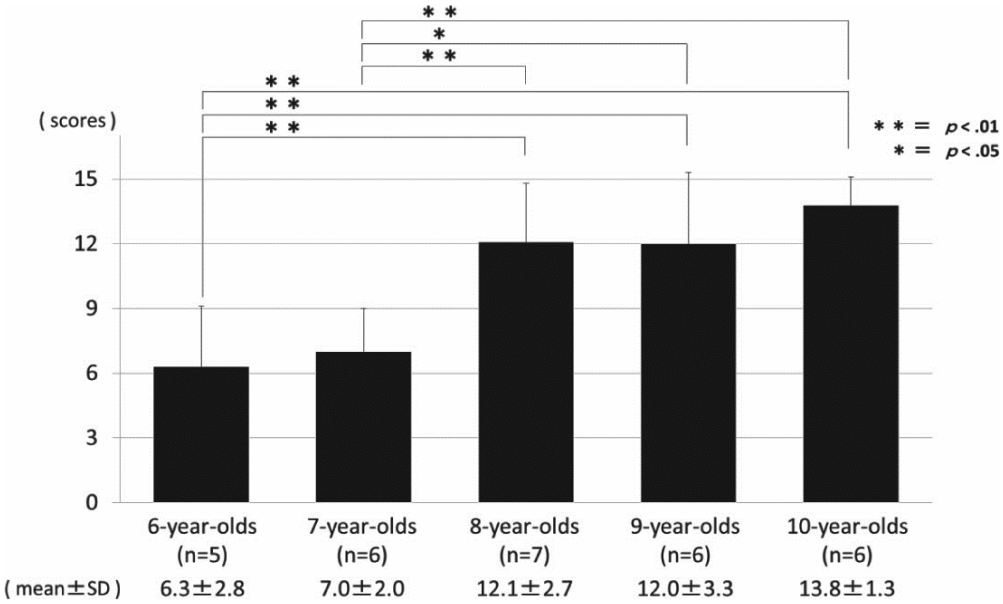


Figure 3. Results of the Isometric Perspective Cube Copying Task

4. Discussion

4.1 The Developmental Changes of the Necker Cube Copying Task

After scoring the Necker cube copying task using the method developed by Yorimitsu et al. (2013), a comparison was made among the scores of the 5-6-year-olds, 7-8-year-olds, 9-10-year-olds, and 11-year-olds or older. A significant increase was found between the scores of the 7-8-year-old and 9-10-year-old groups.

Fujimoto (1979) investigated developmental changes in children based on figure drawings of exercise postures, and noted that children become able to draw three-dimensional shoulders and curved arms and legs at around the third grade in elementary school. Using a cylinder drawing task, Caron-Pargue (1992) found that children become able to combine the circles that characterize the top and bottom surfaces with the rectangular shape of the sides at around eight years of age. By the age of 10 they were found to be able to create a three-dimensional representation of the same. In addition to identifying the use of the term “sense of depth” among the topics for third-graders in the Ministry of Education, Culture, Sports, Science and Technology (MEXT) elementary school instructional booklet, Noda et al. (1995) discussed the fact that the third or fourth grade is the stage at which children are able to create three-dimensional artistic representations. The results of the current study are consistent with these findings, and it is thought that children become able to identify and reproduce the three dimensions of the Necker cube from around the age of nine years.

On the other hand, in the U.K. it has been reported that children can draw the Necker cube from the age of 12 years and 8 months (Keith et al., 2010). Because the Japanese use kanji, with complex forms that may affect visual cognitive ability, Japanese children of typical development are likely to have better visual cognitive ability than children from other countries. Therefore, it is believed that Japanese

children of typical development are able to copy the Necker cube at an earlier age than children from other countries.

4.2 The Developmental Changes of the Isometric Perspective Cube Copying Task

The scores for the isometric perspective cube copying task measured using Otomo's method (2009) were examined. A significant increase was found between the scores of the seven-year-old and eight-year-old groups. Kubota (1965) investigated the relationship between mental age and isometric perspective cube copying task scores, using a four-level evaluation. This was based on subjective assessment ("3 points: The figure's motif is accurately captured", "2 points: Should have been 3 points, but there are many distortions", "1 point: Only some of the figure's motif has been reproduced. Drawings given 1 point will include considerable variation", "0 points: Nearly all essential elements are lacking") of a sample of 236 children of typical development, aged 3-8 years, and of 64 children with intellectual disabilities, from the first grade of elementary school to the third grade of junior high school. This study found that isometric perspective cube copying became possible at a mental age of around eight years, for both groups. Tanabe (1985) also analyzed developmental changes in figure-copying ability, using Kubota's (1965) subjective evaluation criteria. The participants were 31 elementary and middle school students, who had intellectual disabilities and were enrolled in special needs classes. The study found that copying an isometric perspective cube was possible from a mental age of around seven years and six months to 10 years. Ebisawa (1966) asked 250 children of typical development, from first grade to sixth grade, to copy an actual cube. The changes in their artistic expression were then subjectively analyzed. The study found that 30 of 42 (71.4%) second-graders were able to represent a cube with its three dimensions, while only 10 of 41 (24.4%) first-graders could do the same.

Although the results of the analyses of these previous studies were based on subjective evaluations, they are consistent with the results of the present study, which used objective indicators. They are also consistent in their conclusions that it is likely that isometric perspective cube copying becomes possible at around eight years of age.

5. Conclusions

In this study, we analyzed the developmental changes in Necker cube copying and isometric perspective cube copying abilities of Japanese children of typical development. Such children were able to carry out the Necker cube copying task from approximately nine years of age. The isometric perspective cube copying task could be done by children from the age of approximately eight years. Future investigations should more clearly demonstrate the cognitive function involved in the execution of cube copying tasks, with larger sample sizes.

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