RELATIONS BETWEEN MUSIC, SPATIAL AND MATH ABILITIES

RELATIONS BETWEEN MUSICAL, SPATIAL AND MATHEMATICAL ABILITIES

By

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ABSTRACT

Relations between musical, (rhythmic, tonal and chord analysis), spatial (rotation and visualization) and mathematical (computation, number sense, reasoning, spatial discrimination, and measurement) abilities were investigated. Participants were 18 boys and 18 girls, from a grade 6 class (average age = 11.5 years). Spatial scores were significantly related to tonal abilities, and measurement scores to both tonal and rhythmic abilities, after the effects of age, sex and intellectual ability were partialled out. Males outperformed females on both measurement and two-dimensional spatial tests. The possibility of a causal connection between musical and spatial abilities is discussed, specifically whether improving mathematical and spatial abilities may enhance musical ability, or vice versa. Educational implications are also discussed with suggestions for how classroom programs could exploit this mathematical-spatial-musical relationship. The current curriculums are shown to recognize that there is a relationship between mathematical and musical abilities, and to be in tune with the present study's educational suggestions.

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1. INTRODUCTION

In Brant County, government funding decreases have eliminated music instruction by trained music teachers. This means that untrained and even "unmusical" classroom teachers are providing music lessons to students. As one of the many teachers who belong in this category of "musically untrained", yet suddenly providing music instruction, I wonder which music skills are really necessary for students to learn. Are students receiving enough musical benefit by merely singing as a whole class, or are other skills important? The curriculum guides include pages of technical terms, assistance in teaching students rhythmic training, chord analysis, and musical sensitivity, but do such specific skills have an impact on musical development? And how important is musical development to a child's overall development? This is an important question as musical development has also been shown to be related to development in other cognitive areas.

For example, research shows that musical ability is related to many language abilities (Gauvain, 1993, Cahan and Ganor, 1995). Douglas and Willatts (1994) found that children's reading and spelling abilities were correlated with rhythmic awareness: better readers and spellers were also better at rhythmic processing. Bryant and Bradley

(1983, p. 419) found that "the experiences a child has with rhyme before he goes to school might have a considerable effect on his success later in learning to read and to write." Thus, acquiring certain musical skills may be important to the development of language skills.

It is possible that musical ability is also related to other cognitive areas too. "Pythagoras, the great Greek mathematician, argued almost 2,000 years ago that music was numerical, the expression of number in sound" and in believing this, "translated music into number and geometric proportions" (Joseph, 1988, p. 638). Much research has focused on these positive relationships between math and music, specifically in the areas of spatial abilities (Hassler, Birbaumer and Feil, 1985, p. 99).

Spatial ability can be defined by two factors: orientation and visualization. Spatial orientation measures "the ability to judge the spatial position and relationship of stimuli relative to the observer" (Gaulin and Hoffman, 1987, p. 130). Orientation also includes the ability to remain unconfused by the changing orientations in which a spatial stimulus may be presented (McGee, 1979). Spatial visualization measures the ability to "manipulate stimuli mentally without distorting the spatial configuration of the stimulus elements" (Gaulin and Hoffman, 1987, p. 130). McGee (1979, p. 893) adds that spatial visualization involves the ability to "mentally manipulate, rotate, twist, or invert a pictorially presented stimulus object."

Hassler, Birbaumer and Feil (1985, p. 104) found a significant relationship in 9- to 14-year-olds between musical talent and spatial visualization but not between musical talent and spatial orientation. Their research showed that musical children could better solve spatial visualization problems. Hassler, Birbaumer, and Feil (1985, p. 100) explain their findings in terms of right brain dominance for spatial processing.

Brain research shows the brain is divided into left and right hemispheres, with each controlling different functions of human activity. The left cerebral hemisphere "engages in sequential, linear, step-by-step processing; it is analytical focusing on detail, 'the parts'" (Weaver, 1988, p. 395)

The right cerebral hemisphere is

> superior to the left in distinguishing, interpreting, and processing vocal inflectional nuances, including intensity, stress, and pitch contours, timbre, cadence, emotional tone, frequency, amplitude, melody, duration and intonation... The right hemisphere is fully capable of determining and deducing not only what a person feels about what he is saying, but why and in what context he is saying it... (Joseph, 1988, p. 633).

The ability to sing is controlled by the right hemisphere (Joseph, 1988, p. 636). The right hemisphere has also been found to be dominant over the left in the analysis of geometric and visual-space, direction, shape, orientation, position, and perspective (Joseph, 1988, p. 639).

> Because of its importance in visual orientation, the functional integrity of the right brain also aids in performing tasks such as math [keeping digits organized in adding and subtracting large numbers] (Joseph, 1988, p. 642).

Thus, the right brain seems to control aspects of music and mathematics, and a relationship could exist between the two. As stated previously, Hassler, Birbaumer and Feil (1985) found a relationship between music and one small aspect of mathematical ability: visual spatial processing. However, there are many other facets of mathematics which could potentially be related to music, as mathematical ability encompasses a vast array of skills.

One study measured mathematical ability alone with a battery of tests which included "word problems... number concepts, operations, reading graphs and tables, measurement, estimation, computational speed, and two tests of spatial visualization (Lummis and Stevenson, 1990, p. 256).

The present study will try to replicate Hassler, Birbaumer and Feil's (1985) findings that musical ability and visual-spatial ability are positively correlated. The study will investigate which visual-spatial skills are related to musical ability (i.e. rotating and visualizing) and the effects of spatial dimensionality (i.e. two and three-dimensional questions will be used). Hassler, Birbaumer and Feil (1985, p. 106) also found no sex difference between boys and girls in spatial ability. Although investigating sex differences is not the primary focus of the present study, the results will provide an opportunity to replicate Hassler, Birbaumer and Feil's (1985) finding of no sex differences at this age level.

In addition, the present study will test for any relationships between musical ability and other math skills, specifically computation, number sense, reasoning and measurement.

The second part of the present study will discuss the educational implications of these findings in terms of curriculum development and classroom teaching practices. Musical skills that are related to mathematical achievement should probably be given particular emphasis in the classroom, as they may not only increase musical development, but they may also facilitate mathematical development. The present study examines correlations between musical and mathematical skills. Although this study can draw no conclusion about causal relationships exists between these skills, correlations would provide a beginning step toward answering the question of whether it is possible to increase students' mathematical ability through musical training. Future research could then examine causal links directly.

Finally, the study will examine the current curriculums provided by the school board to determine which math, spatial and musical skills they consider important, and whether the musical and mathematical skills that are linked are included in these curriculums.

2. METHOD

2.1 Participants

A total of 36 students, 18 girls and 18 boys, ranging in age from 10.11 to 12.7 years with an overall mean age of 11.5 years, participated in the study. Students were in the same grade 6 class. All students in the class participated.

2.2 Materials

Spatial Test based on Kerns and Berenbaum (1991)

Kerns and Berenbaum (1991) designed a spatial test to be used with children that involved mentally rotating objects and visualizing how flat objects would appear if they were folded (spatial visualization). The test included two- and three-dimensional problems. The test was based on an adult test that showed sex differences. Kerns and Berenbaum simplified the test for pre-adolescent children. The test included four sections:

(i) Geometric Forms - Participant is shown a geometric shape (cube, prism, rectangular pyramid and cylinder) covered in paper and must choose the two-dimensional picture response which shows how the paper would look if it was taken off the shape and laid out flat (visualization). All questions involve multiple-choice responses. (4 trials - see Appendix 1, Items 1 to 4)

(ii) House Plans - Participant must construct a "house" with cubes that matches two two-dimensional views, a frontal view and an aerial view (visualization). Participants were timed for each question (7 trials - see Appendix 1. Items 5 to 11).

(iii) Mirror Images - Participant is asked to identify the figure which is the mirror image of the target stimulus (rotation). The figures are two-dimensional drawings. All questions involve multiple-choice responses. (6 trials - see Appendix 1, Items 12 to 17).

(iv) Mental Rotations - Participant must mentally rotate two shapes constructed from cubes and determine if they are the same or different. Participants were timed for each question (14 trials - see Appendix 1, Item 18).

Kerns and Berenbaum (1991) describe and give one example question for each of the four subtests. They do not include the entire test. Using these descriptors, a similar test was constructed for use in the present study. The same number of questions was included. The test was piloted on eight student volunteers from another Grade 6 class to determine if the difficulty level was appropriate.

Evans Attainment Tests 2 by Wing and West (1973)

The Evans Attainment Tests are designed to assess children's achievements in math at the age of 11 years. All participants were given Mathematics Test 1, which consisted of five basic areas. Note that a spatial subtest (Spatial Discrimination) was included:

(i) Computation - Participant must solve 15 questions involving the four basic math operations, order of operations, fractions and monetary conversions. All questions require open-ended responses.

(ii) Number sense - Participant must solve 18 questions involving number patterns on dice, ordering from smallest to largest, integers, place value, and grouping numbers into blocks. 7 questions involve multiple-choice responses, and the remainder require open-ended responses.

(iii) Mathematical reasoning - Participant must solve 17 questions involving sets, sequences and logical thinking. 3 of the questions involve multiple-choice responses, and the remainder require open-ended.

(iv) Spatial discrimination - Participant must solve 12 questions involving visualizing three-dimensional shapes, labelling three-dimensional shapes and finding two-dimensional shapes. All questions require open-ended responses.

(v) Measurement - Participant must solve 16 questions involving metric conversions, time conversions, measuring distance on a map, and reading a line graph. All questions require open-ended responses.

Bentley's Test of Musical Ability (1966)

All participants were given three of the four subtests of the Bentley Test of Musical Ability. The subtests used were:

(i) Tonal Memory Test - Participant must judge whether a second five-note tune is the same as or different from a preceding five-note tune and, if different, which note has changed (10 trials).

(ii) Rhythmic Memory Test - Participant must judge which beat of two four-beat rhythms is different (8 trials). In order to make the scoring prove valid from a measurement point of view, before this subtest was administered, the two "same" trials in the original test were removed so that the response on each trial simply concerned the location of the beat that was changed.

(iii) Chord Analysis Test - Participant must judge how many separate notes make up a chord (20 trials). Before the test was administered, two trials from this subtest were changed from four note chords to a two note chord in one case and a three note chord in the other. Thus, each chord contained either two or three notes.

Peabody Picture Vocabulary Test - Revised (PPVT-R) by Dunn and Dunn (1981)

Studies have found that math and musical abilities correlate significantly with intellectual measures (Kerns and Berenbaum, 1991), meaning that participants with a higher overall intellectual ability perform better on all tests, making intellectual ability appear to be responsible for any relations between math and music. To account for the effects of general intellectual ability, Douglas and Willatts (1994) suggest measuring participants' intellectual ability and then controlling for it when calculating correlations between other measures.

In order to determine the effects general intellectual ability may have on correlations between musical and mathematical skills, the PPVT-R was administered to measure participants' "receptive (hearing) vocabulary for Standard American English" (Dunn and Dunn, 1981, p. 2). This score gives an independent measure of verbal ability, which is one "important facet of general intelligence" (Dunn and Dunn, 1981, p.2). Applebaum and Tuma (1977, p. 139) further support the use of this test by suggesting "administering the Peabody to children for obtaining valid IQ estimates."

2.3 Procedure

The various tests were administered in the following order: (1) PPVT-R; (2) Kerns and Berenbaum Spatial Test; (3) Evans Attainment Test 2 - Mathematics; and (4) Bentley Test of Musical Abilities.

The PPVT-R and the Kerns and Berenbaum Spatial Test were administered individually. All other tests were administered in a whole class setting.

The Bentley (1966) was presented with recordings of computer synthesized piano sounds created by using Bentley's test outlines.

A parental permission form and survey was sent home to participants' parents inquiring if participants had ever had musical instruction outside of school, the type of lessons and the length of time (in months) that participants took instruction. Parents were also asked to indicate how often their child listened to recorded music at home (see Appendix 2).

3. RESULTS

Partial correlations, which controlled for the effects of PPVT-R, sex and age, were administered for specific analyses of math, spatial and musical relationships. All relationships stated in the Tables are partial correlations controlling for PPVT-R, sex and age, unless otherwise stated.

First the score distributions will be presented. Then the relationships with in the various tests will be presented to show intra-test correlations. Finally, specific relationships between each subtest will be shown.

3.1 Score Distributions

Table 1 shows the mean, range, and chance level for each musical and spatial test. Certain measures provided questions with answer choices. For example, the Bentley Chord Analysis subtests asked participants to choose from two answer choices, thus giving a chance level of 50%. Chance levels could not be determined for the Evans Math test and the Kerns and Berenbaum Spatial House Plans subtest, because no answer choices were provided.

Table 1 - Mean, range and chance level for Bentley Musical, Kerns and Berenbaum Spatial and Evans Math scores

	Mean	Range	Chance Level (%)
Bentley: Tonal	72.8%	20.0 - 100%	20
Bentley: Rhythm	66.7%	12.5 - 100%	25
Bentley: Chord	71.1%	40.0 - 90.0%	50
K & B Spatial:			
Geometric	54.8%	0 - 100%	25
K & B Spatial:			
House Plans	39.3%	0 - 100%	n.a.
Time/Item	65.2 s	27.7 - 119.7 s	n.a.
K & B Spatial:			
Mirror Images	79.2%	0 - 100%	25
K & B Spatial:			
Mental Rotations	76.2%	57.1 - 92.9%	50
Summed Time	44.8 s	9.9 - 104.2 s	n.a.
Evans: Computation	38.3%	0 - 73.3%	n.a.
Evans: Number Sense	58.5%	27.8 - 88.9%	n.a.
Evans: Reasoning	49.0%	0 - 88.2%	n.a.
Evans: Spatial	60.3%	16.7 - 100%	n.a.
Evans: Measurement	29.0%	0 - 62.5%	n.a.
Peabody (PPVT-R)	50.7 p	5 - 95 p	n.a.

n.a. = not applicable s = seconds p = percentile

Figures 1 to 4 show the distribution of scores for the Peabody Revised Vocabulary, Bentley Musical, Kerns and Berenbaum Spatial and Evans Math tests. Participants' scores on the tests used in the present study should form normalized curves, meaning a few students will score at the low and high ends, with the majority of students scoring in the middle.

For the most part, participants' raw scores on the various mathematical, spatial and musical tests are normally distributed. The PPVT-R, Evans Computations, Number Sense, Reasoning, Measurement, Kerns and Berenbaum Spatial Geometric Shapes and Three-dimensional Mental Rotations scores form normal curves. The Bentley, Evans Spatial Discrimination, and Mirror Images scores are high and right skewed. The House Plans scores are irregular curves with low scores.

Figure 1

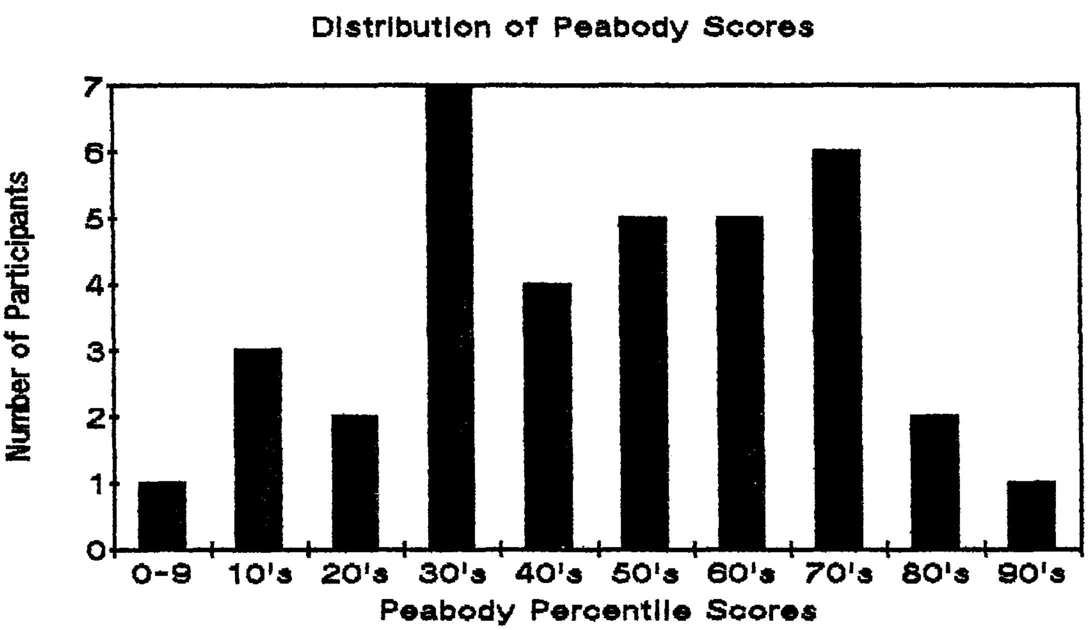


Figure 2

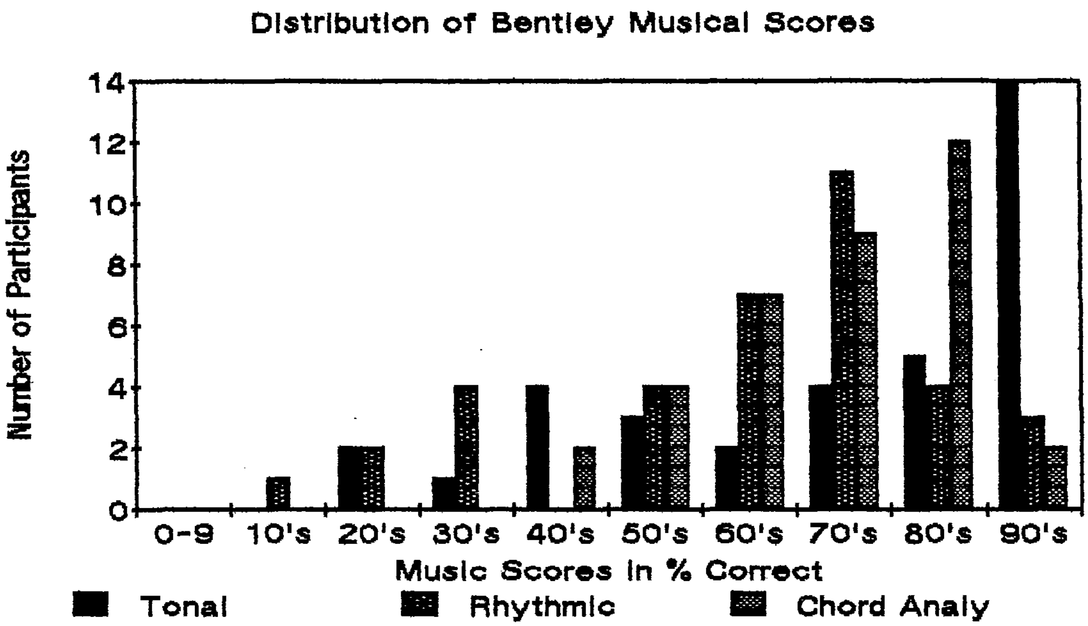


Figure 3

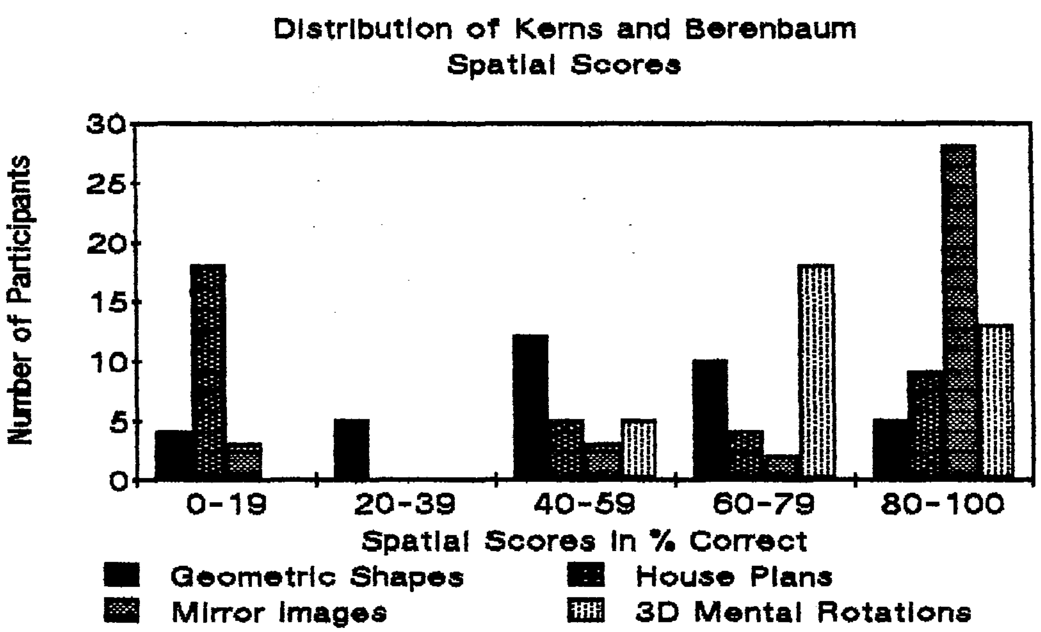
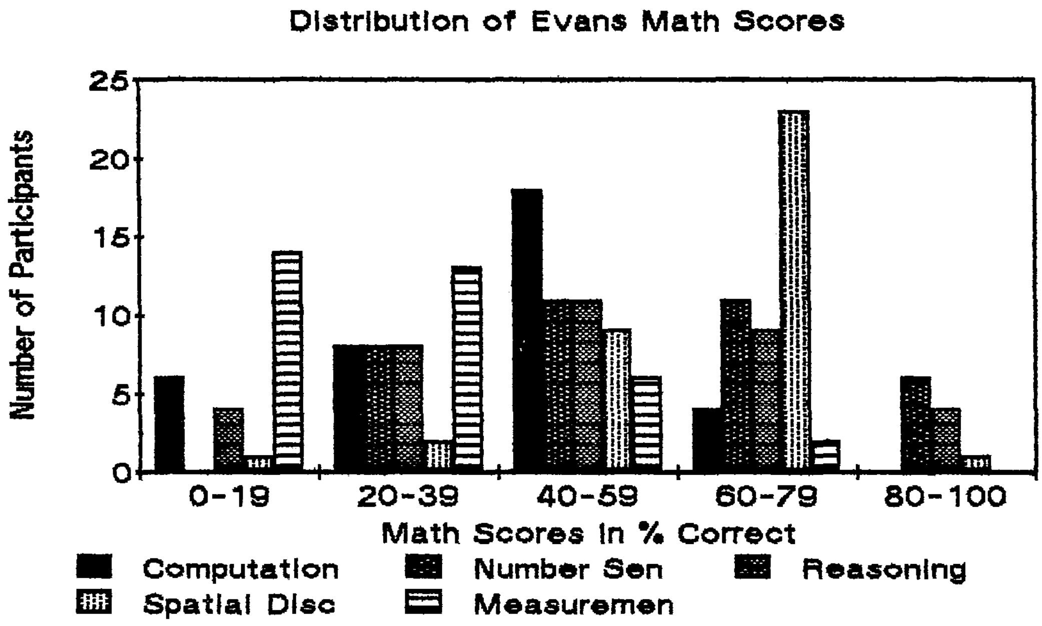


Figure 4


Distribution of Evans Math Scores
Number of Participants
25
20
15
10
5
0
0-19
20-39
40-59
60-79
80-100
Math Scores in % Correct
Computation
Number Sen
Reasoning
Spatial Disc
Measuremen

3.2 Relations between Musical subtests

Table 2 shows relationships among the three Bentley musical scores. Rhythmic and Tonal scores are highly correlated, while Chord Analysis is not related to either Rhythmic or Tonal scores. Chord Analysis seems to be a separate musical skill.

Table 2 - Partial Correlations (controlling for age, sex and PPVT-R) among the Bentley Musical scores

	Bentley Rhythm	Bentley Chord
Bentley Tonal	.648 *	.072
Bentley Rhythm		.128

* $p < 0.001$

3.3 Relations between Spatial subtests

Table 3 shows correlations among the subtests of the Kerns and Berenbaum Spatial test. The Geometric Shapes scores are significantly related to the House Plans scores. Both of these tests involve the spatial skill of visualization.

Geometric Shapes subtest scores are also related to Two-Dimensional Mirror Images scores (which involves the skill of rotation). This finding tends to support the view that visualization and rotational ability are related spatial skills.

The two rotational subtests (Two-dimensional Mirror Images and Three-dimensional Mental Rotations) are not correlated. Dimensionality may play a part in this lack of a relationship.

Table 3 - Partial Correlations (controlling for age, sex and PPVT-R) among the Kerns and Berenbaum Spatial scores

	House Plans	2-D Mirror Images	3-D Mental Rotations
Geometric Shapes	.441 *	.350 *	.058
House Plans		-.123	-.125
2-D Mirror Images			.081

* $p < 0.01$

Participants who took more time to complete the House Plans subtest did significantly better on this test ($r = 0.356$, $p < .033$). The time participants took to complete the three-dimensional subtest had no significant correlation with their scores on this test ($r = 0.212$, $p < .215$).

3.4 Relations between Mathematical subtests

Table 4 shows the relationship between the various subtests of the Evans Math test. Number Sense, Reasoning, and Measurement scores are significantly interrelated. Spatial Discrimination (visualization) is highly related to

Measurement, but not to the other mathematical skills. Perhaps measurement uses more spatial skills than the other mathematical measures.

Table 4 - Partial Correlations (controlling for age, sex and PPVT-R) among the Evans Math scores

	Number Sense	Reasoning	Spatial Discrim.	Measurement
Computations	.216	.143	.194	.256
Number Sense		.401 *	.226	.389 *
Reasoning			.285	.378 *
Spatial Discrim.				.445 **

* $p < 0.05$ ** $p < 0.01$

3.5 Relations between Mathematical and Spatial tests

Table 5 shows relationships between the Evans Math and the Kerns and Berenbaum Spatial scores. The Number Sense and the Geometric Shapes (visualization) subtest scores are significantly correlated. This is the only mathematical measure related to a specific spatial measure. This finding supports the previous finding (see Table 4) that a spatial visualization measure is related to a mathematical measure. No spatial scores involving rotation (Mirror Images or Three-dimensional Mental Rotations) were correlated with mathematical scores.

The Spatial Discrimination subtest, which involves visualization, is related to the Mirror Images subtest, which involves rotational ability. Dimensionality may play a part in this relationship, as both the Mirror Images and Spatial Discrimination subtests are two-dimensional. The Spatial Discrimination subtest scores were not correlated with scores on any subtests that involved three-dimensional questions (Geometric Shapes, House Plans and Three-Dimensional Mental Rotations).

The correlation between visualization scores and rotational scores supports the similar findings found in analyzing the subtests of the Kerns and Berenbaum Spatial test (see Table 3).

Table 5 - Partial Correlations (controlling for age, sex and PPVT-R) between the Evans Math and the Kerns and Berenbaum Spatial scores

	Geometric Shapes	House Plans	Mirror Images	3-D Rotat.
Computations	.119	.162	-.087	-.140
Number Sense	.474 *	.105	.172	.321
Reasoning	.250	-.005	.176	.043
Spatial Discrim.	.081	.084	.392 *	.083
Measurement	.246	.255	.165	.207

* $p < 0.05$

3.6 Relations between Music, Mathematical and Spatial tests

Table 6 shows the relationships between the Evans Math and the Kerns and Berenbaum Spatial subtests with the Bentley Musical subtests. Bentley Rhythmic scores are significantly related to Evans Measurement scores. Bentley Tonal scores are significantly related to Evans Spatial Discrimination (which involved two-dimensional visualization) and Measurement scores. Three-dimensional Kerns and Berenbaum Spatial scores are negatively correlated with Bentley Chord Analysis scores.

Table 6 - Partial Correlations (controlling for age, sex and PPVT-R) between the Evans Math, Kerns and Berenbaum Spatial, and Bentley Musical scores

	Bentley Rhythm	Bentley Chord	Bentley Tonal
Evans Math...			
Computations	.194	.213	.220
Number Sense	.232	.107	.111
Reasoning	.123	.121	.180
Spatial Discrim.	.204	.081	.359 *
Measurement	.464 *	-.065	.369 *
Kerns & Berenbaum Spatial...			
Geometric	.188	.242	.053
House Plans	.238	-.109	-.038
2-D Mirror Images	.180	.042	.150
3-D Rotations	.130	-.397 *	-.028

* $p < 0.05$

3.7 Sex Effects

Males did significantly better than females on the Evans Mathematics Achievement Test. Their overall math scores are almost significantly higher ($r = 0.327$, $p < .055$). However, males only significantly outperformed females on the Measurement subtest of this test ($r = 0.336$, $p < .049$). The only Kerns and Berenbaum Spatial sex difference was on the Two-dimensional Mirror Images subtest, where males scored significantly higher than females ($r = 0.340$, $p < .046$). No other Kerns and Berenbaum Spatial subtests showed a significant sex differences.

3.8 Effects of Musical training

Whether or not students took musical lessons outside of school had no significant effect on any of the Bentley musical measures. However, none of the participants had extensive musical training. Seven participants had taken musical instruction ranging from 1.5 to 30 months, with a mean of 10.1 months. Five of these seven participants had taken instrumental lessons, including three pianists, one guitarist, and one drummer. One of the seven participants had taken only voice lessons, and the final participant of the seven had taken both voice and guitar lessons.

According to parents, twenty-two participants listened to recorded music every day at home, while nine participants listen to recorded music a few times a week, and four participants listened once a week. No participants were described as rarely listening to recorded music.

The amount of time spent listening to music was not associated with increased musical skill. Participants described as listening to music more often did significantly worse on the rhythmic subtest of the Bentley Musical test ($r = 0.332$, $p < .048$), significantly better on the number sense subtest of Evans Math Achievement Test ($r = 0.390$, $p < .019$) and completed the Three-dimensional Mental Rotations questions on the Kerns and Berenbaum Spatial test faster ($r = 0.402$, $p < .015$) than other participants. These relationships are difficult to interpret.

4. DISCUSSION

4.1 Musical and Spatial Relations

Spatial Discrimination from the Evans Math test was found to be related to Bentley Tonal ability (see Table 6). These findings confirm the results of Hassler, Birbaumer and Feil (1985) that spatial visualization is significantly related to musical ability. Hassler, Birbaumer and Feil (1985) do not specifically detail which aspects of their musical testing (e.g. chord analysis, pitch, or phrasing etc.) are implicated, but do state that, "musical talent - especially the ability to compose and/or improvise - is related to spatial ability" (p. 111).

The present study found only tonal abilities to be related to spatial ability. One explanation for this finding could involve brain dominance. As discussed previously, the right cerebral hemisphere is associated with "visual-spatial perceptual functioning..." (Joseph, 1988, p. 631). The right cerebral hemisphere has been found to be dominant over the left in the "analysis of geometric and visual-space, the perception of... shape, orientation, position" (Joseph, 1988, p. 639). The Spatial Discrimination task from the Evans Math test involved visual-spatial perceptual functioning. Participants were asked to visualize which two-dimensional shapes could be joined together into three-dimensional shapes. Thus, the right hemisphere would have been highly involved in this activity.

The right hemisphere is also important to musical functioning. Joseph states, "Right hemisphere predominates in the perception (and/or expression) of... rhythm, chords, tone... melody" (p. 636). Thus, the Bentley subtests, rhythmic, tonal and chord analysis, would be expected to tap the functioning of the right hemisphere. Thus, both the musical and spatial tasks used in the present study seem to involve right brain processes.

According to this brain dominance theory, both rhythmic and chord analysis ability should then also be related to spatial ability. However, the results show no significant correlation between the Evans Spatial Discrimination subtest and performance on the Bentley Rhythm and Chord Analysis subtests.

Similarly, the Kerns and Berenbaum Spatial subtests showed no significant positive correlations with musical ability (see Table 6). Yet, according to brain dominance research, the Kerns and Berenbaum Spatial subtests included many processes linked with the right brain, such as visualizing and rotating. Even the House Plans subtest, which had participants building models with blocks, would involve the right hemisphere, as Joseph (1988) states that "the right brain is also superior to the left in analyzing manipulo-spatial problems.. and performing constructional tasks, block designs and puzzles" (p. 640). It is important to note, though, that the right hemisphere is quite large, and there could be localization within it for different abilities associated with the right hemisphere. However, little is known about the localization of the right brain functions pertaining to spatial ability.

There are several possible explanations why few spatial and musical relationships were found in the present study. The results could be due to the way the tests were constructed. Spatial ability was determined by both expressive (building a shape with blocks) and receptive (choosing the best choice) activities, while musical ability was determined by only a receptive activity (choosing the best choice). Perhaps individual participants do better on one type of task (e.g. some participants may do worse on multiple-choice than open-ended questions) hence causing differences in scores that were due to test style rather than to the particular measures. The findings from the Kerns and Berenbaum Spatial test tend to support this theory as the Geometric Shapes and the House Plans subtests both involved visualization and both were strongly correlated. However, only Geometric Shapes was correlated with rotational ability. Both the Geometric Shapes and the rotational test were receptive tests, while the unrelated House Plans test was expressive. Therefore, for a better comparison, some portions of the music testing should have been expressive (e.g. having participants sing a tune, or clap a rhythm).

Secondly, the lack of stronger spatial and musical correlations may be due to the fact that the Bentley did not get at participants' actual musical ability. Hargreaves (1986) states that "it could well be the case that children's style sensitivity is greater for music that is more familiar to them, and better liked by them" (pp. 57 - 58). Participants from this age group tend not to listen to piano music, but rather to rock or to dance music. Perhaps if the musical sounds were performed with a familiar instrument, different results would have been found.

One final explanation for the lack of a stronger relationship between spatial and musical abilities could be that the Bentley musical test did not involve right brain processes to the extent proposed by brain dominance theorists.

> There is some evidence to indicate that certain aspects of pitch, time sense and rhythm are mediated to a similar degree by both cerebral hemispheres..., perhaps more so by the left... When the sequential and rhythmical aspects of music are emphasized, the left

> hemisphere becomes increasingly involved... it seems that when music is treated as a type of language to be acquired or when its mathematical and temporal-sequential features are emphasized..., the left cerebral hemisphere becomes heavily involved in its production and perception (Joseph, 1988, pp. 637-638).

The Bentley musical test has participants analyzing musical selections for rhythmical aspects in the Rhythm subtest and mathematical and temporal-sequential features in the Chord Analysis and Tonal subtests. On a related note, if spatial and musical differences are a result of right brain activity, then why are sex differences in spatial ability reported often (Kerns and Berenbaum, 1991), yet sex differences in musical ability are rare (Bentley, 1966, p. 120)? It is difficult to conclude, then, that spatial and musical abilities are related due to a similar dependence on right brain dominance, as both hemispheres are most likely used for the musical processing.

A better possible explanation for spatial and musical relationships is a similar dependence on working memory. Bentley (1966) writes that,

> without the aid of memory no active participation in musical activity, however short, is possible... in order to make accurate responses to melody, a child must be able to perceive, and then retain in the memory for at least a short period of time, a given order of pitch intervals and note lengths (p. 28).

According to Bentley (1966), melody perception involves the analysis of both tonal and rhythmic memory traces (pp. 33-34). In order to perform the Bentley Tonal and Rhythmic subtests, participants have to keep a first tune in memory in order to compare it to another tune.

If the Bentley Rhythm and Tonal subtests both strongly rely on memory, this could explain why participants' performance on both tasks was strongly correlated (see Table 2). Participants who did well on the Rhythmic test also did well on the Tonal test. Chord Analysis scores were not correlated with Rhythmic and Tonal scores, possibly because analyzing chords does not rely on memory to the same extent, but rather involves judging concurrent sounds (Bentley, 1966, p. 36).

Another possible reason that Chord Analysis may not be related to rhythmic and tonal abilities is that it develops later in children. "Rhythmic memory is more highly developed at all ages of childhood than tonal memory; both appear to be more advanced than.. [the ability to analyze chords]. Chord Analysis develops more slowly than the rest (Bentley, 1966, p. 120)" Participants in this study averaged 11.5 years, with a range from 10.11 to 12.7 years. Bentley (1966) states that it is "not until the age of eleven years is reached that the mean score clearly exceeds the theoretical guessing score for the test" (p. 118).

Thus, some participants in this study were possibly not able to analyze chords due to their age, and were simply guessing.

According to working memory interpretations, musical and spatial abilities might be related if they both depend on working memory. Kerns and Berenbaum (1991) state that during mental rotations, "subjects form a mental representation of the stimulus and then perform a mental rotation that corresponds to the rotation of the stimulus in physical space" (p. 385). The Evans Spatial Discrimination subtest involves a use of memory, as participants had to hold a three-dimensional shape in their memory as they constructed it visually. This could explain the relationship between spatial discrimination and tonal ability. However, why rhythmic ability was not related to spatial discrimination cannot be explained, as rhythmic ability also relies on memory. The Geometric Shapes subtest of the Spatial tests would also heavily rely on memory, yet no correlation was found between it and musical ability. Gauvain (1993, p. 113) agrees that memory is necessary to spatial ability, but many other cognitive skills are also,

> including perception, memory, communication, and problem solving... spatial understanding may not be a general, underlying and internalized piece of knowledge that exists inside the head and is externalized for use when needed... In other words, spatial understanding may not be separate from

> the activity in which the knowledge is used and thus may be less like a representation, such as a route or a map, and more like a problem solving process.

Thus, the data are not consistent with a reliance on memory being the only link between music and spatial abilities. Many other cognitive skills are likely involved. The many non-relationships between spatial and musical scores could be explained in terms of each depending in varying degrees on similar cognitive skills, or on different cognitive skills. For example, the Evans Mathematical Spatial Discrimination subtest was not significantly related to rhythmic ability, because spatial discrimination may rely more on communication (as participants had to name shapes as part of their score) and less on memory, where as rhythm relied more on memory and not at all on communication ability.

4.2 Sex Differences in Spatial Ability

The finding that only one spatial subtest (Two-dimensional Mirror Images subtest) showed a sex difference (see p. 21) tends to support the results of Hassler, Birbaumer and Feil (1985), who found no sex differences at this age.

However, the fact that only one sex difference was found challenges the findings of Kerns and Berenbaum (1991), who report "a sex difference in spatial ability favouring males" (p. 383). They further explain that

> the spatial ability that shows the largest and most consistent sex difference in adults... is mental rotations...[and] another component of spatial ability which appears to show consistent sex differences in adults... involves visualizing how a flat object would appear if it were folded...[called] spatial visualization (p. 383).

Cahan and Ganor (1995) confirm this finding by stating that "boys continue to hold a clear advantage with respect to mental rotation" (p. 470). The Kerns and Berenbaum Spatial Test used in the present study was based on Kerns and Berenbaum's (1991) test involving rotations and spatial visualizations, which they found showed a strong male advantage. Kerns and Berenbaum controlled for the effects of intelligence, as does the present study, yet the sex difference which Kerns and Berenbaum found was not replicated in the present study.

This lack of replication could be explained by the fact that the present study did not use the identical test that Kerns and Berenbaum used, but rather one that was constructed from their examples only. The questions could have involved rotations of different degrees, and hence difficulty, than those recreated in the present study. Bialystok (1989) found that "distance of rotation was significant in determining problem difficulty, but not in any simple, and certainly not in any linear, manner... hence, the easiest rotations were those that travelled through 250 degrees" (p. 59). However, overall performance on Kerns and Berenbaum's test and the present study's test were very similar, suggesting that the difficulty level of the two tests was similar. Still, it is possible that other changes may have allowed males to outperform females.

Another reason for the lack of replication could be in looking at how some theorists explain sex differences. Hay and Lockwood (1989, p. 18) state that sex differences in spatial activities are usually the result of females being more cautious than males, meaning females take longer and are less likely to guess in case they are incorrect. In the present study, as in Kerns and Berenbaum's (1991), male and female participants were timed for each trial of a spatial task. The present study found no significant time difference between males and females, ($r = 0.119$, $p < .489$) but Kerns and Berenbaum (1991) found that "girls took significantly longer than boys to complete Mental Rotations and House Plans" (p. 390). This shows that the female participants in the present study did not appear to be cautious compared to their male counterparts. Cahan and Ganor (1995, p. 469) found that when girls were encouraged to guess, sex differences began to disappear.

One final explanation for a lack of sex differences in the present study could be in the samples used in both studies. Kerns and Berenbaum (1991) used 81 participants, and the present study used 36 (see p. 7). With a smaller sample, the chances of not detecting relationships that actually exit increases, and the chances of obtaining statistically significant relations also increases. The smaller the difference between male and female performance, the larger the sample needed to detect the difference.

In addition, the participants used in the present study may have had different training in regards to spatial awareness than the participants in Kerns and Berenbaum's study. Perhaps participants in the present study spend more time in class solving spatial problems, or have experienced classroom environments that encourage females to take risks more. The educational background of the participants in both studies would have to be determine if such environmental differences were present.

4.3 Mathematical and Musical Relations

In addition to analyzing relationships between spatial and musical abilities, the present study also examined other math abilities that may be linked to music. The ability to measure was found to be related to both tonal and rhythmic abilities (see Table 6). One explanation for this math and music correlation is that certain mathematical skills, like certain musical skills, include aspects of spatial reasoning. This result is in tune with the findings of brain theorists who state that

> because of its importance in visual orientation, the functional integrity of the right brain also aids in performing tasks such as math... for example, right sided lesions may cause the patient to neglect the left half of digit pairs while adding or subtracting (Joseph, 1988, p. 642).

In the present study, on the Measurement subtest, participants were asked to measure distance on a map and read a line graph, which involves some use of spatial ability. Specifically, the spatial skill of visualization (not rotation) was related to musical ability. Gauvain (1993, p. 110) confirms this relationship by stating that measurement does rely on spatial ability. Thus, spatial ability, which is important in music, is also important to some mathematical operations.

Musical ability was not related to any other math skills (see Table 6). Computations, number sense, and reasoning were not correlated with the Bentley musical results, most likely because these math subtests did not involve the spatial skills of visualization and rotation. Some research does support a link between arithmetic and spatial ability (Lamm and Epstein, 1992, p. 460). However, the skill of arithmetic may not be related as much as the fact that arithmetic can involve tabulating columns, which would involve spatial ability in keeping the digits organized (Joseph, 1988, p. 642). In the Evans Math test, the Computation subtest used no questions that involved adding or subtracting multiple digits, possibly explaining the lack of correlation.

Another reason that musical ability was not found to be correlated with other mathematical abilities could be in the test used to measure mathematical ability. The Evans test is a British test geared for 11 year olds. It is obviously based on British standards, and is dated (it was written in 1973). Mathematical standards have changed much in Ontario in the last twenty-four years. Students are allowed calculators now for all complex calculations and during the Evans test, students are not permitted to use them. The participant's Evans test scores were low, with the mean score being 38.3% on the Computations subtest. Many students did complain that they did not understand much of the test, and their scores prove them correct. Participants did best on the Spatial Discrimination subtest (with a mean score of 60.3%). By chance, spatial concepts had been taught a few weeks before the test, possibly explaining why participants did best on this subtest.

4.4 Other Spatial Findings

As described previously, two separate spatial tests were used. One was the Spatial Discrimination subtest of the Evans Math test, with questions requiring the spatial skill of visualization, and the other was a test reconstruction of Kerns and Berenbaum (1991), with certain questions requiring visualization and others requiring rotational abilities.

The results show no relation between the two rotational subtest scores (see Table 3, two- and three-dimensional tests), no relation between the Evans visualization (Spatial Discrimination) scores and the Kerns and Berenbaum visualization (Geometric Shapes and House Plans) scores (see Table 5), and no relation between visualization and rotational scores (see Tables 3 and 5). Several possible explanations will be discussed for these findings.

The fact that neither of the subtests involving rotational ability were inter-related can be explained by the difference between these two tests, which is dimensionality. One subtest had participants rotating two-dimensional pictures, and the other had participants mentally rotating three-dimensional shapes. Possibly different spatial skills are required to rotate in two as opposed to three dimensions.

Another explanation for the lack of relation between the two rotational tests is that they were not consistent in their question styles. The two-dimensional test used abstract designs (pictures), while the three-dimensional test used concrete questions (actual three-dimensional shapes). Hatakeyama (1989, p. 116) found that abstract and concrete questions can yield different measures of spatial ability and further explained inconsistency in spatial testing as a result of inconsistency in testing materials, with some studies using concrete stimuli while others use abstract stimuli.

Some visualization scores were not correlated. The Spatial Discrimination subtest had participants visualize geometric shapes, much like the Geometric Shapes subtest of the Kerns and Berenbaum Spatial test. However, the results between Spatial Discrimination and Geometric Shapes were not correlated. This could be due to the fact that the Spatial Discrimination subtest required additional skills, requiring participants to name three-dimensional shapes (e.g.. tetrahedron, hexagonal prism, cuboid).

In the spatial subtests, some of the visualization and rotation scores were significantly correlated. This finding tends to support the findings of McGee (1979) and

Gaulin and Hoffman (1987) that rotational ability is related to visualization. Other researchers oppose this view, stating that visualization and rotational ability are independent, unrelated skills (Hassler, Birbaumer and Feil, 1985). The findings of the present study not support the latter view, showing a relationship between rotational ability and visualization. The only difference in spatial skills supported by the findings of the present study is a difference due to dimensionality.

4.5 Other Mathematical Findings

The Evans Math subtest scores were related to each other. Measurement, Number Sense and Reasoning were significantly inter-correlated (see Table 4). These subtests all seemed to involve some spatial concepts, which could explain the performance relationship. The Number Sense subtest included some questions with spatially arranged dice, the Reasoning subtest had participants looking at groups of shapes, and the Measurement section involved reading a map and a line graph. However the spatial component in these tests was apparently minimal, as only Measurement was significantly correlated with Spatial Discrimination (see Table 4). On the other hand, as other researchers describe, spatial ability encompasses many skills and all of these spatial skills themselves may not be related (Kerns and Berenbaum, 1991, p. 385). Therefore, the Spatial Discrimination subtest may have involved different spatial reasoning (visualizing) than the other math subtests (e.g. Number Sense used block designs).

Computation is the only Evans Math subtest not related with the other math results (see Table 4). Again, this could be due to the fact that students are now allowed calculators to solve the types of questions presented on this subtest. Students might have had the understanding of how to solve the questions, but lacked the basic skills that calculators now provide.

In general math seems to include some related skills (Number Sense, Reasoning and Measurement) and other unrelated skills (Spatial Discrimination, Computation).

4.6 Sex Differences in Mathematical Ability

In the present study, the males outperformed females on their overall Evans Math score and specifically on the Measurement subtest of this test (see p. 21). This finding confirms the finding of Cahan and Ganor (1995, p. 469), who state that boys did better than girls on measures of mathematical ability. Hay and Lockwood (1989, p. 17) explain this in terms of both differential expectations of parents for their daughter in terms of math, because of which girls expect less of themselves in the realm of numbers than boys do, and the fact that many "math" problems entail spatial reasoning. Once again, the strongest math relationships were between spatial discrimination and measurement. This finding hints at a male advantage in spatial ability, as the Measurement subtest involved spatial activities. Yet direct spatial tests did not show this male advantage.

5. EDUCATIONAL IMPLICATIONS

The findings of this study have two main implications for the teachers and curriculum of students at this age level. First, how important is musical instruction in enhancing musical ability? Secondly, if musical instruction is seen as important, then how can this math, spatial and musical relationship help to improve student achievement?

5.1 The Importance of Musical Instruction

Another implication of this study is the finding that musical instruction outside of school was not significantly correlated with musical ability (see p. 22). Hargreaves (1986) confirms this finding by stating that

> specific coaching can indeed improve specific skills in many cases, but the long-term stability of these improvements is less well established. Rhythmic tests, for some reason, seem to be more resistant to the effects of music lessons than most others (p. 101).

Thus, the lack of correlation between music lessons and rhythmic ability can be explained. However, no musical abilities (tonal and chord analysis) were related to music lessons.

There are several possible explanations for this lack of significant correlation between musical instruction and musical ability. To begin, perhaps children with outside musical instruction would have been even worse without it, and the children without outside musical instruction would have been better with it. In other words, maybe the less musical children in the sample took music lessons, and did become more musical, but were still lower than the rest of the sample.

Secondly, perhaps the skills that students learn in their music lessons are not related to the skills measured by Bentley's test. More likely, the music instruction that students took was not intense enough or long enough to begin to make a difference (only seven participants had taken musical instruction for a mean of 10.1 months in total).

One last explanation for this lack of correlation is that musical ability cannot be taught, and is rather an ability that is inherent, or develops independently of specific teaching. Bentley (1966) explains this "Inherited versus Acquired" theory further:

> Those who subscribe to the idea of inherited ability admit the importance of environment for the development of what has been inherited... however favourable the environment, the child with little innate capacity is unlikely to make much progress in musical activities. There is plenty of evidence for this last statement. It may be seen in any school age-group

> whose members are subject to very similar environmental background and identical class teaching; the different rates of progress of individuals are most marked... (p. 16)

Bentley (1966, p. 16) furthers his argument by discussing how siblings from the same home environment, with the same musical encouragement, can show such vast differences in their musical ability, thus concluding that "biological predisposition" in music is very evident.

With this theory in mind, do non-musical children gain anything from even learning musical skills at school? Bentley (1966) states that

> all children have something to gain from some sort of musical participation in music, from listener-only to highly skilled instrumental or vocal performer, or even composer; [that] no child should be denied whatever pleasure, satisfaction and self-fulfilment he can obtain from music (p. 16).

Thus, even if students are just listening to music, or singing, they are still benefiting in some way from the experience, no matter how simplified. Therefore, it seems important to be "teaching" music in some form to students.

5.2 Investigating A Causal Link between Music and Math

The results of the present study and others (Hassler, Birbaumer and Feil, 1985) have shown correlations between mathematical and musical abilities (specifically rhythmic and tonal with measurement, and spatial discrimination with tonal abilities). From these correlations it can be assumed that an increase in one ability could also cause an increase in another. Thus, possibly increasing students' musical ability could increase their spatial or mathematical ability or vice versa.

As discussed previously, certain musical and language abilities are highly correlated as they both rely on the similar skills of "perception and memory for pitch and sequence, or analysis of the structure of complex sounds and stress patterns" (Barwick, Valentine and Wilding, 1989, p. 253). Some causality has been shown, mainly that musical ability can help improve reading ability. Reading recovery programs suggest, in teaching children to read, to "teach students first to sing and then to read songs [and] choose songs that incorporate both rhythm and rhyme, and invite rhythmic movement" (Weaver, 1988, p. 405). Similarly then, the correlations between musical and mathematical abilities could also have a causal link, as they share similar skills, especially a reliance on spatial ability and geometry (Joseph, 1988, p. 638). For example, in learning to count, children may use rhythms to remember patterns of numbers, much like they learn their ABC's to catchy tunes.

If the development of children reflects man's historical development, then history shows that early man's understanding of music has led to much mathematical and spatial understanding. For example, the Egyptians developed early cosmologies from musical ratios, the Parthenon in Athens was designed from the repeating musical patterns of the "golden rectangle" and Plato later applied musical proportions to theories of numbers and planetary motion (Joseph, 1988, p. 638). Indeed, the development of mathematical understanding has been highly dependent on musical understanding.

However, in dealing with children, it seems more likely that improving mathematical ability would increase musical ability. For example, children do not understand time signatures until they understand ratios (1:2 yields an octave) and fractions (3/4 time). An understanding of repeating geometric patterns would help increase understanding of detailed musical patterns in the natural world (Joseph, 1988). Similarly, developing spatial skills would help children to visualize the placement of notes in an octave, and to place notes on musical grids.

If mathematical and spatial abilities are believed to increase musical understanding, then an understanding of how to increase spatial awareness is important.

Spatial awareness could be enhanced in several ways. First, students could be given many opportunities to practice some of the many spatial skills, such as visualizing and mentally rotating objects. Solving spatial questions also improves students' use of their working memory, which could possibly help increase musical abilities, as rhythmic and tonal analyses rely on memory. Computers could also help practice spatial skills, as McClurg and Chaille (1987) report that

> certain computer games may enhance spatial ability... [and these games should include] physical and mental manipulation of two and three dimensional objects, coordination of the horizontal and vertical axes, and wholistic [sic] processing of images necessitated by the pace of the game (pp. 95-96).

Secondly, as sex differences in spatial ability could impede spatial development for females, encouraging females more in math is also necessary. Research shows that encouraging females to take chances eliminates most sex differences in math (Hay and Lockwood, 1989). Curriculum should provide encouragement for all students and many opportunities for risk-taking in a supportive environment. Additionally, research has also shown that a male advantage in math is also due to females taking longer to solve spatial questions (Petrusic, Varro and Jamieson, 1978); however the present study found no such sex difference. Still, eliminating time constraints for children solving problems may also eliminate sex differences.

6. CURRICULUM ANALYSIS

The current curriculum that is provided for teachers will be examined to determine whether it is in tune with the findings of this study and the educational implications identified. Three documents will be examined, The Common Curriculum (1995), and both of The Brant County Board of Education's curriculums, Junior Mathematics (1993) and Grade 6 Music (1991). All will be shown to mention a relationship between math and music, and the importance of teaching certain math and music skills.

The Common Curriculum (1995) is the current government document in force in Ontario that lists essential outcomes (knowledge, skills and values) that all students will achieve in their schooling. Many statements included in The Common Curriculum demonstrate an understanding of the link between math and music. For example, it states, "Mathematics is useful in many fields - in the arts,...a knowledge of geometrical principles is useful in... music" (p. 70). The Common Curriculum (1995) also discusses the importance of spatial ability in math. In listing areas of math, geometry and spatial sense are mentioned (p. 70).

Many of the specific musical, math and spatial skills measured in the present study are deemed essential to students in <u>The Common Curriculum</u> (1995). For example, one outcome states:

> By the end of Grade 3 students will... describe the results of sliding, flipping, and turning a variety of objects and shapes, using their knowledge of spatial relationships and the effects of motion geometry (e.g. describe the effects of flipping two-dimensional figures on a grid- a motion that changes the position of figures, but not their size or shape (p. 72).

Some of the musical skills mentioned that relate to the present study are that students will "describe aesthetic qualities of things they perceive in the world around them (e.g. harmony, balance, variety, unity and rhythm perceived in everyday sights, sounds, shapes, textures)" (p. 40), and "translate various kinds of symbols (e.g. musical notation into sounds)" (p. 45).

The junior math curriculum, <u>Junior Mathematics</u> (1993), discusses all of the implications from the present study's findings. It addresses ways to teach spatial skills, improve working memory and encourage all students (not solely females) to be better trained risk takers.

In dealing with the teaching of spatial abilities, activities are included which have the students folding and gluing paper into three-dimensional objects, much like Kerns and Berenbaum's Geometric Shapes Spatial subtest and the Evans Spatial Discrimination subtest. The document places much emphasis on concrete rather than abstract questions, by stating that "even the most advanced students may relate to the use of concrete materials to support... spatial reasoning" (p. 5). The document also expresses the belief that mathematics is a connected whole and not made up of separate unrelated skills.

> Students need to see how mathematical ideas are related. The mathematics curriculum is generally viewed as consisting of several discrete strands such as number or space, which are often taught in isolation from one another. It is important that students connect ideas both among and within the areas of mathematics. Students need to broaden their perspective to view mathematics as an integrated whole and to recognize its usefulness and relevance both inside and outside of school (p. 7)

Computer usage is also described as important to the development of mathematical ability, especially spatial ability: "every classroom should have available at least one computer for student use.... software such as... geometric drawing programs should be available to all classrooms" (p. 9).

Junior Mathematics (1993) mentions the importance of enhancing aspects of both hemispheres in mathematical functioning, by stating that math programs should have increased emphasis on both "analyzing and... problem solving" (p. 10) which fits under the realm of the left hemisphere and on "teaching number concepts and operations for understanding through patterns and use of concrete and pictorial models" (p. 100), which describes functioning of the right hemisphere (Weaver, 1988, p. 395).

In dealing with the issue of sex differences in mathematical achievement being a result of socialization, Junior Mathematics (1993) states: "Our goal is to help students develop the belief that they have the power to do mathematics and that they have control over their own success or failure" (p. 5). Similarly, the document places no emphasis on time constraints. Students work co-operatively to solve problems that should sometimes "require an extended period of time to solve" (p. 6). This means that students are not given a problem sheet to solve in a half hour. Instead, students are encouraged to "share their thinking and approaches with other students..." (p. 6), with problems that could take many days to solve. Thus, how quickly students can solve problems is not a skill considered important in the problem solving process. Important skills are: "understands problems, organizes information, checks reasonableness of answer" (Junior Mathematics, 1993, p. 21), not whether a time limit was met. If specific skills are being enforced, such as the skill of addition, the document states that during speed drills, "some students may have difficulty mastering quick recall of facts. It is suggested that these students be given opportunities for additional experience with addition..."

(p. 78). Thus, even speed drills should be individualized for students, giving more time, or support materials (e.g. number lines, math grids). With this increased focus on encouragement, meaningfulness and individualized completion times, sex differences in mathematics should lessen.

Grade 6 Music (1991) includes many essential musical attitudes, skills and knowledge. For example, the following skills are some of the many identified: "to identify, read, write and create rhythm patterns using rhythm symbols and names, [and] to develop an understanding of the concepts of pitch, melody, harmony, rhythm, form, dynamics, expression, style" (pp. 1-2). Other than an omission of chord analysis, the skills mentioned are in tune with the skills outlined in Bentley (1966) as important to musical ability. Chord analysis may not be included, as discussed previously, because the skill cannot be developed in students until about the age of 11 years.

This curriculum document puts much detail into how to teach these specific skills to children; however the document assumes the teacher has some musical background as many of the lessons are very detailed and difficult for non-musical teachers. For example, one of the first activities described in the document for September is "to reinforce known tones in the 5-tone pentatonic scale. When the song is well known, sing it to the sol-fa names with hand signs.

A tone ladder and/or moveable sol-fa discs can be used as visual aids" (Monthly Outline, p. 2). There is no explanation of the terms "5-tone pentatonic scale", "tone ladder" and "moveable sol-fa discs". It seems that the curriculum identifies important attitudes, skills and knowledge, but gears the guidance in teaching them to a well-trained musical professional. Thus, musical instruction is deemed important, and every child should learn specific musical skills, not just musically-inclined students.

7. CONCLUSIONS

Mathematical, spatial and musical abilities have been shown to be related. The results of Hassler, Birbaumer and Feil (1985) were replicated: spatial visualization and musical ability are related, and few sex differences existed at this age. The present study furthered Hassler, Birbaumer and Feil's (1985) work by showing that it is tonal abilities specifically that are related to spatial-visualization. However, Kerns and Berenbaum's (1991) findings of a strong relationship between rotational and musical abilities, and a strong male advantage were not replicated. The present study also found that measurement skills are related to rhythmic and tonal abilities and that boys did better than girls on measurement questions.

From these results, many implications were discussed in terms of teaching practice. The necessity of music instruction was discussed and shown to be important, even if specific musical skills are not enhanced. A causal relationship between musical and mathematical abilities was discussed, particularly that enhancing math and spatial understanding would increase musical ability because of music's reliance on geometric patterns, ratios, fractions, and visualization. Based on these understandings, the curriculums that could enhance spatial ability by providing practice in visualization, especially with computer programs, were described. Curriculums should also encourage all students to be co-operative, risk-taking problem solvers, especially females.

Ministry Outcomes and Math and Music curriculums were analyzed to show that all recognize a mathematical and musical relationship, although no mention of causality is discussed. Specifically, the math curriculum emphasizes teaching spatial skills through concrete and abstract exercises and computer usage, and eliminating time constraints for problem solving, which better encourages all students, especially females. The music curriculum emphasizes teaching specific skills, although the process it describes is highly technical for an untrained teacher.

More research is needed to further analyze the role that music plays in spatial and math abilities. It is impossible to draw any firm conclusions about causation from the present data. Perhaps music and mathematics' only relationship is a reliance on working memory, and other skills that rely on working memory would also be related, such as reading. Future research could focus on testing younger children's musical ability before they have any formal mathematical experience, to see if future mathematical experience could be predicted through pre-mathematical performance on musical tasks.

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Appendix 1

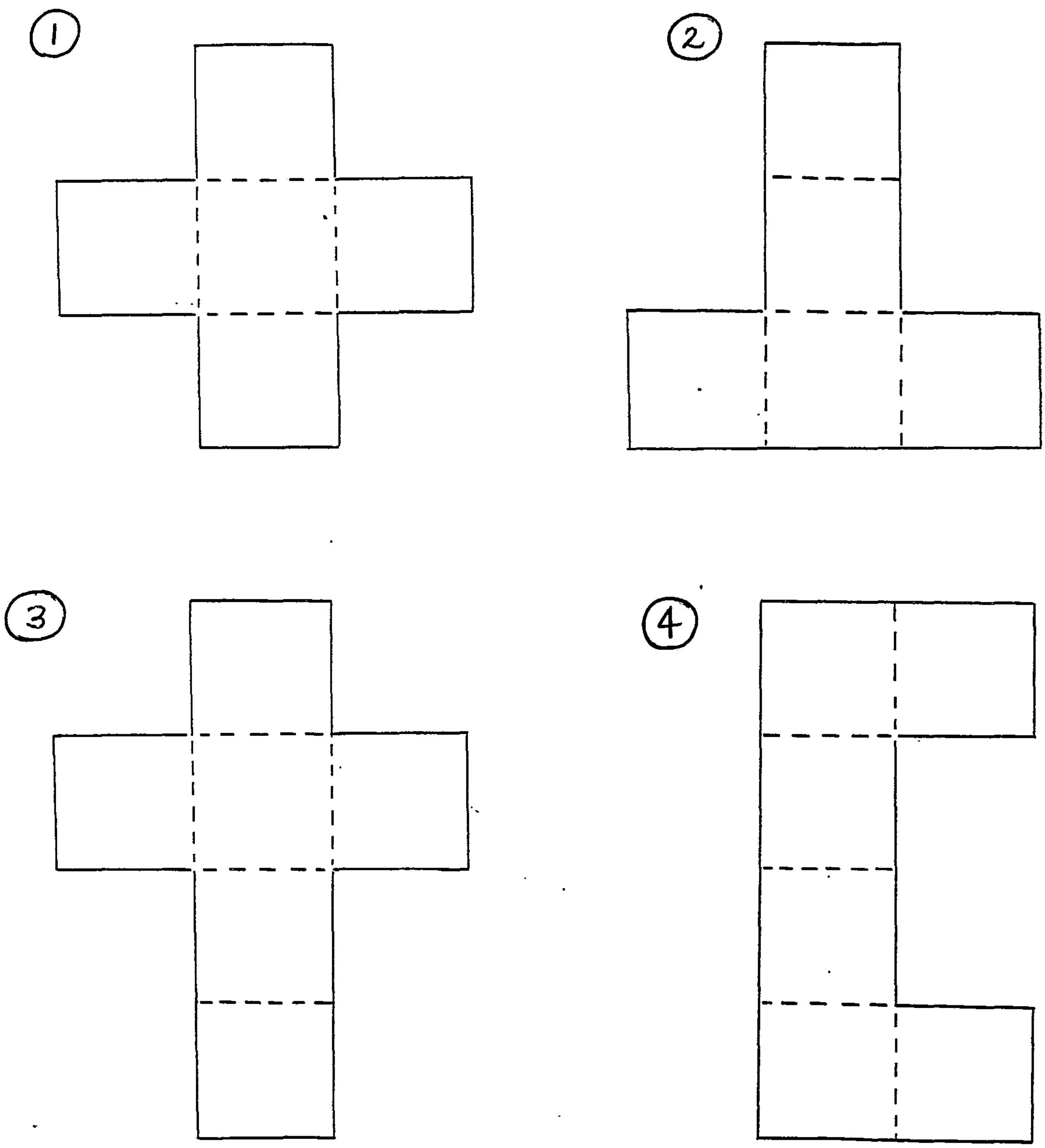
The Spatial test questions used in the present study based on Kerns and Berenbaum (1991).

The test included four sections:

1. Geometric Shapes
2. House Plans
3. Mirror Images
4. Mental Rotations

Appendix 1 - Item 1

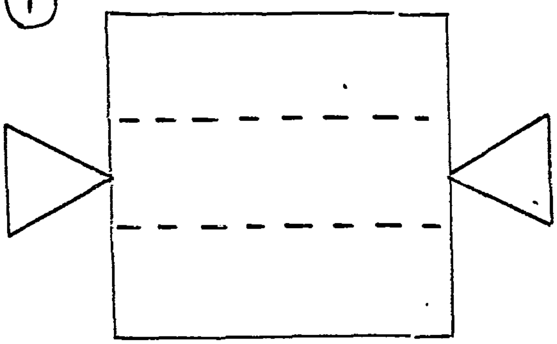
Geometric Forms - Participant is shown a cube covered in paper and must choose the two-dimensional picture response which shows how the paper would look if it was taken off the shape and laid out flat (visualization). The correct answer is choice 3.



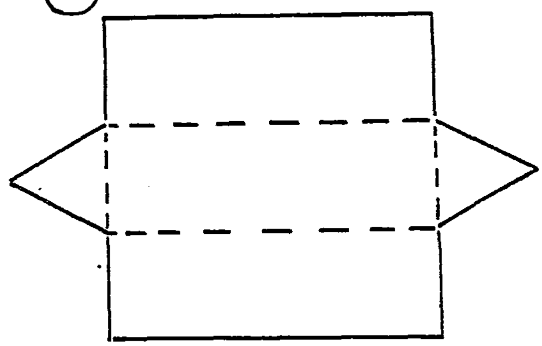
Appendix 1 - Item 2

Geometric Forms - Participant is shown a prism covered in paper and must choose the two-dimensional picture response which shows how the paper would look if it was taken off the shape and laid out flat (visualization). The correct answer is choice 2.

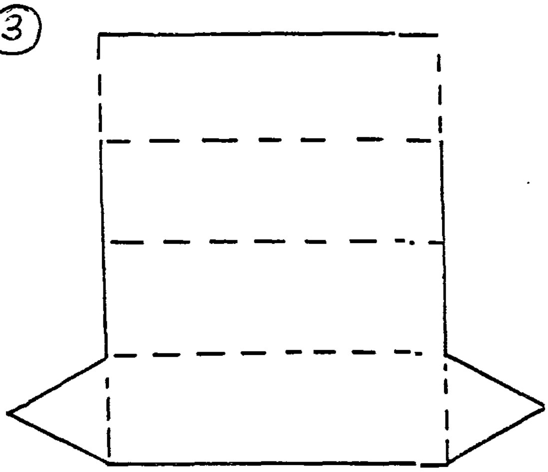
(1)



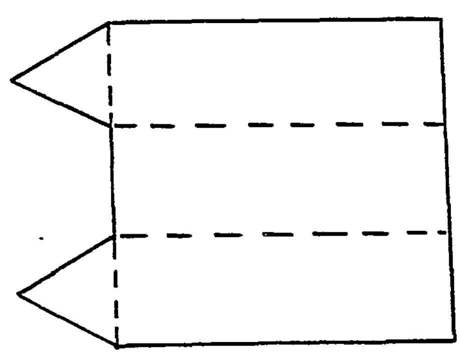
(2)



(3)

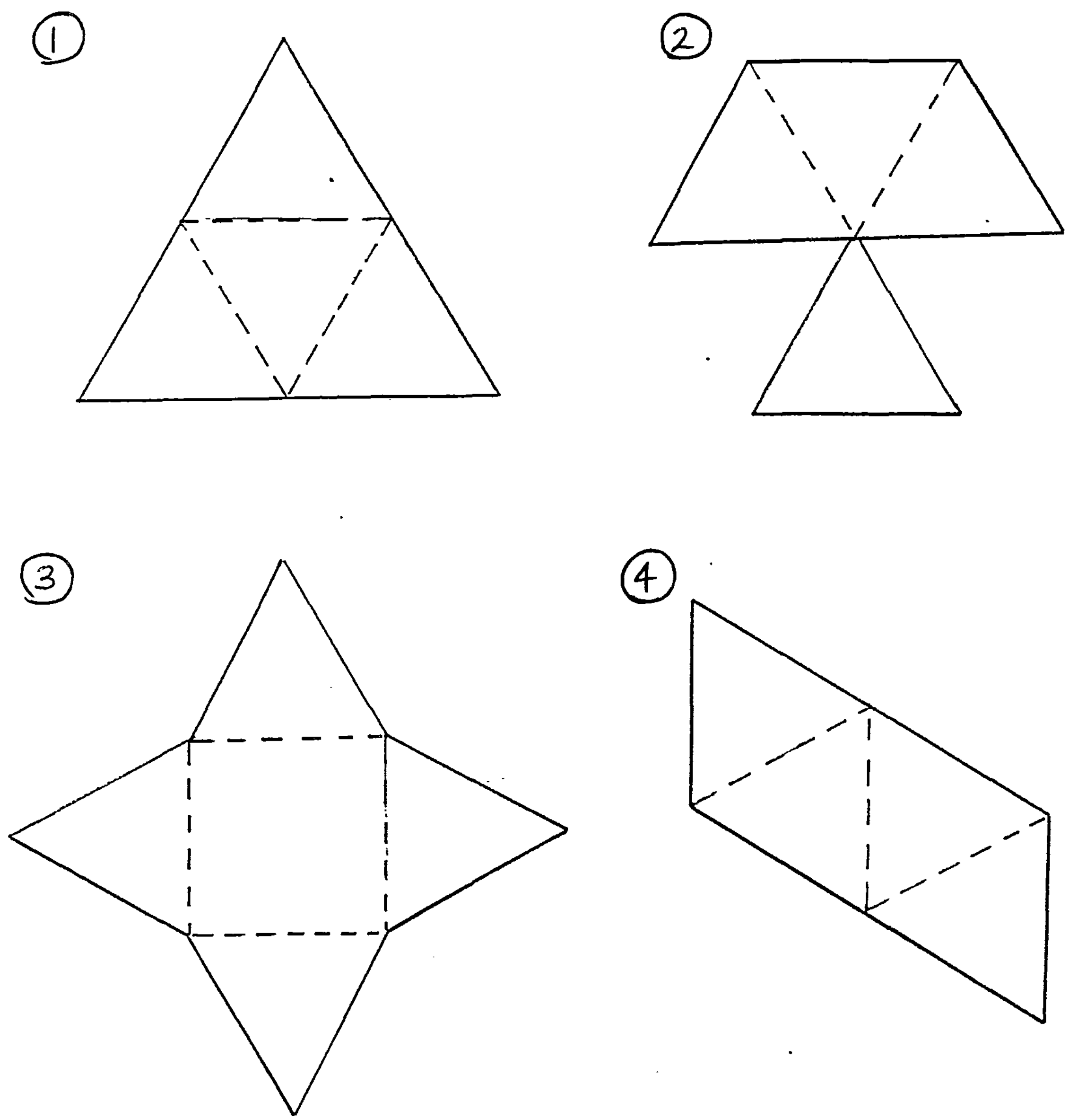


(4)



Appendix 1 - Item 3

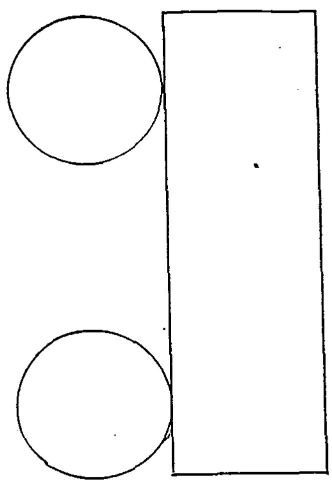
Geometric Forms - Participant is shown a rectangular prism covered in paper and must choose the two-dimensional picture response which shows how the paper would look if it was taken off the shape and laid out flat (visualization). The correct answer is choice 3.



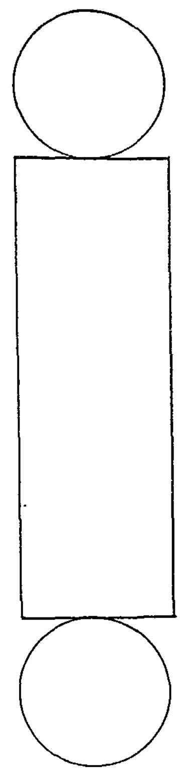
Appendix 1 - Item 4

Geometric Forms - Participant is shown a cylinder covered in paper and must choose the two-dimensional picture response which shows how the paper would look if it was taken off the shape and laid out flat (visualization). The correct answer is choice 4.

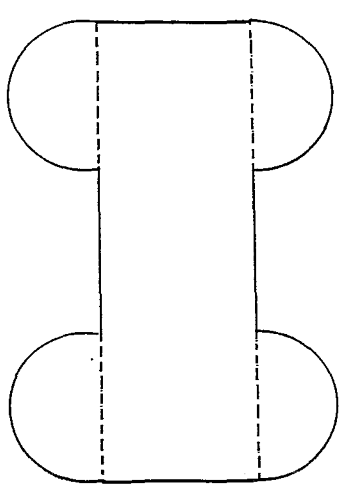
(1)



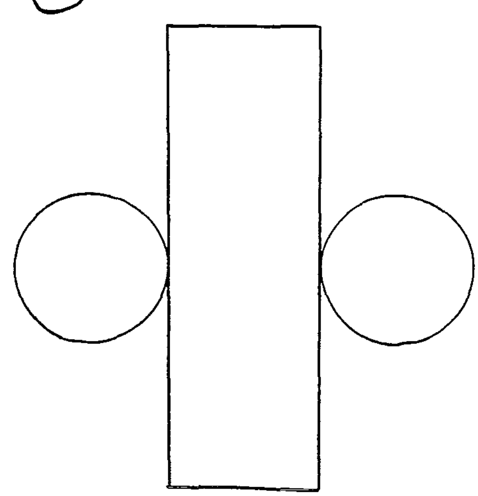
(2)



(3)



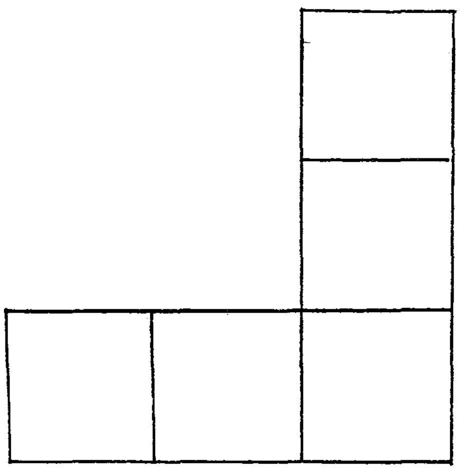
(4)



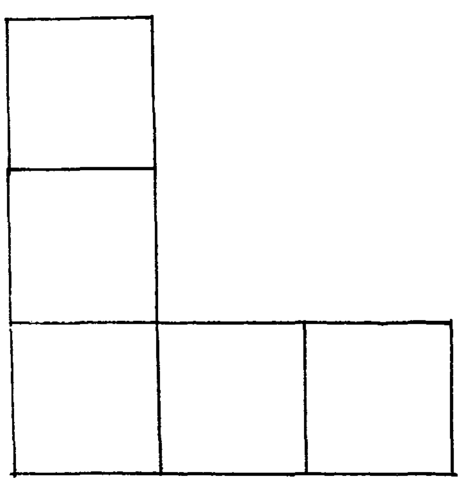
Appendix 1 - Item 5

House Plans - Participant must construct a "house" with cubes that matches two two-dimensional views, a frontal view and a aerial view (visualization).

F R O N T A L   V I E W



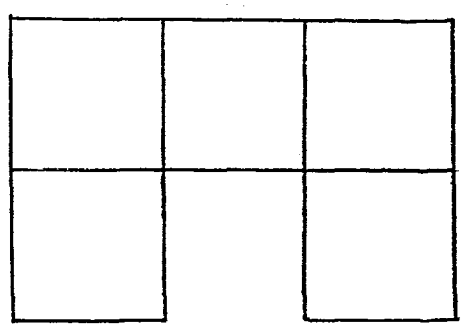
A E R I A L   V I E W



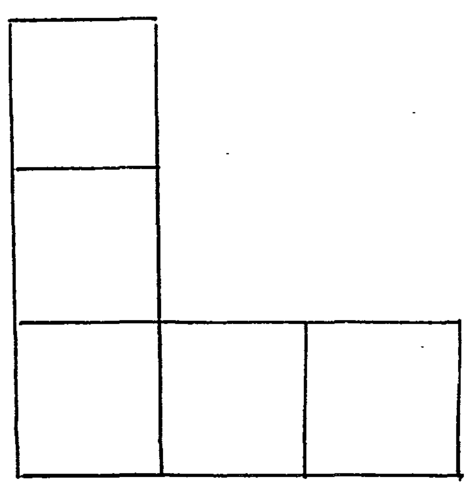
Appendix 1 - Item 6

House Plans - Participant must construct a "house" with cubes that matches two two-dimensional views, a frontal view and a aerial view (visualization).

F R O N T A L   V I E W



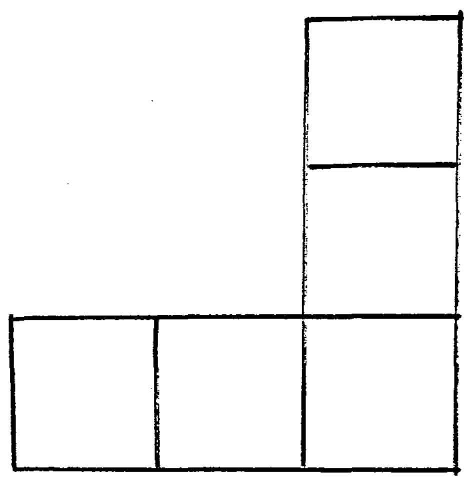
A E R I A L   V I E W



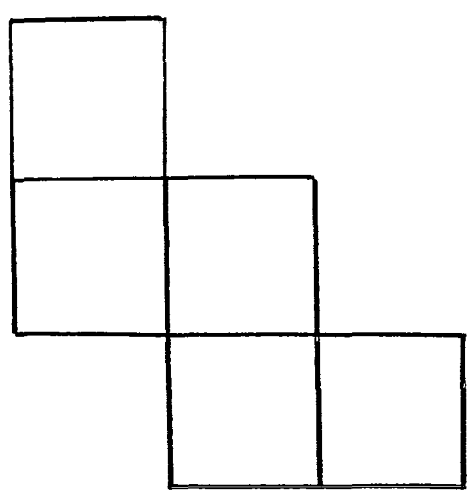
Appendix 1 - Item 7

House Plans - Participant must construct a "house" with cubes that matches two two-dimensional views, a frontal view and a aerial view (visualization).

F R O N T A L   V I E W



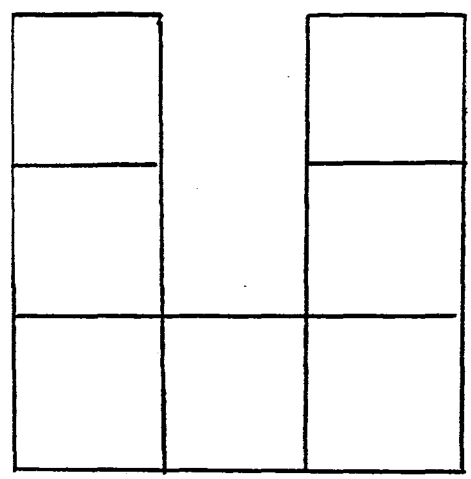
A E R I A L   V I E W



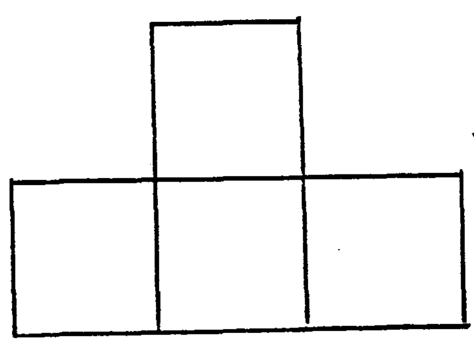
Appendix 1 - Item 8

House Plans - Participant must construct a "house" with cubes that matches two two-dimensional views, a frontal view and a aerial view (visualization).

F R O N T A L   V I E W



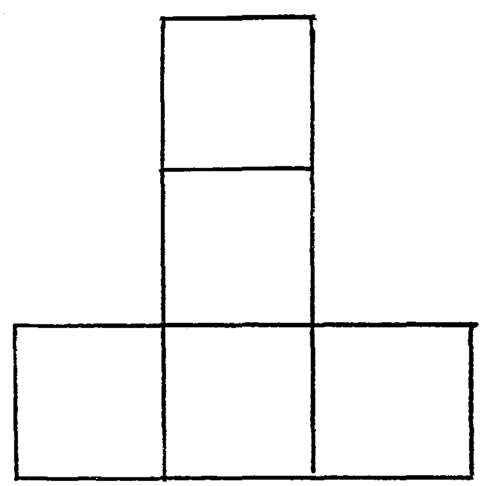
A E R I A L   V I E W



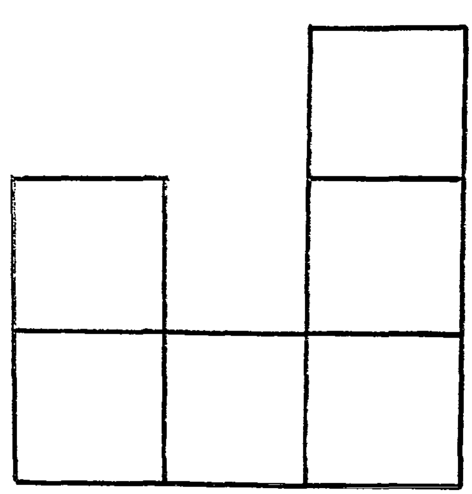
Appendix 1 - Item 9

House Plans - Participant must construct a "house" with cubes that matches two two-dimensional views, a frontal view and a aerial view (visualization).

F R O N T A L   V I E W



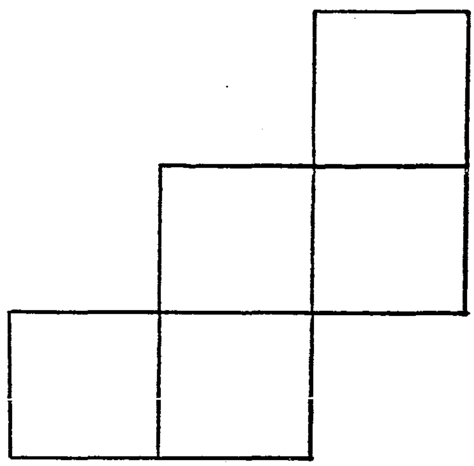
A E R I A L   V I E W



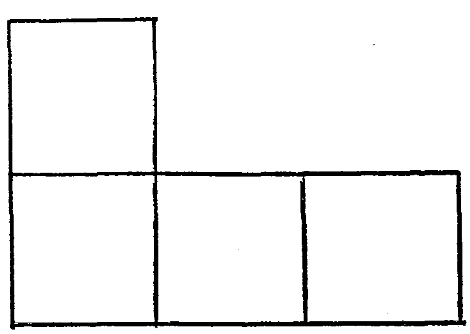
Appendix 1 - Item 10

House Plans - Participant must construct a "house" with cubes that matches two two-dimensional views, a frontal view and a aerial view (visualization).

F R O N T A L   V I E W



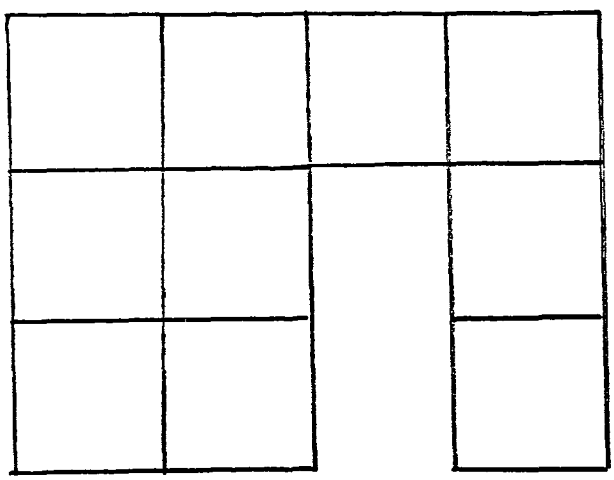
A E R I A L   V I E W



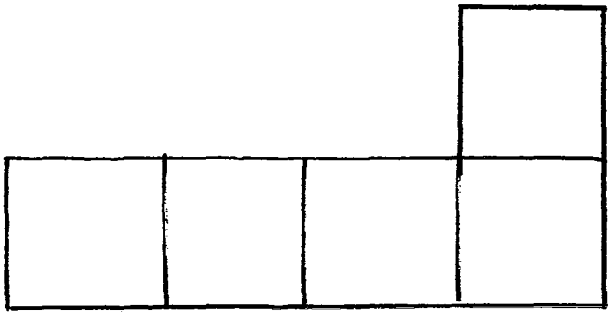
Appendix 1 - Item 11

House Plans - Participant must construct a "house" with cubes that matches two two-dimensional views, a frontal view and a aerial view (visualization).

FRONTAL VIEW

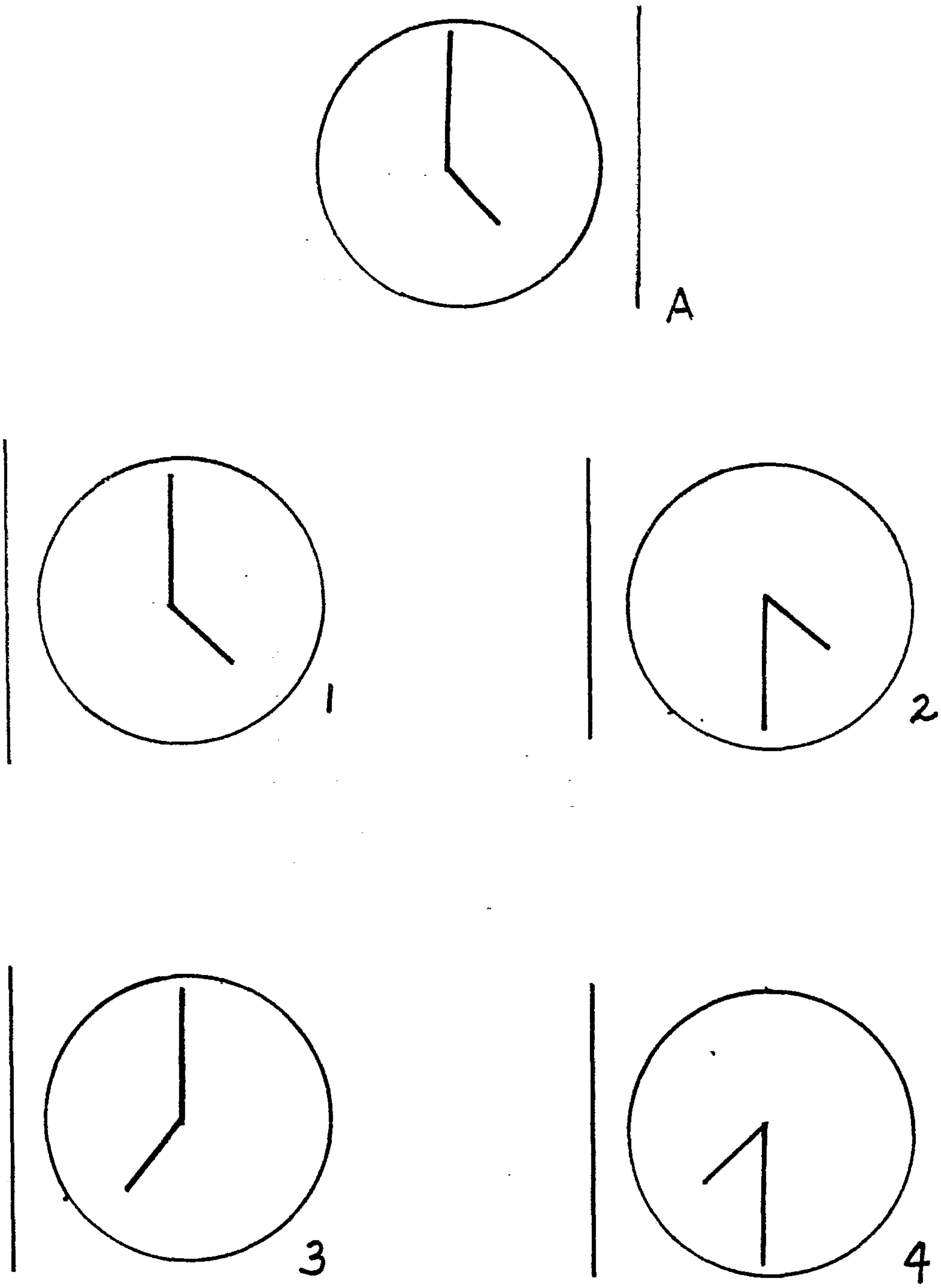


AERIAL VIEW



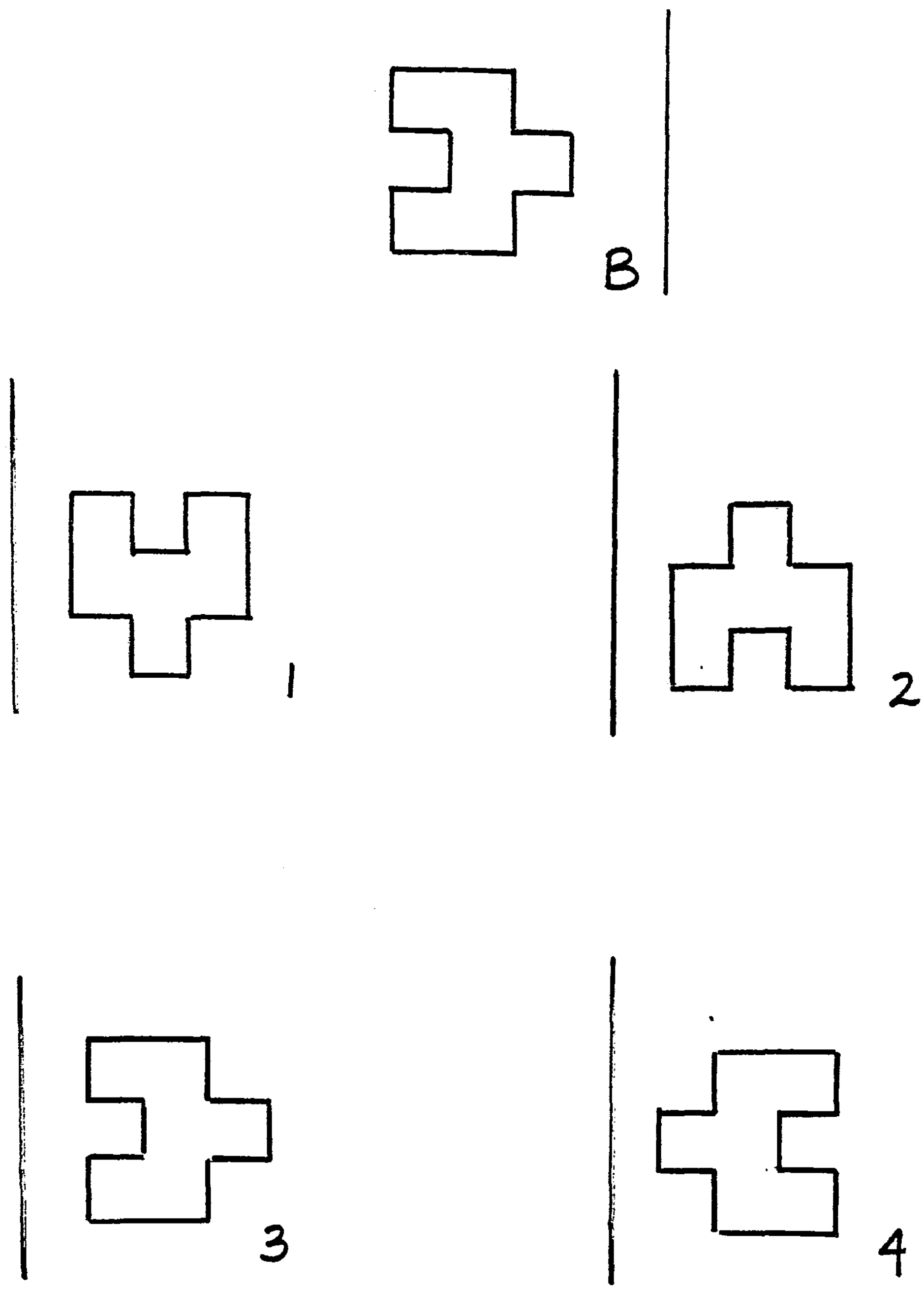
Appendix 1 - Item 12

Mirror Images - Participant is asked to identify the figure which is the mirror image of the target stimulus (rotation). The correct answer choice is 3.



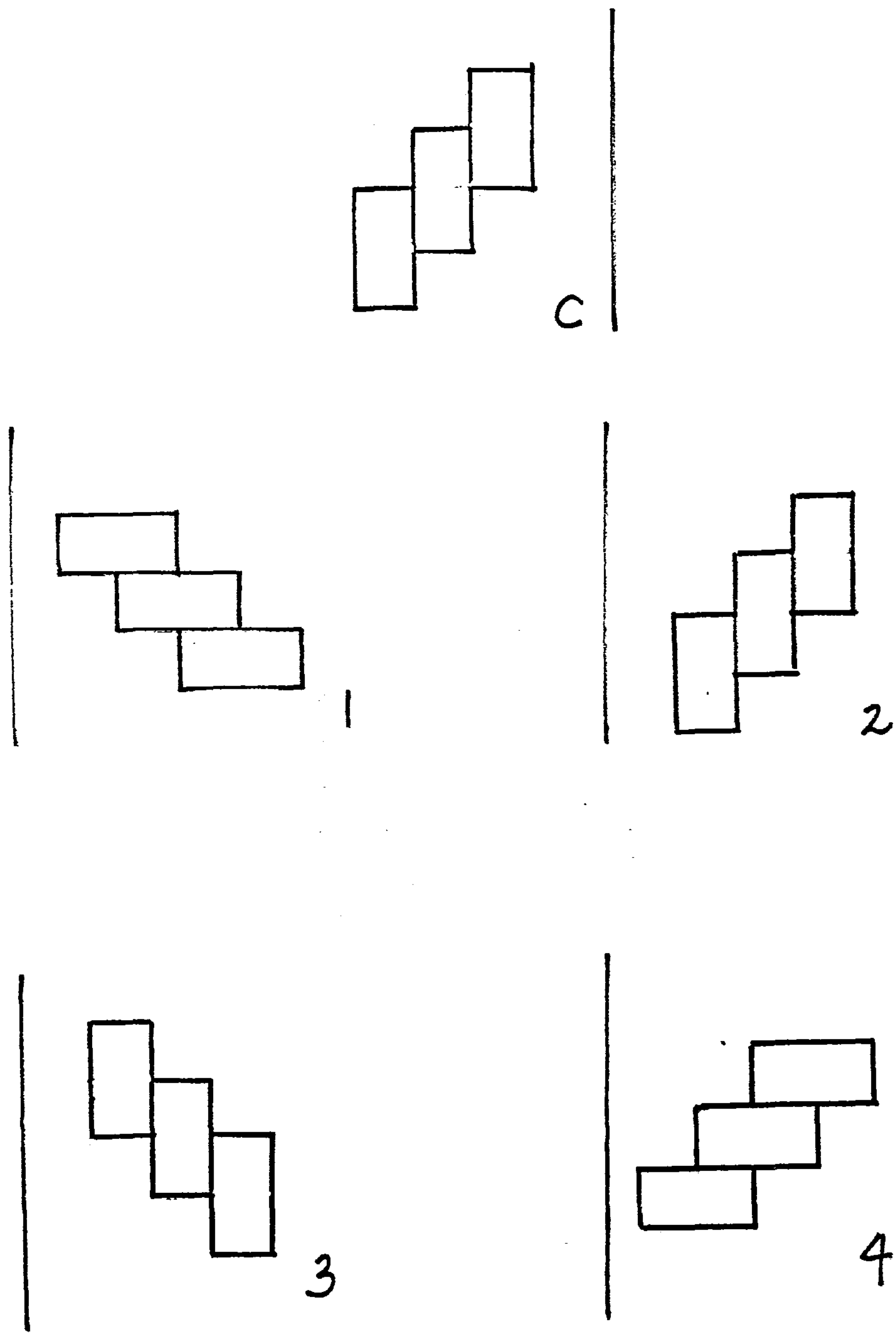
Appendix 1 - Item 13

Mirror Images - Participant is asked to identify the figure which is the mirror image of the target stimulus (rotation). The correct answer choice is 4.



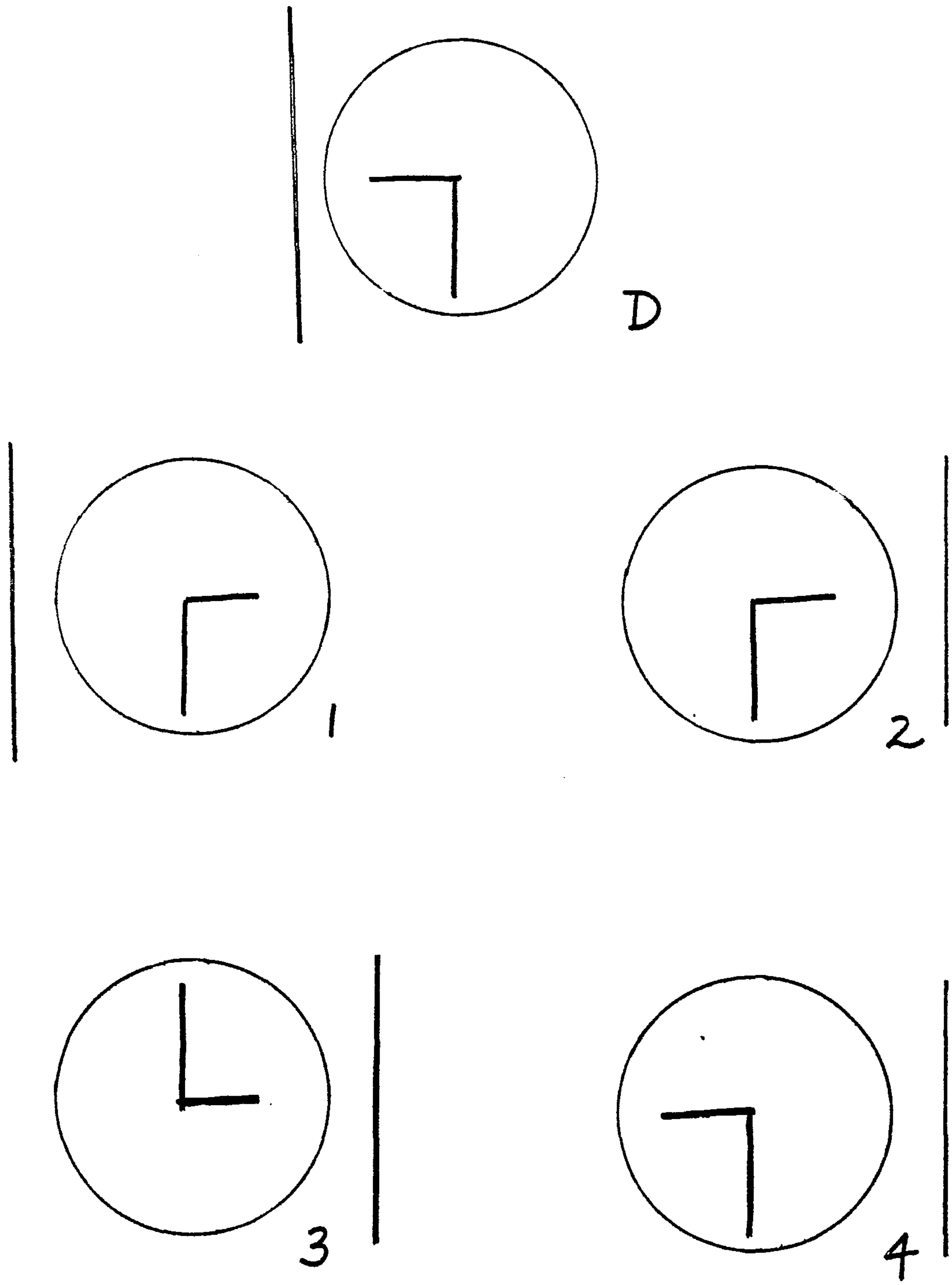
Appendix 1 - Item 14

Mirror Images - Participant is asked to identify the figure which is the mirror image of the target stimulus (rotation). The correct answer choice is 3.



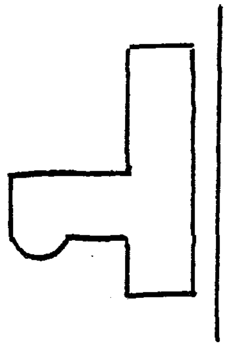
Appendix 1 - Item 15

Mirror Images - Participant is asked to identify the figure which is the mirror image of the target stimulus (rotation). The correct answer choice is 2.

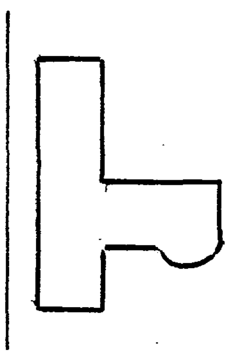


Appendix 1 - Item 16

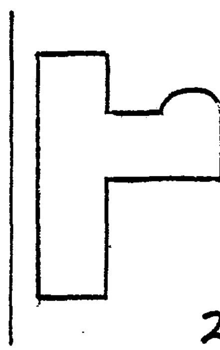
Mirror Images - Participant is asked to identify the figure which is the mirror image of the target stimulus (rotation). The correct answer choice is 1.



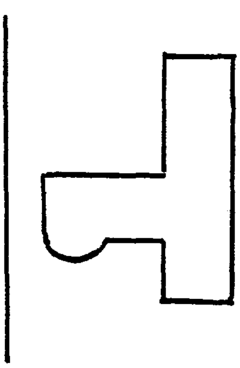
E



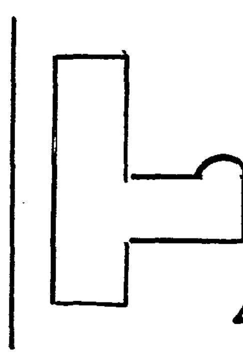
1



2



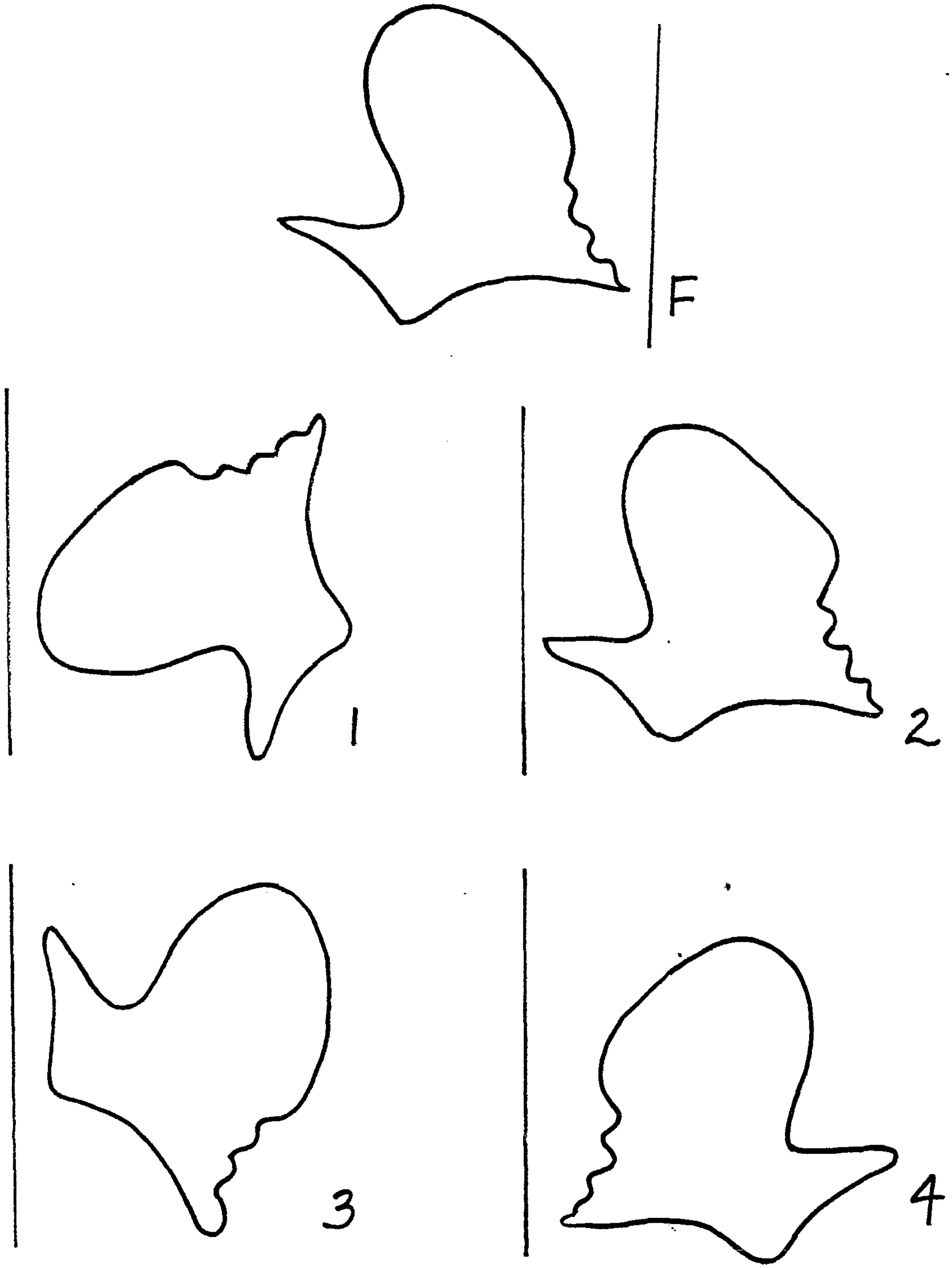
3



4

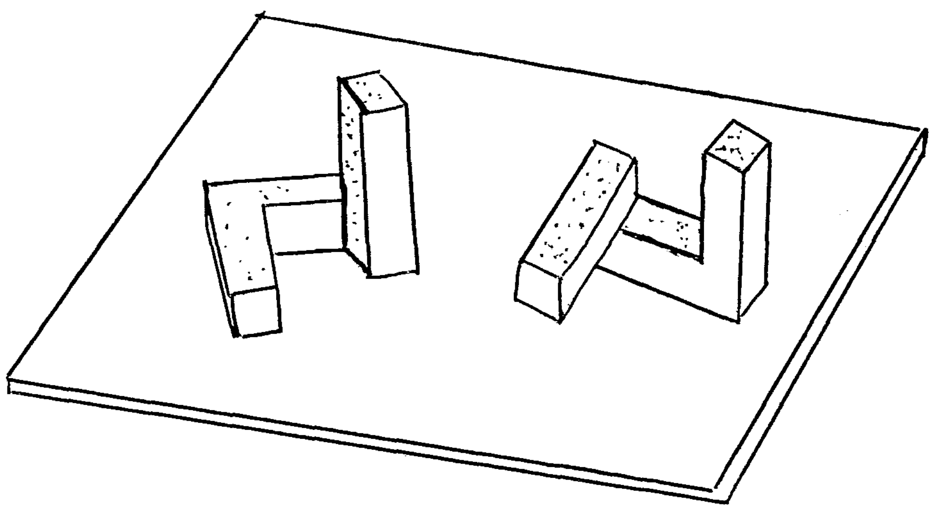
Appendix 1 - Item 17

Mirror Images - Participant is asked to identify the figure which is the mirror image of the target stimulus (rotation). The correct answer choice is 4.



Appendix 1 - Item 18

Mental Rotations - Participant must mentally rotate two shapes constructed from cubes and determine if they are the same or different. One example is shown below. The correct answer is "same."



Appendix 2

C O R O N A T I O N   S C H O O L

Please complete and return the following form:

I give ______________________________ my permission to be part of the music and math study conducted by Mr. Neeb.

Signed: ______________________________

Please complete the following survey:

1. Has your child ever received music lessons by an instructor outside of school?

   yes _____   no ______

2. If yes, approximately for how many months did your child take music lessons (or is currently taking music lessons?)

   ___________ months

3. What type of lessons were they?

   voice ________

   musical instrument (specify) ___________

4. How often would your child listen to recorded music in your home?

   [ ] everyday

   [ ] a few times a week

   [ ] once a week

   [ ] rarely