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# A Comparison of 3-D Mental Models in Solving Visuospatial Problems between Gifted and Nongifted High School Students†

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**Abstract**

Construction of three-dimensional mental models is often required for solving many spatially related problems. In three experiments, we examined whether differences existed in the 3-D mental models constructed by gifted and nongifted high-schoolers. In Experiment 1, subjects were presented with 2-D orthographic projections of a 3-D object and were asked to judge whether or not the projected views were compatible with one another The results indicated that the subjects experience more difficulty in construction when dealing with objects of higher complexity. However, without explicit instructions, neither gifted nor nongifted high school students seemed to engage in constructing 3-D mental models while solving the compatibility task. In Experiment 2, subjects were explicitly told to construct 3-D mental models while viewing 2-D orthographic projections. The results showed that gifted students spent less time on construction than the nongifted students did, and that male students spent less time than their females counterparts. Experiment 3 examined the possibility to mentally rotate a 3-D model during construction. Gifted students performed more accurately than nongifted students in identifying 3-D objects. Similar differences were also found between male and female students. These results suggest that gifted students are more efficient at constructing 3-D mental models than nongifted students, when they are asked to do so. The relationship between gender difference and giftedness is also discussed.

**Key Words:** giftedness, 3-D mental models, gender difference

## I. Introduction

Given that one of the major goals of the natural and biological sciences is to understand the structure of the physical world, macro as well as micro in scale, it is not unreasonable to assume that spatial abilities may play an important role in an individual's scientific and mathematical aptitudes (Benbow, 1988, 1992; Geary, 1996). During the past two decades, many studies have attempted to understand the relationship between spatial abilities or mathematical abilities and sex differences; the relationship between spatial abilities and scientific aptitude per se, however, has not been adequately addressed (Geary, 1996; Horowitz & O'Brien, 1985; Sternberg & Davidson, 1986; Voyer, Voyer, & Bryden, 1995). The general assumption appears to be that since there are many more men than women going into fields such as the sciences and engineering, and that there are also demonstrable differences in spatial and mathematical abilities

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between males and females (Geary, 1996; Voyer, Voyer, & Bryden, 1995), therefore, the relationship between scientific and mathematical aptitudes and spatial abilities must exist and be self-evident. However, more direct evidence is needed to prove these assumptions. Evidence is particularly needed when we consider spatial abilities that are used for constructing a three-dimensional (3-D) mental model from two-dimensional (2-D) displays, a task frequently encountered in spatial ability tests measuring spatial visualization, such as paper folding, cube counting, and spatial views (Levy & Levy, 1992). The main goal of our study was to reduce the gap in our knowledge in this regard.

The process of constructing 3-D mental structures is essential in everyday life. We usually make inferences to figure out the mapping relation between external information and its internal representations. This mapping can be very selective if some of the external features are more salient than others in that the corresponding internal representations are primarily representations of those salient features. There are also cases, however, in which mental representations of structure in the world may correspond well to those of external ones in a depictive or analog sense (Kosslyn, 1994; Shepard, 1994). As demonstrated by Cooper and her colleagues, people may use different strategies to solve spatially related problems in that they may or may not mentally construct the corresponding 3-D structures (Cooper, 1988, 1989).

In order to understand the process and the nature of constructing 3-D mental models, we recently conducted a series of experiments in which subjects were given problems that required constructing a 3-D mental model of an object while viewing its 2-D orthographic projections. We then presented isometric drawings of 3-D objects to probe the internal representations that were created in the course of problem solving (Huang & Shyi, 1994, 1995, 1997; Shyi & Huang, 1995). This procedure was adopted from that used in a number of studies reported by Cooper and her colleagues (Cooper, 1988,1989, 1990, 1991; Cooper & Mumaw, 1985). In Cooper's (1988, 1989) studies, subjects were first asked to perform a compatibility task, in which they were shown a set of orthographic projections of the top, front, and right views of a 3-D target object. The three orthographic projections were presented in two consecutive slides; the first slide contained the top and front sides and a blank placeholder for the right side, and the second slide contained only the projection of the right side. Subjects were asked to judge whether or not the orthographic projections presented in the two slides were compatible with one another in the sense that the same object was portrayed by the projected views.

Subjects may be able to solve compatibility problems via at least two different strategies. First, they may merely examine the local features contained in each of the three projected views and try to determine if matches exist among those local features. Or, they may opt to construct a 3-D mental model of the likely object from the first two projected views and then verify the compatibility of the third projected view against the constructed 3-D model. In order to gain insight into the strategies that subjects actually used, Cooper asked them to perform an unexpected recognition task, following the compatibility task. In a forced-choice format, two isometric drawings of 3-D objects were shown side by side in each trial, and subjects had to decide which object was the one whose orthographic projections presented in the compatibility task. Evidence suggesting that the subjects indeed were constructing 3-D models when solving the compatibility problems was indicated by the fact that the contingent probability of correctly choosing an isometric view of an object in the recognition task, given that the object's corresponding compatibility problem was solved correctly (PCC), was greater than the contingent probability when the compatibility problem was not solved correctly (PCI) (Cooper, 1990).

Following Cooper's (1988, 1989, 1990) paradigm, Huang and Shyi (1994, 1995; Shyi & Huang, 1995) used a $3 \times 3 \times 3$ based cube, consisting of 27 small blocks, and removed 2, 5, or 8 blocks from the base cube to construct stimulus objects varying in complexity. They showed that the possibility of constructing a 3-D mental model was closely related to a 3-D object's rated complexity (and the rated complexity of its corresponding 2-D orthographic projections). For example, subjects were more likely to use a constructive strategy for solving compatibility problems with orthographic projections of less complex objects than they were to do so when more complex objects were used. They also found that the constructed 3-D models were incomplete in that more structural details were preserved at the focal attentional region during problem solving than in the unfocused area (Huang & Shyi, 1997). Furthermore, 3-D models for an object with low complexity appeared to be more complete than those for an object with high complexity. In the present study, we aimed to extend Cooper's and Huang & Shyi's studies to compare the abilities in constructing 3-D mental models between scientifically gifted high school students and their nongifted counterparts. To that end, three experiments were performed. In Experiment 1, we examined whether gifted and nongifted students differed in their overall performance in solving compatibility problems. In Experiment 2, we explicitly asked subjects to construct 3-D models of an object while viewing its 2-D orthographic projections. In particular, we wanted to know whether or not gifted and nongifted high school students would differ in how complete their constructed 3-D models were. Finally, in Experiment 3, we examined whether or not mental rotation was required for constructing 3-D models and if so, whether or not gifted and nongifted students would also differ in that regard.

## II. Experiment 1

The purpose of Experiment 1 was twofold: First, we attempted to see whether or not our findings with college students (Huang & Shyi, 1994, 1995; Shyi & Huang, 1995) could be generalized to high school students. Our studies have shown that as the complexity of an object increases, the likelihood of solving compatibility by constructing 3-D mental models decreases. Likewise we expected to find, among high-schoolers, stronger evidence for 3-D models for objects with low and perhaps medium complexity rather than for those with high complexity. Second, we wanted to see whether differences in strategy existed between gifted and nongifted high school students in solving spatial problems involving 3-D model construction.

### 1. Method

*A. Subjects*

Thirty-four high school students from Chia-Yi Provincial High School and Chia-Yi Girls High School, all in the second year of high school, served as subjects in this experiment; each subject was rewarded with a gift of NT$100 at the conclusion of their participation. Sixteen of them were scientifically gifted students, nine males and seven females. The students were identified as scientifically gifted because of their outstanding academic performance in courses covering natural sciences (physics and chemistry), biology, and mathematics. These students were selected and placed together to form a unique class in each school as a result of their academic performance. Eighteen were nongifted students, half males and half females. The nongifted students were randomly selected from the classes that were not identified by the respective schools as gifted. All the subjects had vision that was normal or corrected to normal.

*B. Stimulus Materials and Apparatus*

The stimulus objects used in Experiment 1 were those constructed and used in our previous study (Huang & Shyi, 1994, 1995; Shyi & Huang, 1995), consisting of a set of 30 objects representing three levels of complexity. There were 10 objects for each level of complexity, and the mean rated complexity was 28.19 (*SD*=8.16) for the low group, 44.12 (*SD*=10.82) for the medium group and 70.05 (*SD*=10.49) for the high group. (See Shyi & Huang, 1995, for a complete exposition of the rating and selection procedure.) The least and most complex objects of each complexity group, 6 objects in total, were used for practice. As a result, eight objects in each group, totaling 24 objects, served as the target stimuli (*M*'s=28.62 for the low group, 44.00 for the medium group, and 69.44 for the high group, respectively). For each target object, we also constructed and selected a corresponding distractor to be used in the isometric recognition test because the test took the form of two-alternatives-forced-choice (2AFC).

For each target object, we first constructed 6 possible distractors, each sharing an orthographic view (top, front, or right) with the target. Similarity and complexity ratings were taken, and the distractor with medium similarity and complexity comparable to its corresponding target was selected. The mean complexity rating for the distractors was 22.98 (*SD*=4.41) for the low group, 35.25 (*SD*=5.05) for the medium group, and 57.24 (*SD*=5.91) for the high group, which did not reliably differ from the mean complexity of their corresponding targets (Huang & Shyi,1994; Shyi & Huang, 1995). Isometric drawings of distractors and their right orthographic view were used in the present experiment. An example of the isometric (3-D) drawing and orthographic projections of a target object along with the isometric drawing of its distractor and the right orthographic view of the distractor is shown in Figure 1.

*C. Procedure*

Subjects participated in the experiment individually in a group test session that took place in the computer room of the respective school. Each subject had access to his or her own computer as the apparatus--an Acer 80486 PC, equipped with a color monitor--for stimulus presentation and response recording. Typically, the testing session consisted of a group of 14 to 16 students in which half were from the gifted class and the other half were from the nongifted class. Subjects were asked to perform two tasks, an orthographic compatibility task and an in-

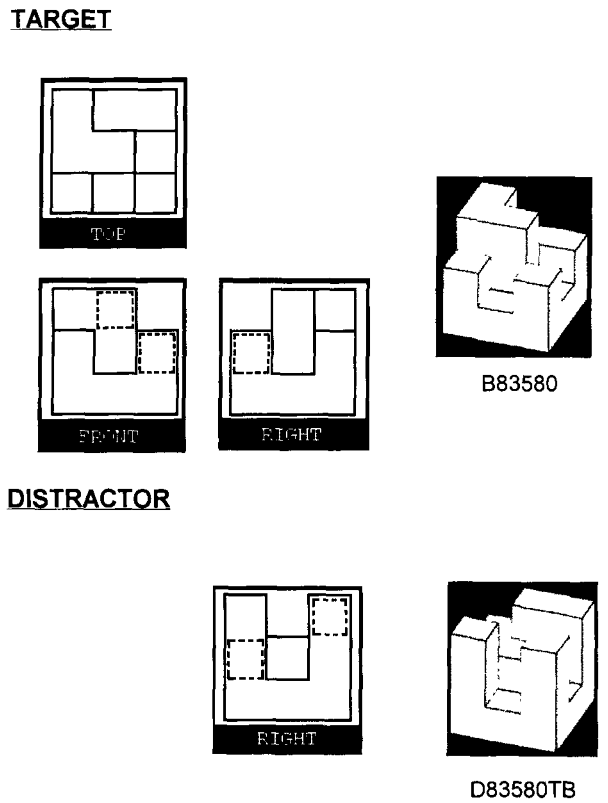


**Fig. 1.** An example showing the isometric (3-D) drawing of a target object and its orthographic projections (top panel) along with the isometric drawing of its distractor and the right orthographic view of the distractor (bottom panel) used in Experiment 1.

cidental recognition task. In each trial in the orthographic compatibility task, they were shown in the first frame the top and front view of a target object and an empty placeholder representing the right view, and in the second frame they were shown only the projection representing the right view. The subjects were asked to judge whether or not those three orthographic views could have arisen from the same object. They were allowed to inspect each of the two frames ad lib until they could reach an answer. At this point, they pressed designated response keys on the computer keyboard to indicate their judgments. Response latencies were recorded from the onset of the first frame to the depression of a response key; the proportion of time spent on each frame was also computed. Half of the trials entailed "yes" responses in that the third view was compatible with the previous two views; the other half entailed "no" responses because the third view was incompatible with the first two.

Immediately following the compatibility task, the subjects were given a previously unmentioned recognition task. In each trial of the recognition test, a pair of isometric drawings of 3-D objects were presented, and the subjects judged for which object orthographic projections had been presented earlier in the compatibility task. Both the compatibility and recognition tasks contained a total of 24 trials.

**Table 1.** The Mean Proportion of Correctly Solving Compatibility Problems as a Function of Gender, Giftedness, and Object Complexity in Experiment 1 ($N$=34)

| | Gifted | | Nongifted | |
|---|---|---|---|---|
| Complexity | M | F | M | F |
| Low | .87 (.24) | 79 (.26) | .85 (.18) | .76 (.14) |
| Medium | 89 ( 10) | .77 ( 18) | .83 (.14) | .74 (.18) |
| High | .79 (.09) | .64 (.24) | .74 (.22) | .61 (.10) |

*Note*: The numbers in parentheses are standard deviations; $M$=males, $F$=Females

## 2. Results and Discussion

### *A. Orthographic Compatibility Task*

The overall accuracy in the compatibility task was 77.5%, which was almost was identical to the results obtained by Cooper (1990) (76.5%) and by Huang & Shyi (1994) (77%). The means and standard deviations for each condition are listed in Table 1. Subjects' accuracy in solving compatibility problems was submitted to a 2 (sex)×2 (class: gifted or nongifted) x 3 (complexity) mixed analysis of variance (ANOVA). The main effect of sex approached significance, $F(1,30)=5.17$, $MSe=.06$, $p<.05$, indicating that male subjects ($M$=83%) outperformed their female counterparts ($M$=71%); the main effect of class failed to reach significance, $F<1$. As in the study by Huang & Shyi (1994; Shyi & Huang, 1995), the main effect of complexity was highly significant, $F(2, 60)=8.42$, $MSe=.02$, $p<.001$. Further analyses indicated that the subjects did equally well with objects of low and medium complexity ($M$'s=82% and 81%, respectively), and did significantly worse with those of high complexity ($M$=69%). The difference between the gifted and nongifted students was not significant, however, $F<1$. No other main effects or interaction were significant, $F$'s<1 or $p$'s>.35.

The subjects on average took about one minute (60.51 s) to correctly solve a problem, which was about the same amount of time found by Huang and Shyi (1994) (62.10 s), where college students were used. The mean solution times and their standard deviations for each condition are listed in Table 2. The same ANOVA reveals only one reliable main effect: complexity, $F(2,60)=21.08$, $MSe=231.04$, $p<.001$. The subjects spent more time solving problems of high complexity ($M$=74.46 s) than solving problems of low and medium complexity ($M$'s=52.22 s and 54.85 s, respectively); the latter two did not differ from each other, $F<1$. No other main effects nor any of the interactions were found to be significant, $F$'s<2.45 or $p$'s>.13.

*B. Incidental Recognition Test*

The average accuracy of recognition was 64%, replicating that obtained by Huang and Shyi (1994) (.63), but lower than that obtained by Cooper (1990) (.85). Recognition accuracies were submitted to the same mixed ANOVA as before. Again, only the main effect of complexity was reliable, $F(2,60)=7.58$, $MSe=.03$, $p=.0012$, reflecting the fact that the subjects recognized more objects of low and medium complexity ($M$'s=.69 and .68) than of high complexity ($M$=.54).

*C. Contingency Probability*

The critical evidence for claiming that subjects solved the compatibility problems by constructing a 3-D mental model from 2-D displays was that the probability of correctly recognizing a target object when its corresponding compatibility problem was correctly solved (PCC) was greater than the probability of correctly recognizing a target object when its compatibility problem was not correctly solved (PCI) (Cooper, 1990; Huang & Shyi,1994; Shyi & Huang, 1995). The average PCC was .65 and average PCI was .59. Although the average PCC was reliably greater than chance, $t(32)=7.36$, $p<.001$ and average PCI was not, $t(32)=1.85$, $p>.08$), their difference failed to reach significance, $t(32)=1.15$, $p>.20$. Furthermore, when the overall PCC and PCI data were submitted to a 2 (sex) × 2 (class) × 2 (type: PCC or PCI) mixed ANOVA, none of the main effects nor any interactions were found to be reliable ($F$'s<1). These results do not allow us to conclude with confidence that high-schoolers were actually engaged, at least for some trials, in constructing 3-D models when they were solving the compatibility problems. Moreover, there is no indication that gifted students were more inclined to adopt a constructive strategy than their nongifted counterparts in solving those problems.

**Table 2.** The Mean Time (in sec) Spent on Solving Compatibility Problems as a Function of Gender, Giftedness, and Object Complexity in Experiment 1 ($N$=34)

| | Gifted | | Nongifted | |
|---|---|---|---|---|
| Complexity | M | F | M | F |
| Low | 45.33 | 52.22 | 49.32 | 61.99 |
| | (27.11) | (14.28) | (15.66) | (24.01) |
| Medium | 46.91 | 62.19 | 50.54 | 61.41 |
| | (13.95) | (16.48) | (22.65) | (18.26) |
| High | 77.61 | 73.84 | 67.00 | 79.24 |
| | (20.18) | (17.96) | (25.83) | (24.98) |

*Note*: The numbers in parentheses are standard deviations; M = males, F=Females.

It is worth noting, nonetheless, that nearly half of high-school students who participated in Experiment 1, like the college subjects we tested before, exhibited missing data on PCIs across three levels of complexity ($N$=16) (Huang & Shyi, 1994, 1995; Shyi & Huang, 1995). (Note that PCIs would be incomputable if subjects failed to give any incorrect answers for the compatibility problems; see Shyi & Huang, 1995, for further discussion.) As in our previous studies, we instead analyzed subjects' PCC data via a 2 (sex) × 2 (class) × 3 (complexity) mixed ANOVA. The main effect of complexity was found to be significant, $F(2, 60)=6.98$, $MSe=.05$, $p<.01$. Objects of low (.70) and medium (.70) complexity had higher PCCs than did those of high complexity (.52), $F(1,30)=11.06$, $MSe=.04$, $p<.01$ for low versus high, and $F(1,30)=9.35$, $MSe=.05$, $p<.01$ for medium versus high, respectively. No other effects were reliable, $F$'s<1.3, $p$'s>.28. Previously, we have taken such a finding to suggest that subjects were more inclined to use a constructive strategy in solving compatibility problems with low and medium complexity than in solving problems with high complexity. In the present study, however, this conclusion must be drawn with caution because the overall PCC did not differ reliably from the overall PCI, which gave no clear clues that compatibility problems were solved by constructing 3-D mental models.

In summary, the results of Experiment 1 to a large extent replicated our previous findings obtained with college students, and this was particularly the case insofar as the effect of object complexity is concerned. We found reliable effects of object complexity on a number of measures such as accuracy of compatibility task, time spent on solving problems, accuracy of recognition rate, and contingency probability of PCC. These findings suggest that the high school students, like their college counterparts, had a more difficult time solving compatibility problems with high complexity. Unlike the college subjects, however, the high-school subjects exhibited no clear indication that they would voluntarily engage in constructing 3-D models in solving those problems; as a consequence, no reliable difference in problem solving strategy could be expected between gifted and nongifted students.

The fact that the high-school subjects did not voluntarily adopt constructive strategies to cope with the compatibility task may not be too surprising given that, in the instructions provided for the task, there was no mention of and no clues were given that a constructive strategy would be useful for solving compatibility problems. In fact, Cooper reported in her initial studies that she was surprised by the fact that her (college) subjects voluntarily engaged in constructing 3-D mental models despite that all problems could have been solved using local features matching strategies (Cooper, 1988, 1989). Therefore, what we demonstrated in Experiment 1 was that the high-school students, unlike college students, faithfully followed the instructions they received for solving the compatibility task and were not motivated to use any alternative strategies that were not mentioned or implied in the instructions. We, therefore, decided for the following experiments to change the compatibility task to a *construction* task, where subjects were explicitly asked to construct 3-D mental models while viewing 2-D orthographic displays (Huang & Shyi, 1995, 1997).

## III. Experiment 2

In Experiment 1, we failed to find a difference in performance between gifted and nongifted high school students. Moreover, there was no evidence suggesting that students engaged in 3-D model construction to solve problems when they were not explicitly instructed to do so. In Experiment 2, we therefore explicitly instructed our subjects to engage in constructing 3-D mental models while viewing the corresponding 2-D displays, with the hope that the construction task would allow us to answer the questions we raised with regard to Experiment 1. Another goal in Experiment 2 was to examine the characteristics of the 3-D models constructed by the high-school students. In particular, we wanted to know whether or not the 3-D models constructed by high-schoolers would exhibited the same properties as did those constructed by the college students. As mentioned earlier, we have found in previous studies that object complexity affected the completeness of the constructed 3-D models in that more structural details were preserved for models of objects with low complexity than those of objects with high complexity. Furthermore, more structural details were preserved in the focal-attention region than in the peripheral region (Huang & Shyi, 1995, 1997). Here, we hoped to see whether the same conclusions could be drawn for high-school subjects and whether or not the 3-D models constructed by gifted students would differ from those constructed by their nongifted counterparts.

### 1. Method

#### A. Subjects

Thirty-five high-school students, 19 males (9 gifted and 10 nongifted) and 16 females (8 gifted and 8 nongifted) from the same classes and schools as in Experiment 1, participated in Experiment 2. As in Experiment 1, each subject was rewarded with a NT$100 gift for their participation. All the subjects had vision that was normal or corrected to normal.

#### B. Stimuli Materials and Apparatus

In order to test our predictions regarding the nature of the mental models constructed, we created a new set of stimulus objects. To ensure that the subjects could perform 3-D construction, we used stimulus objects that were of moderate level of complexity so as not to defeat a constructive strategy. Twenty-six stimulus objects were chosen from the original set of 135 objects; all were of the kind in which 5 blocks were removed from the base cube. Half of them had relatively low complexity ratings ($M$=29.61), and 13 had medium to high complexity ratings ($M$=50.82) (Huang & Shyi, 1995, 1997). For each target object, two distractors were then created. The *c-distractors* were generated by adding or removing one or two blocks from the target object in the intersecting area specified by the top and front view, and the *p-distractors* were created by adding or removing one or two blocks in a region outside the intersecting area (see Huang & Shyi, 1995, for a detailed description of stimuli construction and selection). These distractors were created to test the prediction that when subjects make an error in misidentifying the target object, they are more likely to pick the p-distractor than the c-distractor because the constructed mental model is more clearly specified in the focal region than in a peripheral region. Examples of a target object and its matching c- and p-distractors are illustrated in Figure 2.

For a given target, its c- and p-distractors were altered by the same amount as much as possible to the same degree. The target objects and their distractors were rated by another group of 10 subjects to ensure that, overall, the two sets of stimuli had comparable complexity ($M$'s 38.58 for targets and 39.20 for

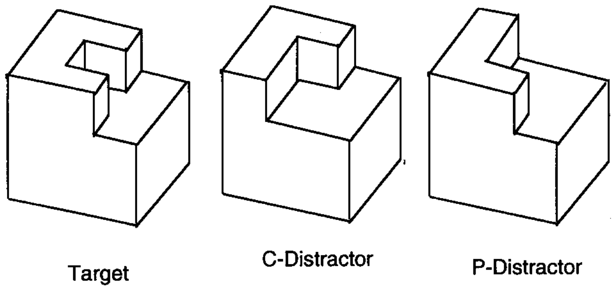


**Fig. 2.** Examples illustrating a target object and its respective c-distractor and p-distractor, and their orthographic projections in Experiment 2. Note how the two distractors differed from the target either centrally or peripherally.

distractors). Finally, we drew a set of two orthographic projections (top and front views) for each target object and their distractors. The same apparatus used in Experiment 1 was used here for stimulus presentation and response recording.

*C. Procedure*

As before, subjects were tested individually in group sessions as in Experiment 1. They were asked to perform two tasks. In the first task, the subjects were shown, in each trial, a pair of orthographic projections (top and front view) and were explicitly told to form or construct a mental image of a 3-D object that would correspond to the presented 2-D views. As Cooper's (1990) and Huang & Shyi's (1994, 1995) studies have demonstrated, only two orthographic views were needed to uniquely determine the corresponding 3-D object, and the third orthographic view was primarily for the purpose of verification once the 3-D model was constructed. Upon completing the construction of a mental model, the subjects pressed the spacebar on the keyboard, and an array of three isometric drawings of 3-D objects appeared on the screen. One was the target, corresponding to the orthographic views shown earlier, and the other two were c- and p-distractors, respectively. The positions of the three testing objects were randomly assigned. The subjects were asked to indicate which 3-D object resembled most to the one they had imagined. After they responded, the subjects were asked to rate how confident they were in their judgments. There were a total of 26 trials.

Immediately following the construction task, the subjects were given an unexpected recognition test. Each trial in this test consisted of two pairs of orthographic projections representing the top and front views. One pair corresponded to those shown at the beginning of each trial in the construction task; the other pair, not shown at all in the construction task, corresponded either to the matching c-distractor or the matching *p*-distractor. The reason for including an orthographic recognition test was that we wanted to evaluate the possibility that subjects might have solved the construction task not by mentally imagining 3-D objects, but by memorizing the 2-D target projections and then unpacking or decomposing the 3-D objects into sets of 2-D projections and locating the match.

**Table 3.** The Mean Accuracy of Construction Task as a Function of Gender, Giftedness, and Object Complexity in Experiment 2 ($N$=35)

| | Gifted | | Nongifted | |
|---|---|---|---|---|
| Complexity | M | F | M | F |
| Low | .91 (.17) | .82 (.13) | .92 (.09) | .90 (.09) |
| Medium | .79 (.19) | .75 (.17) | .76 (.19) | .78 (.18) |

*Note*:The numbers in parentheses are standard deviations; M=males, F=Females.

## 2. Results and Discussion

*A. Construction Task*

The average accuracy in selecting the 3-D object that corresponded to the 2-D orthographic projections was quite high (83.40%). As can be seen in Table 3, the results of ANOVA indicate that only the main effect of complexity was reliable, $F(1, 31)=28.41$, $MSe=.01$, $p<.0001$. The subjects performed better on problems with lower complexity ($M$=.90) than on those with higher complexity ($M$ .77). This result is quite consistent with that found in the Experiment 1 and with those of previous studies (Huang & Shyi, 1994, 1995; Shyi & Huang, 1995). No difference was found between gifted and nongifted students, however, nor between students of opposite sex. Furthermore, none of the interactions was significant, $F$'s<1 or $p$'s>.50.

The mean time spent on constructing a 3-D mental model was 27.13 s, which was longer than that spent on selecting a 3-D isometric drawing, 12.78 s, leading to a total solution time of 39.91 s for each problem. The results of ANOVA for total solution time indicate that the main effects of class, sex, and complexity were all significant. As shown in Table 4, gifted students ($M$=34.85 s) needed less time than nongifted students did ($M$=44.70 s), $F(1,31)=5.41$, $MSe=348.80$, $p<.05$; females needed more time ($M$=49.98 s) for solution than males did ($M$=31.44 s), $F(1,31)=17.56$, $MSe=348.80$, $p<.001$; finally, problems with higher complexity ($M$=47.53 s) required more time to solve than did those with lower complexity ($M$=32.30 s),

**Table 4.** The Mean Time (in sec) Spent on Construction Task as a Function of Gender, Giftedness, and Object Complexity in Experiment 2 ($N$=35)

| | Gifted | | Nongifted | |
|---|---|---|---|---|
| Complexity | M | F | M | F |
| Low | 20.54 | 36.63 | 28.84 | 45 54 |
| | (8.03) | (12.78) | (11.82) | (11.84) |
| Medium | 32.42 | 51.90 | 42.98 | 65.87 |
| | (11.60) | (15.25) | (21 44) | (14.34) |

*Note*: The numbers in parentheses are standard deviations; M=males, F=Females.

**Table 5.** The Mean Number of Errors in the Construction Task of a Function of Gender, Giftedness, and Error Type in Experiment 2 ($N$=35)

| | | Gifted | | Nongifted | |
|---|---|---|---|---|---|
| Complexity | Error type | M | F | M | F |
| Low | P | 0.44 | 1.38 | 0.60 | 0.62 |
| | | (0.73) | (1.19) | (0.84) | (1.06) |
| | C | 0.78 | 0.50 | 0 40 | 0.50 |
| | | (1.64) | (0.76) | (0.52) | (0.53) |
| Medium | P | 1.89 | 1.88 | 2.10 | 2.00 |
| | | (2.09) | (1.55) | (1.60) | (1.60) |
| | C | 0.89 | 1.38 | 1.00 | 1.00 |
| | | (0.78) | (1.19) | (1.15) | (1.07) |

*Note*: The numbers in parentheses are standard deviations; M=males, F=Females.

$F(1,31)=93.40$, $MSe=44.08$, $p<.0001$.

After the subjects made their choices of 3-D objects, they were asked to rate how confident they were in their judgments. The gender difference was found to be reliable, $F(1, 31)=11.85$, $MSe=.36$, $p<.01$, in that males ($M$=4.36) appeared to be more confident in their judgments than females ($M$=3.66). A significant class by gender interaction indicates that, while no difference existed between gifted and nongifted male subjects ($M$'s=4.28 and 4.44 respectively), the gender difference arose mainly from the fact that gifted females ($M$=4.03) in general had higher confidence than nongifted female subjects ($M$=3.29).

Most importantly, subjects misidentified $p$-distractors ($M$=2.71) as targets more frequently than they misidentified $c$-distractors as targets ($M$=1.60), $F(1,31)=15.81$, $MSe=.68$, $p<.001$. The main effect of complexity also reached significance in that more errors were made for the objects with higher complexity ($M$=1.52) than for those with lower complexity ($M$=.64), $F(1,31)=30.28$, $MSe=.85$, $p<.0001$. The interaction between the type of error and complexity was marginally significant, $F(1,31)=3.70$, $MSe=1.09$, $p=.06$. As can be seen in Table 5, while subjects made about an equal number of c- and p-type errors with objects of low complexity ($M$'s=.74 and .54, respectively), $F(1,31)=1.51$, $MSe=.54$, $p=.23$, they made more $p$-type errors ($M$=1.97) than $c$-type errors ($M$=1.06) with more complex objects, $F(1,31)=11.33$, $MSe=1.24$, $p<.01$. Gifted and nongifted students had a similar tendency to make more errors on $p$-distractors than on $c$-distractors, however, $F<1$.

These findings again replicate those that were obtained with college subjects (Huang & Shyi, 1995, 1997), and they suggest that the likelihood of constructing a 3-D mental model decreased as the complexity increased, and that the extent to which structural details were preserved in the model decreased as object complexity increased. Furthermore, these results provide evidence to support the claim that the 3-D mental models contained more details in the region of focus of attention, in this case the area of the intersection of the top and front orthographic views, and that details outside the focal region were not as clear or as accessible as those located in the focal region.

### *B. Recognition Test*

An incidental recognition test of 2-D orthographic projections was conducted at the end of the experiment. In each trial, subjects had to identify which of the two pairs of orthographic projections were presented earlier in the construction task. The overall average accuracy of the recognition test was 70%. This recognition accuracy was submitted to a 2 (sex) × 2 (class) × 2 (complexity) mixed ANOVA. The main effect of complexity was marginally reliable, $F(1,31)=3.46$, $MSe=.01$, $p<.07$. The subjects tended to recognize more correctly for problems with lower complexity ($M$=.73) than for those with higher complexity ($M$=.67). The three-way interaction among sex, class, and complexity was also significant, $F(1, 31)=5.99$, $MSe=.01$, $p=.05$. Further analysis indicated that while the difference did not vary between male and female gifted subjects in solving problems with different levels of complexity (male-female were -.08 (low) and .03 (medium)), $F(1,15)=1.33$, $MSe=.02$, $p=.27$, it did vary between those of male and female nongifted subjects (male-female were .05 (low) and .11 (medium)), $F(1,16)=7.58$, $MSe=.007$, $p<.05$.

### *C. Contingent Probabilities*

An important reason for including the *ortho-*

*graphic* recognition test was to examine the possibility that subjects performed the construction task not by mentally imagining 3-D models but by memorizing the target orthographic views and unpacking the isometric drawings of each 3-D object into their respective set of orthographic views, and then comparing those with the ones they had memorized. If so, we would expect a high correlation between the accuracy in the construction task and that in choosing the correct (old) set of orthographic projections. This was indeed what we found—the correlation was modest and yet reliable, $r(35)=.34$, $p<.05$. However, an unpacking or decomposing strategy would not predict that differences existed between the contingency probability of choosing the correct set of orthographic projections given that the 3-D object construction was done correctly (PCC) and the contingent probability of choosing the correct set of orthographic views given that construction was done incorrectly (PCI). (Note that the implications of the contingent probabilities computed here are quite different from those of the contingent probabilities computed in Experiment 1, which were used to index the extent to which compatibility problems were solved by constructing 3-D mental models.) If the subjects were merely unpacking the 3-D objects into a set of 2-D patterns, there seemed no reason to expect that PCC would be in any way different from PCI. However, when we submitted the overall PCC and PCI to a 2 (sex) × 2 (class) × 2 (type: PCC or PCI) ANOVA, we found that the main effect of type was to be reliable, indicating that PCC (.72) was greater than PCI (.59), $F(1, 29)=5.33$, $MSe=.04$, $p<.05$. No other main effects nor interactions were found reliable. An unpacking or decomposition strategy also would not predict a difference in the type of error subjects committed in the construction task. There seemed to be no a prior reason that, by unpacking or decomposing, subjects should err more on *p*-distractors than on *c*-distractors, which was exactly the result we obtained.

Taken together, these results for the recognition test suggest a coexistence of an accessible 3-D mental model along with its corresponding 2-D orthographic projections in the course of the experiment; the former supported subjects' performance on the construction task, and the latter supported their performance on the recognition test. Most importantly, our results indicate that the constructed 3-D mental models were partially complete in that the region falling within the focus of construction contained more structural details than did those falling outside the focal area (Hochberg, 1982; Shyi & Peterson, 1992; Peterson & Gibson, 1991).

# IV. Experiment 3

In coping with the construction task, while inspecting a set of orthographic projections (e.g., top and front view) and constructing the corresponding 3-D mental model, subjects might need to rotate their viewpoint toward the third view (e.g., right view) in order to judge which isometric drawings that were shown subsequently matched the constructed model. The basic idea is that the internal mental model may be constrained by the two displayed orthographic views. In the case where top and front views are shown, subjects may choose to construct a 3-D mental model based on a top-front perspective. Since such a perspective may occlude the right view of the object, subjects would need to perform mental rotation to allow information of the third view to be available. To do so, subjects would probably mentally rotate the constructed 3-D structure to the left in their mind's eye in order to make a required judgment. In the present experiment, we examined whether there were differences between gifted and nongifted high school students in their abilities to mentally rotate constructed 3-D models.

## 1. Method

### *A. Subjects*

Thirty-five subjects, 8 gifted and 9 nongifted males and 9 gifted and 9 nongifted females, recruited from the same high schools as in the previous experiments, participated in Experiment 3. As before they were rewarded with NT$100 gifts for their participation at the end of the experiment. All the subjects had normal or corrected to normal vision.

### *B. Stimulus Materials*

Fifteen objects with low and medium complexity, selected from the stimulus objects used in Experiment 1, served as the test material. These stimulus objects were used for the same reason to encourage subjects to engage in a construction strategy. For each target object, distractors sharing top, front, or right views with the target and with similar complexity ratings were constructed and selected (see Huang & Shyi, 1994, for details). The target and its distractor were paired and tested under rotations of 15°, 45°, or 75° along the y-axis of the display screen (i.e., depth plane). An example showing the orthographic views of the target and those of the distractor, and three rotated pairs of objects used in the construction task are shown in Figure 3.

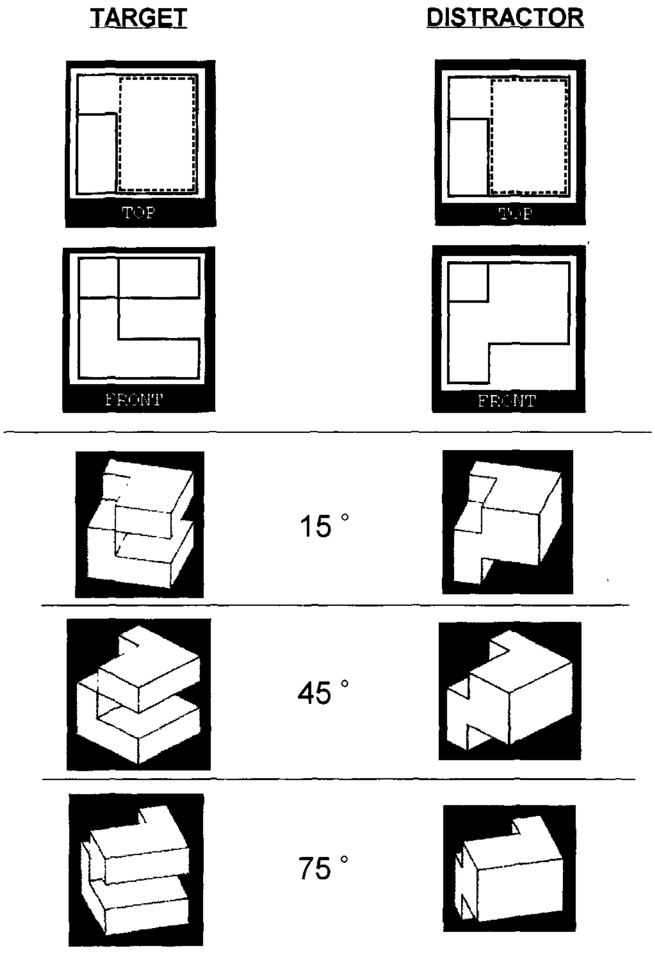


**Fig. 3.** An example of a target and its distractor presented at 15°, 45°, and 75° of rotation in Experiment 3.

*C. Procedure*

As before, each subject was tested individually in a group session. They were asked to complete two tasks: the construction task and the recognition test. In the construction task, the subjects were explicitly instructed, as in Experiment 2, to construct corresponding a 3-D mental model for each set of the orthographic projections. They were then asked to choose from a pair of objects and indicate which corresponded to the one they had imagined. The pairs of objects were rotated, with equal likelihood, 15°, 45°, or 75° along the depth plane (i.e., the *y*-axis); five trials were assigned to each rotation angle.

The second task was a recognition test, in which the subjects were shown two sets of orthographic projections and were asked to identify the set of orthographic projection presented in the construction task. One of the two sets was the target, and the other set was the orthographic projections of the paired distractor.

**Table 6.** The Mean Accuracy of Construction Task as a Function of Gender, Giftedness, and Rotation Angle in Experiment 3 (*N*=35)

| | Gifted | | Nongifted | |
|---|---|---|---|---|
| Rotation Angle | M | F | M | F |
| 15° | .95 (.09) | .76 ( 22) | .78 (.18) | .78 (.12) |
| 45° | .97 (.07) | .73 (.28) | .89 (.14) | .64 (.28) |
| 75° | .95 (.09) | .76 (.26) | .80 (.24) | .64 (.31) |

*Note*:The numbers in parentheses are standard deviations; M=males, F=Females.

## 2. Results and Discussion

*A. Construction Task*

In general, the accuracy in the construction task (.80) was similar to that of Experiment 2 (Table 6). The accuracy data were submitted to three-way mixed ANOVA of sex, class, and angle of rotation. The main effect of gender was found to be significant in that males (.88) answered more accurately than females (.72), $F(1, 31)=11.55$, $MSe=.067$, $p<.01$,. The gifted students (.85) also appeared to perform better than the nongifted (.76) although the difference failed to reach significance, $F(1,31)=3.74$, $MSe=.067$, p=.06. No other main effects nor interactions were found to be significant, $F$'s<1.40, $p$'s>.25.

The mean solution time for the construction task was 24.61 s, which was slightly shorter than the mean construction time for Experiment 2. The solution times for the construction task were also submitted to a 2 (sex) × 2 (class) × 3 (rotation angle) mixed ANOVA. None of the main effects were found to be reliable, $F$'s<1 or $p$'s>.16. However, the interaction of rotation angle and class was reliable, $F(2, 62)=3.99$, $MSe=20.57$, $p=.023$. As shown in Table 7, while gifted students had a tendency of need more time to pick up the target isometric as the angle of rotation increased (25.57 s, 26.27 s, and 28.83 s for 15°, 45°, and 75° of rotation, respectively) , nongifted students exhibited an opposite trend (24.54 s, 20.68 s, and 21.81 s for 15°, 45°, or 75° of rotation, respectively).

*B. Recognition Test*

As in Experiment 2, an incidental recognition test of 2-D orthographic projections was conducted at the end of the overall experiment. In each trial, subjects had to identify which of the two pairs of orthographic projections were presented earlier in the construction

**Table 7.** The Mean Total Solution Time (in sec) Spent on the Construction Task as a Function of Gender, Giftedness, and Rotation Angle in Experiment 3 (*N*=35)

| | Gifted | | Nongifted | |
|---|---|---|---|---|
| Rotation Angle | M | F | M | F |
| 15° | 23.76 | 27 17 | 23.35 | 25.72 |
| | (7.37) | (13.36) | (8.97) | (7.68) |
| 45° | 22.57 | 29.56 | 19.21 | 22.14 |
| | (9.22) | (13.36) | (8.38) | (6.10) |
| 75° | 24.92 | 32.32 | 20.11 | 23.51 |
| | (9.11) | (15.10) | (8.29) | (6.49) |

*Note*: The numbers in parentheses are standard deviations; M=males, F=Females.

task. The overall average accuracy of the recognition test was 74%, which appeared to be slightly better than that in Experiment 2 (70%). This recognition accuracy was submitted to a 2 (sex) × 2 (class) × 3 (angle of rotation) mixed ANOVA. Only the main effect of sex was reliable, $F(1, 31)=16.22$, $MSe=.061$, $p=.0003$, indicating that males ($M=.84$) outperformed their female counterparts ($M=.64$). There was also a marginal interaction between sex and class, $F(1, 31)=3.30$, $p=.079$, reflecting the tendency that while gifted female students ($M=.72$) did much better the nongifted females ($M=.57$), gifted males ($M=.83$) performed at about the same level as did nongifted males ($M=.85$). No other main effects nor interactions were reliable, $F$'s<1 or $p$'s>.12.

As for Experiment 2, we included the *orthographic* recognition test to check for the possibility that the subjects performed the construction task not by using a 3-D model construction strategy, but by using a 2-D unpacking strategy. If so, we would expect a high correlation between the accuracy in the construction task and that in choosing the correct (old) set of orthographic projections. This was indeed what we found--the correlation was relatively high and reliable, $r(35)=.70$, $p<.01$. Therefore the result of the construction task could mean that the subjects in Experiment 3 used a 2-D unpacking strategy to cope with the construction task. However, we doubted that this was actually the case for the following reasons. First, recall that the subjects were asked to solve construction problems over a series of 15 trials, which was slightly more than half of what the subjects in Experiment 2 had to cope with. The smaller number of trials not only gave rise to a much lower load, thus reducing memory interference at the time of the recognition test, but also led to a much shorter retention interval between the presentation of the orthographic projections and the recognition test. Recall that it took on average 27.13 s for the subjects to solve each problem in Experiment 2, which means about 12 min had elapsed before the recognition test began, given that there were 26 problems to solve. In contrast, it took on average 24.61 s for the subjects in Experiment 3 to solve each problem, which means that only a bit more than 6 min had elapsed before the recognition test began, given there were only 15 problems to solve. Second, as we suggested for Experiments 1 and 2, the high-school students behaved very differently from the college students we tested before in that the high-schoolers appeared to be more willing to obey instructions. As a result, they were reluctant to use a strategy (e.g., 3-D model construction) for problem-solving if they were not explicitly told or encouraged to do so. We also suspected that the group testing scenario used throughout the study due to practical constraints may also have put some pressure on the high-school subjects such that they would try as much as they could to comply with instructions. Together, and including the reasons discussed in Experiment 2, we think that the high correlations between construction performance and the orthographic recognition test should be interpreted as evidence for the coexistence of accessible 3-D mental models along with their corresponding 2-D orthographic views.

In summary, the accuracy and response time of the construction task revealed that when they spent about the equal amounts of time on the construction task, gifted students solved the construction problems more accurately than did their nongifted counterparts. Similarly, male subjects performed with a higher accuracy rate than did their female counterparts when both groups spent about the same amount of time on the construction task. These results suggest that the gifted students and male subjects seemed to perform better in terms of construction accuracy.

There was no clear indication that the gifted and nongifted students differed in their abilities to rotate a 3-D model once it was constructed. Likewise, there was no evidence that males could perform better than females in that regard. In fact, the results appear to suggest that the 3-D models may have been constructed using a nonspecific perspective such that the need for mental rotation was obviated (Cooper, 1988; Marr, 1982). Of course the negative findings could also mean that we failed to use a sufficient range of rotation angle such that the specific 3-D model constructed from the top-front perspective could allow subjects to recognize isometrics rotated from 15° to 75° without invoking mental rotation. Tarr (1995; Tarr and Pinker, 1989) recently proposed a multiple-view model to account for human object recognition in which multiple representations of an object, corresponding to different viewpoints, are built during the course of familiarization. His view has received both psychophysical and neurophysiological support (Tarr, 1995; Tarr & Pinker, 1989; Logothetis & Sheinberg, 1996; Perrett, Oram, Hietanen, & Benson, 1994). In particular, Logothetis and Sheinberg, and Perrett et al. have provided estimates, based on single-cell recording from primate brains, that each representation constructed for a specific view may encompass a range of approximately 60° to 80° of viewing arc. Such findings suggest that we may need to consider a broader range of rotation angle in order to understand the operation of mental rotation.

## V. General Discussion

Three experiments were conducted in the present study to examine whether scientifically gifted and nongifted students would differ in the strategy as well as product of constructing 3-D mental models from viewing 2-D orthographic projections. In Experiment 1, we replicated our previous findings of the robust effect of complexity in that subjects experienced more difficulty in construction when dealing with objects of higher complexity than with objects with lower complexity (Huang & Shyi, 1994, 1995, 1997; Shyi & Huang, 1995). Without explicit instructions, however, neither gifted nor nongifted high school students seemed to engage in constructing 3-D mental models while solving the compatibility task in Experiment 1.

In both Experiments 2 and 3, when we explicitly asked the subjects to engage in 3-D model construction while viewing 2D displays, gifted students appeared to be more efficient, in terms of both speed and accuracy, than nongifted students in problem-solving. In Experiment 2, for example, gifted students needed less time in construction to achieve the same degree of accuracy as nongifted students did. In Experiment 3, when asked to identify the corresponding 3-D structure in a recognition test in which objects were presented with different angles of rotation, the gifted high school students achieved a higher level of accuracy than did their nongifted counterparts although they spent about the same amount of time. Taken together, the results of these two experiments suggest that the gifted students had better spatial abilities and were more efficient at solving visuospatial problems.

In addition, we found that the likelihood of constructing a mental model decreased as complexity increased, and that the extent to which structural details were preserved in the constructed models decreased as object complexity increased. These results replicate Huang and Shyi's previous findings on college samples and suggest that those high school students also retained clearer 3-D mental models in regions of attentional focus. And, as a consequence that the accessibility of structures outside the focal region decreased.

To conclude, we will discuss briefly some of the implications of our results for issues related to giftedness: The first issue concerns the differential performance on the *implicit* and *explicit* tasks. It is obvious that in Experiment 1, when they were asked to perform the compatibility task which only implicitly required subjects to engage in a construction strategy, neither the gifted nor the nongifted students exhibited an inclination to construct 3-D models. Clear indication for 3-D model construction and evidence for differential abilities in 3-D construction between the gifted and nongifted studnets emerged in Experiment 2, where the subjects were explicitly instructed to engage in a construction process. It is interesting to speculate on what could have led to such differences other than the seemingly innocuous task demands, particularly in light of both Cooper's and our previous studies which consistently demonstrated that college students voluntarily adopted a constructive strategy to solve compatibility problems. We suspect that the educational practices and cultural influences prevalent in our society may have played a large role here (Huang & Sun, 1995; Wu,1989): Students in general, and those in the lower level of the educational hierarchy in particular, are expected to conform and comply faithfully with demands emanating from authoritative figures such as school teachers and administrative personnel (to which group research assistants from a university aptly belong). That is, the fact that the subjects did not voluntarily engage in 3-D model construction may reflect some social-cultural constraints rather than cognitive inability.

Once they received clear instruction with regard to how the problems should be solved, both gifted and nongifted students were quite able to solve the problems by constructing 3-D mental models, as reflected in the null differences in overall performance accuracy. Gifted students, however, were able to solve the problems more efficiently than their nongifted counterparts in that on average they required less time to solve each problem than did the nongifted students. Such differences may suggest that, compared to nongifted students, gifted students may have an advantage in their capacities of spatial working memory (Shah & Miyake, 1996; Just & Carpenter, 1992). Constructing the mental model of a 3-D objects out of its orthographic projections no doubt requires a number of component processes. Having a greater capacity in spatial working memory could mean that the completion of some or all those component processes were speeded up. As a consequence, the gifted students were able to solve each problem with less time. It would be interesting for future study to provide measures of the capacity of spatial working memory for both the gifted and the nongifted students to bear out these speculations.

Another issue concerns the fact that we found clear evidence for *gender differences* in Experiments 2 and 3. Males seemed to spend less time in model construction and to have greater confidence in their judgments on 3-D structures than their female counterparts did in Experiment 2. Likewise, in Experiment 3, males yielded a higher accuracy rate in their responses.

Gender differences in spatial ability have been suggested by many researchers in the past (Harris, 1978; McGee, 1982). Maccoby and Jacklin (1974), for example, pointed out that gender differences in spatial ability first appear in early adolescence when sex roles become more salient; therefore, males and females are likely to engage in different activities and developing different interests and abilities (Nash, 1979). Other researchers have suggested that gender difference exist prior to adolescence. For example, there is evidence suggesting that boys are more accurate than girls in spatial representations, such as in constructing toy models of their classrooms and towns in kindergarten (Hart, 1979; Siegel & Schadler, 1977). One should be cautious, however, about drawing premature conclusions regarding the true relationship between spatial abilities and gender differences because, as pointed out recently by Geary (1996) and Voyer et al. (1995), their relationship may be far more complicated than has been suggested by earlier researchers. One main problem with previous studies, those with college students as subjects in particular, has been a lack of control of differences in the academic backgrounds, training, and experience of men and women (Newcombe, 1982). The present study was not designed specifically to examine gender differences. However, it would be interesting in future research to investigate possible gender differences in the gifted population. Such a comparison could avoid the pitfall of not being able to control factors that may confound or blur the true relationship between genders and visuospatial abilities.

It is important for the purpose of present study that the results we obtained with respect to differences in performance between gifted and nongifted students cannot be solely attributed to differences between sexes. That is why we included both male and female gifted (and nongifted) students as subjects for the present study. The results we obtained across three experiments were never the case that only gender differences existed while differences between the gifted and nongifted were totally absent. That is, whenever gender differences were found, those differences were always accompanied by differences in giftedness. It is therefore very clear that giftedness and gender differences were very distinct factors contributing to subjects' performance on the tasks used in the present study. How giftedness may be related to sex difference is in itself an interesting empirical question and awaits further research.

Finally, in light of the idiosyncratic selection process that each school uses to identify gifted youngsters, we need to consider how to more systematically identify some basic differences between gifted and nongifted students based on measures other than their academic performance. (Note that academic performance was the criterion used by the schools from which our subjects were recruited.) Some of these differences may be critically related to high-school students' abilities in solving visuospatial problems but may not be completely related to the criteria used to identify giftedness. It is very likely that one such difference entails spatial abilities, which have been implicated in mathematical and scientific thinking. A widely shared belief has been that an individual's scientific aptitude may be closely related to his or her ability to perform spatial reasoning. There is little doubt that the mastery of curriculum subjects such as mathematics and science in high school may require good spatial abilities (Geary, 1996; Benbow, 1988, 1992). However, there may be factors other than spatial abilities which contribute to an individual's excellent academic performance. These extra factors may have little to do with spatial abilities. What is needed is to determine in what ways and to what extent spatial abilities can help nourish a student's scientific aptitude. To obtain complete answers to those and related questions requires, we think, microgenetic probing of the mental structures and processes that are involved in solving visuospatial problems. In our judgment, investigating and understanding how an individual constructs 3-D mental models while viewing 2-D orthographic displays is a good direction to take in future research.

## References

Benbow, C. P. (1988). Sex differences in mathematical-reasoning ability in intellectually talented preadolescents: Their nature, effects, and possible causes. *Behavioral and Brain Sciences*, **11**, 169-232.

Benbow, C. P. (1992). Academic achievement in mathematics and science of students between ages 13 and 23. Are there differences among students in the top one percent of mathematical abilities. *Journal of Educational Psychology*, **84**, 51-61.

Cooper, L. A. (1988). The role of spatial representations in complex problem solving. In S. Schiffer & S. Steele (Eds.), *Cognition and Representation*. Boulder, CO: Westview Press.

Cooper, L. A. (1989). Mental models of the structure of visual objects. In S. Ballesteros & B. Shepp (Eds.), *Object Perception: Structure and Process* (pp. 91-119). Hillsdale, NJ: Erlbaum.

Cooper, L. A. (1990). Mental representation of three-dimensional objects in visual problem solving and recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, **16**, 1097-1106.

Cooper, L. A. (1991). Dissociable aspects of the mental representation of visual objects. In Logie, R. H. & Denis, M. (Eds.), *Mental images in human cognition* (pp. 3-34). Elsevler Science Publishers.

Cooper, L. A. & Mumaw, R. J. (1985). Spatial aptitude. In R. F. Dillion (Ed.), *Individual differences in cognition* (Vol. 2) (pp. 67-94). New York, NY: Academic Press.

Geary, D. C. (1996). Sexual selection and sex differences in mathematical abilities. *Behavioral and Brain Sciences*, **19**, 229-284.

Harris, L. J. (1978). Sex differences in spatial ability: Possible environmental, genetic, and neurological factors. In M. Kinsbourne (Ed.), *Asymmetrical function of the brain*. Cambridge, MA: Cambridge University Press.

Hart, R. (1979). *Children's experience of place*. New York, NY: Irvington.

Hochberg, J. (1982). How big is a stimulus? In J. Beck (Ed.), *Organization and representation in perception* (pp. 191-217). Hillsdale, NJ: Erlbaum.

Horowitz, F. D., & O'Brien, M. (Eds.) (1985). *The gifted and talented: Developmental Perspectives*. Washington. DC: American Psychological Association.

Huang, S.-T. T. & Shyi, G. C.-W. (1994). Constructing three-dimensional mental models from viewing two-dimensional displays (I): The effects of object complexity and viewpoints. *National Sciences Council (NSC83-0111-S-194-003) Research Report*, Taiwan, R. O. C. (in Chinese)

Huang, S.-T. T. & Shyi, G. C.-W. (1995). Constructing three-dimensional mental models from viewing two-dimensional displays (II): An investigation of the constructive processes and component skills. *National Sciences Council (NSC84-2511-S-194-005) Research Report*, Taiwan, R. O. C. (in Chinese)

Huang, S.-T. T., & Shyi, G. C.-W. (1997). Characterizing the nature of three-dimensional mental models constructed from viewing two-dimensional displays. Manuscript submitted to *Journal of Experimental Psychology: Learning, Memory, and Cognition* for publication.

Hunag, S.-T. T., & Sun, Y.-P. (1995). The effect of an individual's understanding of social convention on restitutional forgiving process. Paper presented at the 66th Annual Meeting of the Eastern Psychological Association, Boston, MA.

Just, M. A., & Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, **99**, 122-149.

Kosslyn, S. M. (1994). *Image and brain: The resolution of imagery debate*. Cambridge, MA: MIT Press.

Levy, J. U., & Levy, N. (1992). *Mechanical aptitude and spatial relations tests* (2nd ed.). New York, NY: Prentice-Hall.

Logothetis, N. K., & Sheinberg, D. L. (1996). Recognition and representation of visual objects in primates: Psychophysics and physiology. In R. Llinas and P. S. Churchland (Eds.), *The mind-brain continuum* (pp. 147-172). Cambridge, MA: MIT Press.

Maccoby, E. E. and Jacklin, C. N. (1974). *The psychology of sex difference*. Stanford, CA: Stanford University Press.

Marr, D. (1982). *Vision*. San Francisco, CA: W. H. Freeman Company.

McGee, M. (1982). Spatial abilities: The influence of genetic factors. In Potegal (Ed.), *Spatial abilities: Development and physiological foundations*. New York, NY: Academic Press.

Nash, S. C. (1979). Sex role as a mediator of intellectual functioning. In M. A. Wittig & A. C. Petersen (Eds.), *Sex-related differences in cognitive functioning*. New York, NY: Academic Press.

Newcombe, N. (1982). Sex-related differences in spatial ability: Problems and gaps in current approaches. In Potegal (Ed.), *Spatial abilities: Development and physiological foundations*. New York, NY: Academic Press.

Perrett, D. I., Oram, M. W., Hietanen, J. K., & Benson, P. J. (1994). Issues of representation in object vision. In M. J. Farah and G. Ratcliff (Eds.), *The neuropsychology of high-level vision* (pp. 33-61). Hillsdale, NJ: Erlbaum.

Peterson, M. A. & Gibson, B. (1991). Directing spatial attention within an object: Altering the functional equivalence of shape descriptions. *Journal of Experimental Psychology: Human Perception and Performance*, **17**, 170-182.

Shah, P., & Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: An individual differences approach. *Journal of Experimental Psychology: General*, **125**, 4-27.

Shepard, R. N. (1994). Perceptual-cognitive universals as reflections of the world. *Psychonomic Bulletin & Review*, **1**, 2-28.

Shyi, C.-W. G. & Huang, S.-T. T. (1995). Constructing three-dimensional mental models from viewing two-dimensional displays, *Chinese Journal of Psychology*, **37**(2), 101-122.

Shyi, C.-W. G., & Peterson, M. A. (1992). Perceptual organization in a brief glance: The effects of figure size, figure location, and the attentional focus. *Chinese Journal of Psychology*, **34**, 57-74.

Siegel, A. W. & Schadler, M. (1977). The development of young children's spatial representations of their classrooms. *Child Development*, **48**, 388-394.

Sternberg, R. J., & Davidson, J.(Eds.) (1986). *Conceptions of giftedness*. New York, NY: Cambridge University Press.

Tarr, M. J. (1995). Rotating objects to recognize them: A case study on the role of viewpoint dependency in the recognition of three-dimensional objects. *Psychonomic Bulletin & Review*, **2**(1), 55-82.

Tarr, M. J., & Pinker, S. (1989). Mental rotation and orientation-dependence in shape recognition. *Cognitive Psychology*, **21**, 233-282.

Wu, D. Y. H. (1989). Explicit and implicit moral teaching of preschool children in Chinese societies. Paper presented at the CCU-ICP International Conference on Moral Values and Moral Reasoning in Chinese Societies, Taipei, Taiwan.

Voyer, D., Voyer, S., & Bryden, M. P. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, **117**, 250-270.

# 資優生與非資優生解決視覺空間問題之心智模式比較

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## 摘　要

建構三度空間的心像模型是解答許多與空間相關問題的必要條件。在本研究中所進行的三個實驗中，我們檢驗資優與一般高中生所建構的立體心像模型是否有差異。實驗一中受試者首先看見兩張直角投射平面圖然後判斷第三張平面圖是否與先前兩張屬於同一立體物。結果顯示受試者對於解答具高複雜度之物體的作業有較多的困難。然而在沒有明確的指示下，資優生與一般生均無以建構策略解答相容作業的證據。實驗二中便明確要求受試者依呈現之平面投射圖建構所對應之立體模型。結果顯示資優生較一般生所需建構時間爲短，並且男生較女生所需時間爲短。實驗三考驗在建構歷程中進行心像旋轉的可能性。結果發現在花費約略相同的時間進行建構作業的情況下，資優生較一般生更能正確選出對應平面圖的立體圖型。同時，男生也比女生表現出較高的正確率。這些結果反映出，在明確的指示下，資優生較一般生表現出較佳的建構立體心像的能力。性別差異與資優之關係亦於文中加以討論。