BRIEF REPORT

This research studies mental rotation in different cultural groups. An experiment is described in which 72 pupils from Ahidjan (Ivory Coast) and 79 from Matran (Switzerland) responded to a computerized mental rotation task. When compared to classical studies, results show, for both groups, similar patterns of reaction times (RTs) across degrees of rotation. RTs, however, are significantly longer in Ivoarian children, and for the Swits (only) they decrease with age. Results do not entirely match the postulated linearity of the relationship between reaction time and degree of rotation, in particular at 30 and 350 degrees, for which RTs are longer than expected. Data also show that incorrect answers do not occur randomly, suggesting that the widely used criterion of RT based on correct responses only should be reconsidered. No gender differences were found.

MENTAL ROTATION IN CHILDREN FROM IVORY COAST AND SWITZERLAND

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Studies performed in the early 1970s have shown a close relationship between angle of rotation of two drawings and the time needed for the subjects to decide whether the two stimuli represent identical or mirror-image objects (Cooper & Shepard, 1973; Shepard & Metzler, 1971). The results showed a linear increase in reaction times (RTs) as a function of the angle of rotation between both presented objects. Subjects reported having "rotated" the image of the stimulus in their head, which has been taken as support for the explanation of why RTs increased with angle of rotation. These results

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were confirmed with several experimental variations (Shepard & Cooper, 1982), although a few studies have challenged the linearity of the phenomenon (Bryden, George, & Inch, 1990; Rossi & Collyer, 1986; Shimoz, 1981).

To our knowledge, no cross-cultural study of mental rotation proper has yet been reported. Perhaps the closest to this would be some work done by Jahoda (1979, 1980). He investigated ethnic and sex differences in a 3-dimensional mental rotation task, but with a quite different technique, namely, a multiple choice among several proposed drawings.

Three questions motivated our cross-cultural study. First, we wanted to know whether we would find the same kind of phenomenon as in the classical studies done in the United States, that is, a linear relationship between angle of rotation and RT, with an axial symmetry at 180 degrees, where RTs reach the maximum value. The second question concerned the amount of time needed for reaction. We thought that this variable could be influenced by the amount of experience with electronic media, especially electronic games, for which fast reactions to stimuli presented on electronic screens are an essential ability. Thus, RTs in Ivory Coast, where such media are relatively less available, were expected to be longer than in a Western country like Switzerland, where they are part of everyday life. Finally, we wanted to study how RTs would vary in relation to developmental aspects. Because most of the classical studies have been made with adult subjects and only a few articles report results with children (Lejeune, 1994; Lejeune & Decker, 1994; Marmor, 1975), little is known about the subtleties of development. These studies, however, show that young children's RTs are much longer than adults', and therefore it was reasonable to expect a continuous diminution with age.

**METHOD**

**SUBJECTS**

Taking part in the study were 151 children, of whom 72 were from Abidjan, Ivory Coast (36 boys and 36 girls) and 79 from Matran, Switzerland (38 boys and 41 girls). Swiss subjects were taken from four age groups (8, 9, 10, and 12 years), and the Ivoreans from three age groups (9, 11, and 13 years). Because of substantial differences between the school systems of the two countries, it was not possible to match the age groups exactly. The African sample was selected from three public schools of the city of Abidjan that were situated in different neighborhoods representing three different socioeconomic levels.
Mental rotation was studied by means of a time reaction task. A set of 44 cards was presented sequentially to each subject, each card containing a pair of stimuli, as shown in Figure 1. The upper stimulus was standing in an upright position, whereas the lower one was rotated clockwise every 30 degrees, either in a "flipped" manner or in a normal way. Subjects were required to press a button answering "yes" or "no"—as fast as they could—to the question of whether the lower stimulus corresponded to a true rotation of the upper one.

Two kinds of stimuli were used: the capital letter "R" and an image of a hand. The collection of stimuli presented to each subject was thus composed of 2 images (R and Hand), 2 formats (normal and flipped), and 11 different degrees of rotation (30 to 330 degrees). This made a total of 44 items. One out of four different series of cards was presented to each subject to balance an order effect.

The experimental procedure consisted of two phases, a practice phase and the experimental test. During the first phase, subjects were introduced to the device used for the test. They were asked to practice with three cards, which
would be repeated in case further training was needed. During the experimental phase, subjects worked alone, evaluating the 44 experimental cards.

This mental rotation task was part of a larger set of instruments and questionnaires, because this research was inserted into a broader project conceived to study spatial cognition. The language used was French (the official language of instruction for both countries).

APPARATUS

The task was administered with a laptop computer (Macintosh Powerbook 180), which managed the presentation of the cards and measured reaction times. In several schools of Ivory Coast, we used a car battery as source of electric power to solve the problems created by the lack of electricity in some school buildings. The software was written in HyperTalk. The size of the cards was 512 x 342 pixels (approximately 16.5 cm x 11 cm). “Times” was the font used for the stimulus “R” (55-point type).

DESIGN

For the main part of the analysis, a repeated measures ANOVA was performed on individual reaction times: 2 x 2 x 2 x 2 x 11 (Country x Gender x Type of Stimulus x Format of Rotation x Degrees of Rotation). One encompassing design was conceived to avoid the exponential augmentation of error in the statistical hypothesis testing. Because of the difference between age groups studied in the two countries, however, separate ANOVAs were performed to study the effect of age: 2 x 4 x 2 x 2 x 11 (Gender x Age x Type of Stimulus x Format of Rotation x Degrees of Rotation) for the Swiss group, and 2 x 3 x 2 x 2 x 11 for the Ivorian group.

RESULTS

DESCRIPTIVE AND PRELIMINARY ANALYSES

To provide a comparison between our data and that of previous classical ones, in this section we present preliminary descriptive analyses of RT considering—as the early studies did—only correct responses. Figure 2 shows RT values across degrees of rotation of the stimuli. The shapes of the curves of both groups, Ivory Coast and Switzerland, are remarkably similar to those described in the literature (Cooper & Shepard, 1973; Lejune, 1994; Shepard & Cooper, 1982; Shepard & Metzler, 1971) when one considers only
the angles of rotation analyzed in these studies (i.e., 60, 120, 180, 240, and 300 degrees).

When all 11 degrees of rotation are taken into account, however, our observed values differ from their corresponding inter and extrapolation values, in particular at 30, 270, and 330 degrees (Figure 3, bottom). As a result, the expected linear change is no longer observed. It is worth noticing that at the extremes (i.e., 30 and 330 degrees), mean RTs are longer than the immediate corresponding inner degrees (i.e., 60 and 300 degrees, respectively). This characteristic is observed in both countries.

Errors

Some exploratory analyses on incorrect responses were done to determine whether they were produced randomly and independently of the effects we were studying. The proportion of errors across degrees of rotation also is shown in Figure 3. Overall, for both countries the shapes of the curves for reaction times and errors across degrees of rotation show a similar hatlike pattern, with a slight increase at the extremes and a maximum at 180 degrees. The correlation of mean RTs and the error rates is highly significant, $r = 0.94$, $p < .0001$, $n = 22$. 

Figure 2: Mean Reaction Time as a Function of Orientation of Test Stimulus, Comparing Classical Data With Those Obtained With a Population From Ivory Coast and Switzerland
Figure 3: Mean Reaction Time and Error Rates as a Function of Orientation of Test Stimulus With Observations Every 30 Degrees.

We observe that both Ivorean error rates and RTs are systematically higher than Swiss ones. A 2 x 2 x 2 x 11 ANOVA (Country x Gender x Type of Stimulus x Format of Rotation x Degrees of Rotation) performed on the accuracy of the answer (dichotomized as incorrect = 0 and correct = 1) confirms these observations. The analysis shows a highly significant between-subjects country effect. F(1, 147) = 35.75, p < .001. Tests involving the within-subjects effect of degrees of rotation show that this effect is indeed
Figure 4: Error Rates as a Function of Degree of Rotation of the Stimulus, by Age, for the Ivorian and Swiss Subjects

highly significant: Wilks’s lambda = .68, $p < .0001$. The parallelism of the curves observed in Figure 3 also is confirmed by the ANOVA. The interaction of Country x Degrees of Rotation is in fact not significant, Wilks’s lambda = .91, $p = .220$. Finally, tests involving within-subjects effects of stimulus and format of rotation show that their effects are significant, $F(1, 147) = 11.14$, $p < .001$ and $F(1, 147) = 10.20$, $p = .002$, respectively.

When error rates are split by age in the Ivorian group, errors decrease with age (Figure 4). By contrast, distributions of errors across age groups are much more homogeneous in the case of Swiss children.
Figure 5: Reaction Times, Regardless of the Correctness of the Answer

INFERENTIAL STATISTICS ON RTs

The following analyses were performed on RTs, regardless of the correctness of the answer. Figure 5 shows these data for both countries.

Degrees of Rotation

Mean RTs produced by Ivorians were higher (approximately 1,500 milliseconds) than Swiss ones for all degrees of rotation. The repeated measures ANOVA performed shows that there is a statistically significant between-subjects country effect, $F(1, 142) = 40.77, p < .0001$. Tests involving the within-subjects effect of degrees of rotation shows that the variability produced by this effect is highly significant, Wilks's lambda $= .56, p < .0001$. The interaction of Country x Degrees of Rotation turned out to be not significant, Wilks's lambda = .89, $p = .116$.

Type of Stimulus (Hand and R)

Overall, the Hand stimulus demanded higher RTs. The ANOVA shows that the within-subjects stimulus effect is significant, $F(1, 142) = 15.07, p < .0001$. Tests involving a within-subjects Stimulus x Degrees of Rotation effect reveal that this interaction is not statistically significant, Wilks's lambda = .92, $p = .323$. 
Figure 6: Mean Reaction Time, by Groups of Age, as a Function of Orientation of Test Stimulus

Format of Rotation (Flipped and Normal)

In general, flipped stimuli demanded higher RTs for almost all degrees of rotation. The ANOVA shows that the within-subjects format of rotation effect is highly significant, $F(1, 142) = 22.91, p < .0001$. Tests involving a within-subjects Format × Degrees of Rotation effect reveal that this interaction is statistically significant, Wilks's lambda = .80, $p < .001$. This interaction effect, when analyzed by country is not significant, Wilks's lambda = .93, $p = .451$.

Gender

A test of gender effects yielded a nonsignificant value of $F(1, 142) = .97$, $p = .326$.

Age

Figure 6 shows mean RT as a function of orientation of test stimulus, split by country and age. Overall, younger subjects tended to present longer RTs than older subjects; however, the effect of age seems to play a different role depending on the country. Among Swiss children, RTs tend to improve with age across the different degrees of rotation. This can be seen through the remarkable parallelism in RTs produced by all four age groups across degrees of rotation. It is worth noticing, however, that the slowest group turns out not
to be the youngest one (8-year-olds) but the next to the youngest one (9-year-olds). For Ivorean children, the improvement of RTs with age is far from evident. For example, young Ivoreans performed slower than older ones for some degrees of rotation (e.g., 90, 150, and 240 degrees), but not for others (e.g., 60 and 180 degrees).

Separate repeated measures ANOVAs performed for each country group confirm these impressions. Whereas for the Swiss group, the between-subjects effect for age is highly statistically significant, $F(3, 71) = 4.93, p = .004$, for the Ivorean group the same effect is nonsignificant, $F(2, 61) = .42, p = .657$. Moreover, tests involving the interaction of Age $\times$ Degrees of Rotation shows that whereas there is no interaction for the Swiss group, Wilks’s lambda $= .70$, $p = .770$, there is an almost significant interaction effect in the Ivorean group, Wilks’s lambda $= .57, p = .032$.

**DISCUSSION**

Results show that the relationship between angle of rotation and RTs is similar to the one reported in the literature. This is particularly true when one considers only the degrees of rotation studied in several of the now classic studies. We have observed this similarity in both the Ivorean and the Swiss groups. The fact that we considered more angles of rotation than those traditionally studied allowed us to observe in more detail the increment of RTs as a function of degrees of rotation. The variation of RTs turned out not to change in a linear manner in relation to degrees of rotation. In particular, we observed that at 30 and 330 degrees—which are corresponding angles relative to the line of symmetry—RTs not only were higher than expected (breaking the linear effect), but also were even higher than the values of their neighbors (i.e., 60 and 300 degrees, respectively), changing dramatically the direction of the expected curve. What is even more striking is that this situation was observed in both the Ivorean and the Swiss groups. If we add these results to others that have challenged—in one way or another—the linearity of the phenomenon (Banks, 1981; Bryden et al., 1990; Rossi & Collyer, 1986; Shimojo, 1981), we realize that much more research needs to be done to understand how RTs vary across degrees of rotation. Precise descriptions are needed of the thresholds where changes in RT occur. It also may be of interest to analyze individual curves to study subjects who may have “rotated” the figures and those who may have not, and try to find general cognitive principles.

In this study, we chose to include all responses, despite the fact that many important studies have considered correct responses only. In general, the
argument for excluding the RTs obtained with incorrect answers has been built on the fact that the number of incorrect answers is low (Shepard & Cooper, 1982). This situation may make sense when studying adults, for whom error rates are low, but when studying children, error rates are much higher, not random, and therefore nonnegligible. Although a detailed analysis of errors is beyond the scope of this article, for the purposes of this report we can say that we have observed the following:

1. A very high correlation between mean RTs and error rates across degrees of rotation,
2. statistically significant values for the effects of country, degrees of rotation, stimulus, and format of rotation in the account of the variability of accuracy values, and
3. that incorrect answers are distributed differently through age levels in the two country groups, with error rates appearing to be more homogeneous in Switzerland than in Ivory Coast.

Because of these findings, we believed that there were no arguments for leaving out incorrect answers. We therefore performed our main analysis on RTs using all the answers, correct and incorrect. In any case, and leaving these methodological considerations aside, we think that to better understand the mechanisms underlying mental rotation, it is necessary to study incorrect answers in more depth.

In comparisons of RTs between the two countries, we have observed a clear difference. Mean RTs are much longer in Ivory Coast than in Switzerland (a difference of approximately 1.5 seconds). Several factors could explain this big difference. First, there is the matter of the cultural relevance regarding what a “quick” answer is. The positive value of doing things quickly, and more generally the idea that time is a resource that can be saved by fast performance, is very present in the Western culture (including schools). This value is not necessarily present in the Ivorian culture. The very understanding of the relevance of timing during the performance therefore could have affected the scores of Ivorian children. Second, Swiss subjects are much more familiar with computers and electronic devices such as video games, which are, after all, the most popular toys in the Western world. The task, as presented in this research (involving computers), could have helped Swiss children in that they may have felt that they were facing a very familiar challenge (or game). These two factors taken together make the difference between the two countries not so surprising. What remains surprising, however, is the striking similarity of the shapes—including nonlinear patterns—of the RT curves of the two countries.
Finally, as far as the effect of age is concerned, we have observed that only in the Swiss group do RTs diminish with age. This may be due to the cultural relevance regarding time already mentioned above. Western children are socialized, in a more or less permanent manner, to perform better and faster than in previous years. In a certain way, there is an expectation to perform better and faster as they develop, and children may become more conscious of this aspect as they grow. This may not be the case in the Ivorean group. One can observe a much higher heterogeneity of ages in the classrooms, such that the issue of time performance in relation to age is not so present. In addition, as stated above, time performance seems to be less valued in the Ivorean culture. Furthermore, one may expect that older Western children have been more exposed to new technologies than have younger children. As Swiss children grow, they may have gathered more time exploring and practicing with devices such as computers and video games. Again, this may not be the case of children from Ivorean society, such that being older is not an advantage in this respect.

REFERENCES


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