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THE UNIVERSITY OF ALBERTA

ORIENTATIONAL ANISOTROPIES WITHIN AND ACROSS THE VISUAL AND HAPTIC MODALITIES

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH
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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled "Orientational Anisotropies Within and Across the Visual and Haptic Modalities" submitted by Angeline Verenka in partial fulfilment of the requirements for the degree of Master of Science.

Eugene C. Lechelt
Supervisor

Gerard M. Kysela

Date Sept. 19, 1977

To My Parents
By whose love and faith
this thesis was produced

ABSTRACT

Two experiments were conducted in which stimulus orientation anisotropies were examined within and across the visual and haptic modalities under two temporal conditions of response, simultaneous matching and memory-delay matching. Stimulus orientations examined were 0°, 45°, 90°, 135°, 225° and 315°.

Discrimination between horizontal and vertical orientations was reliably more accurate than discrimination of oblique orientations for all modality by response conditions, i.e., the "oblique effect" was obtained. Haptic and visual modalities were also found to differ reliably in their ability to reproduce specific stimulus orientations. In the intramodal study, the VV condition was most accurate in the simultaneous matching conditions whereas in the HH condition the memory-delay matching condition yielded the most accurate reports. Both modality conditions of the cross-modal study (VH, HV) were significantly more accurate in the memory-delay matching condition for all orientations except 135° and 225°. Across the 2 experiments, the descending order of accuracy of the modality conditions was visual stimulus inspection - visual reproduction (VV), visual stimulus inspection - haptic reproduction (VH), haptic stimulus inspection - visual reproduction (HV), and haptic stimulus inspection - haptic reproduction (HH).

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Introduction

About 85 years ago Jastrow (1893) recorded preferences for horizontal and vertical orientations when compared with oblique stimuli. An intensified empirical investigation into this phenomenon, termed the "oblique effect", has been resumed in the past 15 years. The present thesis extends this investigation by testing discrimination and memory for orientations perceived in differing sensory modalities, vision and touch.

Many studies have demonstrated the occurrence of the "oblique effect" in the visual systems of animals, children, and adults (a review of the research is provided by Appelle, 1972). Smith (1962), for example, required adult observers to estimate the radial position of radar trails and found greatest accuracy at the horizontal and vertical axes. A number of other response dimensions have been similarly examined in a test of this phenomenon in humans, for instance, grating acuity (Emsley, 1925; Leibowitz, 1953), parallelism (Onley & Volkman, 1958), optical illusions (Leibowitz & Toffey, 1966), etc. Rudel & Teuber (1963), testing 3 1/2 - 8 1/2 year-old children, noted that although vertical lines were readily discriminated from horizontal, there was a decrease in ability to discriminate between right and left obliques with a corresponding decrease in age. Stimulus comparison conditions have also been reported to affect the discrimination of mirror-image obliques by children (Bryant, 1969); few errors were made in simultaneous comparisons, but the number of errors increased in successive comparisons with a corresponding decrease in age.

Demonstrations of the "oblique effect" in the animal kingdom have been made by testing the rate of learning to respond differentially to two or more stimuli; the rate of learning is used as a measure of ability to discriminate between objects in different orientations. This phenomenon and technique are exemplified in a study showing that the goldfish requires twice the number of horizontal-vertical discrimination trials to learn right and left oblique discriminations (Mackintosh & Sutherland, 1963).

Three viable theoretical explanations have been advanced to explain both the occurrence and bases of the "oblique effect". An empiricist position, as represented by Ross (1974) and Segall, Campbell & Herskovits (1966) postulates a cultural-learning basis. That is, living in a carpentered world in which there is a preponderence of horizontal and vertical contours increases awareness of these 2 planes and hence one would predict a greater accuracy of orientation perception and response at these 2 particular orientations. As early as 1905 Rivers observed that non-Western peoples, i.e., those reared in cultures lacking rectangularity in their visual environments to any great degree, were reliably more subject to the horizontal-vertical ~~illusion~~ than were Western peoples, i.e., those raised in "carpenterized" or "urban" environments full of physical structures with vertical and horizontal right angles.

A second explanation, favoring the nativistic position, suggests that such stimulus orientation asymmetries reflect an endogenous predisposition (Leehay, Moskowitz-Cook, Brill & Held, 1975). Leventhal & Hirsch (1975) demonstrated a marked increase in the distribution of visual cortical cells showing vertical and horizontal orientation preferences when young cats were exposed to horizontal and vertical stimulus orientations; exposure to diagonal lines produced no resulting modification in the distribution. Andrews (1967) interpreted his results on acuity for line orientation in terms of units that are "most selective when tuned to the horizontal or vertical directions". Similarly, larger evoked potentials have been detected when viewing vertical or horizontal test patterns (Maffei & Campbell, 1970). An endogenous basis for the "oblique effect" is strongly suggested by the results of these studies.

An eclectic explanation, synthesizing the above empirical and nativistic positions, has been advanced by Annis & Frost (1973). They interpret their finding of discrepant orientational anisotropies in visual acuity for groups reared in different ecological environments to be the result of the preponderance of vertical and horizontal contours over other orientations in the early environment; that is, orientation-specific detectors in humans are tuned by the early visual environment. Annis & Frost found the visual environment of Cree Indians from the east coast of James Bay, Quebec, to differ from that of city-raised Euro-

Canadians. The Euro-Canadians were raised in a "carpentered" environment; the Cree Indians were raised in a traditional setting containing a more heterogenous array of contour orientations. Corresponding orientational anisotropies in visual acuity also differed between the two cultures - the "oblique effect" was absent in the Cree Indian sample.

Although the "oblique effect" in vision has been clearly demonstrated, more recent research has examined the accuracy of perceived orientation within other modalities as well as between modalities. The existence of the "oblique effect" in the haptic modality was recently demonstrated by Lechelt at al. (1976). Specifically, these authors found that haptic performance was significantly poorer than visual in stimulus orientation perception. Reliable differences were also obtained between simultaneous matching and memory conditions; performance was superior for the simultaneous matching condition in the visual modality at all oblique orientations and in the haptic modality for only two of four oblique stimulus orientations.

Of primary interest in the present study is the comparison of visual and haptic cross-modal as well as intramodal stimulus orientation perception. Results obtained from this investigation would provide some indication of the pervasiveness and robustness of the "oblique effect".

A secondary interest is the effects of the response comparison conditions (simultaneous matching, memory-delay matching) on the accuracy of orientation reproduction. Information may, therefore, be obtained concerning the effects of different temporal conditions on the magnitude of the "oblique effect" within and between visual and haptic modalities.

Another interest is the degree of constancy and accuracy of orientation reproduction across all modality by temporal comparison conditions. The obtained results may provide information concerning differences among conditions in the encoding and central processing of stimuli varying in spatial orientation.

Visual and haptic modalities are expected to differ in their ability to reproduce specific stimulus orientation in that: (1) reliable visual and haptic modality differences have been obtained in related research (Rudel & Teuber, 1964; Milner & Bryant, 1968; Goodnow, 1971; Rose, Blank & Bridger, 1972; Abravanel, 1972; Lechelt et al., 1976), and (2) visual and haptic phenomenal worlds are clearly unique and different. The discrepancy in the phenomenal worlds of the visual and haptic modalities has been expounded in depth by Cutsforth (1951) who, in an examination of blind children, noted among other things that, for a blind child, forms of triangles must differ a greater amount haptically than what is required for a sighted child to detect visually.

Cross-modal differences in orientation perception are also expected even under conditions in which identical stimulus arrangements and procedures are employed. Recent research in cross-modal matching of form has provided discrepant results for different cross-modal conditions (Gaydos, 1956; Eastman, 1967, 1968; Garvill & Molander, 1968; Milner & Bryant, 1968; Goodnow, 1971; Abravanel, 1972). Of interest in the present study are cross-modal comparisons of stimulus orientation and whether stimulus inspection and response in different modalities yield similar "oblique effects".

A vast majority of visual and haptic studies using geometric or "nonsense" forms have been concerned with intra- and cross-modal transfer and matching in children. An increment in accuracy of cross-modal matching with a corresponding increase in age has been reported by Bryant (1968). The results of most experiments generally indicate that for normal children and adults intramodal visual comparisons are the easiest (Cashdan, 1968; Milner & Bryant, 1970; Rudel & Teuber, 1971; Abravanel, 1972; Rose, Blank & Bridger, 1972). Opposing views are held as to the sequence occupying the second position of facility. Several studies have obtained results suggesting the visual-tactile sequence as the more accurate (Cashdan, 1968; Milner & Bryant, 1970; Goodnow, 1971; Rudel & Teuber, 1971; Abravanel, 1972; Rose, Blank & Bridger, 1972); another group of studies support the converse (tactile-visual) sequence (Gaydos, 1956; Eastman, 1967, 1968; Garvill & Molander, 1968). The majority of studies agree, however, that of the cross-modal sequences (i.e., matching visual to haptic or matching haptic to visual) one is equally as difficult or more difficult than the other. The intramodal tactile (haptic) sequence is typically the most difficult or equally as difficult as the cross-modal sequence(s).

Temporal conditions employed in this study are also predicted to influence differentially the accuracy of orientation reproduction in each modality condition. There is, for instance, much evidence that modality and memory are interrelated. Goodnow (1971) examined the effects of delay in visual and haptic intra- and cross-modal form-matching tasks. Memory demands appeared to have little effect on information gathered visually; however, accuracy diminished with increases in delay in the intra-modal tactile matches. Cross-modal matching conditions were equally difficult when imposed delay was minimal, but increases in delay, although decreasing in accuracy generally, resulted in superior performance by the visual-tactile sequence (visual standard).

The aforementioned studies provide no definite information concerning the "central processes" responsible for cross-modal matching and transfer. Nevertheless, they do suggest that there are some central mechanisms for the detection of information about form common to visual and haptic perception. E. J. Gibson (1964) suggests that stimulus information is invariant among the modalities and that cross-modal transfer or discrimination may be dependent on invariant features common to several modes of stimulation. Questions remain, however, as to whether this common information is processed in equivalent manners and with equal veridicality by different modalities (Lechelt et al., 1976) and whether all stimulus input is referred to a common perceptual mechanism (Brumaghim & Brown, 1968). From the results of their investigation, Brumaghim & Brown conclude "that within an adjustment for differential acuity between vision and active touch input is referred to a common perceptual mechanism." The suggestion is that once the stipulated adjustments have been made the similar graphic representations obtained provide support for a single perceptual mechanism.

Briefly, the present thesis is concerned with the investigation of the "oblique effect" within and across the visual and haptic modalities and, in particular, the accuracy of orientation reproduction both intra- and cross-modally. In the intramodal conditions, the visual modality is expected to result in more accurate orientation reproduction than the haptic modality. No specific prediction is made regarding the superiority of the visual-haptic vs. the haptic-visual conditions due to the discrepancy in results found in the literature. Also of interest is the effect of different temporal conditions on the accuracy of orientation reproduction in all modality conditions; the simultaneous matching condition is predicted to produce, in all modalty conditions, reliably more accurate responses than the memory-delay matching condition.

Method

The order of intra- and cross-modal treatments was counterbalanced across subjects such that half of the subjects first served in the intramodal experiment and for the other half, the order was reversed.

Experiment I: Intramodal Study

Subjects

Sixteen university students, 7 males and 9 females, were selected for participation in this study under the restriction that they have a right hand preference; i.e., the right hand is used for writing. Subjects were payed on an hourly basis. The first experiment took approximately 2 1/2 hours.

Design

This experiment consisted of a 6x2x2x2 repeated measures design, ~~the~~ conditions respectively being orientation (0°, 45°, 90°, 135°, 225°, 315°), modality (visual, haptic), response comparison condition (simultaneous matching, memory-delay matching) and response side (r. [illegible] left).

Three repeated measures were taken of each of the 6 orientations for each response side by modality by response comparison condition. Each of these 18 stimulus orientation presentations [illegible] given in a different random order for each response side condition. The experiment thus comprised a total of 36 trials per response comparison condition and 72 trials per modality.

In the haptic modality condition, response side was defined in terms of: (1) the assignment of standard and comparison stimulus rods to either the right or left side, and (2) perceiving and response hands, respectively; i.e., the perceiving hand inspected the orientation of the standard stimulus and the responding hand manipulated the comparison stimulus to produce an orientation equivalent to the standard. Response side in the visual modality condition was comparatively defined in terms of position (right or left) of the standard and comparison stimuli.

The memory-delay matching condition consisted of a 5 sec. stimulus inspection interval of the standard stimulus followed by a 10 sec. interlude and then the response. A "ready" signal was given at the beginning of each trial and the onset and termination of each interval was signaled by an auditory cue. In the simultaneous matching condition, subjects made their response, visual or haptic, by adjusting the orientation of the comparison rod while viewing or feeling the standard rod, respectively.

Visual Stimuli

Two 5/16 by 8 in. aluminum rods painted a luminescent pink were mounted separately on 18 in. diameter circular plywood frames painted in flat black. One of the rods was attached to an axle protruding through the frame center and connected to a Selsyn motor behind the frame. The Selsyn motor was, in turn, connected to a remote control unit which was employed by the subject to manipulate the orientation of the comparison rod which could be rotated both clockwise and counterclockwise. The other luminous rod was attached directly to the second frame in radial orientation from the center; the frame itself was attached at its center to an axle. Movement was under manual control. The axles of both frames were separated approximately 19 in. horizontally. Behind each of the plywood frames, 360 degree protractors were attached to the axles enabling the experimenter to determine the exact position of each rod.

In the visual modality, the rod connected to the Selsyn motor invariably served as the response stimulus, the other rod serving as the standard stimulus. Changes in response side necessitated a change in the position of the rods and their frames.

Haptic Stimuli

The stimulus rods used in the visual condition were also employed as the haptic stimuli. However, a clamp was attached to each axle behind the frame, enabling the experimenter to fix and hold either rod at any desired orientation. Standard and comparison rods were, again, identical to the visual stimuli in all physical specifications.

General Apparatus

In order to eliminate environmental or contextual cues, subjects sat on a black wooden stool in a small booth (72 in. x 27 in. x 40 in.) the interior of which was painted a flat black. A black curtain, hanging from a curved curtain rod inside the booth, was arranged in a quasi semi-circular manner around the subject and across the opening of the booth. In order to permit inspection of the rods two adjacent holes were cut in the cloth, their centers at a height approximating average shoulder level to a person sitting on the wooden stool. The stimuli were mounted at the appropriate height behind the curtain.

Haptic access to the stimulus rods was via sleeved openings fastened to the curtain; this arrangement prevented viewing of the stimuli. Subjects, by putting their hands through the sleeves, could manually manipulate and explore the orientation of the aluminum rods. In the visual condition subjects were able to see only the stimulus rods and their background circular frames. However, for the memory-delay matching condition in the visual modality, a circle of black construction paper concealed the rod and frame of the standard stimulus.

Procedure

Visual Condition. The experiment began with the subject being seated between and 21 in. from the stimulus rods. The subjects were free to look about the apparatus as the instructions were read (see Appendix). Briefly, the subject was informed that he/she would be requested, under 2 different response comparison conditions, to explore a standard stimulus orientation and reproduce it by either using the remote control unit (visual condition) or by manual manipulation of the rod (haptic condition). Speed and accuracy were emphasized. Following the instructions, the subject was shown the 6 orientations to be used in the experiment. The curtain was then drawn in the booth and the laboratory lights were turned off. Subjects were given approximately 5 mins. to adapt to the illumination in the booth.

Prior to the start of each trial, the comparison stimulus was randomly set to one of the 5 orientations not being tested on that trial. The comparison stimulus in the simultaneous matching condition was adjusted by the subject to be at an orientation equivalent to that of the standard. In the memory-delay matching condition, the circle of black construction paper concealing the standard was removed by the experimenter and then replaced after 5 secs. of exposure to the stimulus. A 10 sec. interval elapsed and was followed by the subject's attempt to reproduce, via the comparison stimulus, the orientation that he/she had seen just 10 secs. earlier.

A 5-10 minute intersession between the 2 modality conditions provided a rest for the subject and enabled the experimenter to make necessary apparatus adjustments.

<u>Haptic Condition</u>. The black cloth sleeves were placed over the holes in the curtain and wooden braking devices

were attached to the axles behind the frames. After placing his/her hands through the sleeves in the simultaneous matching condition, the subject was requested to explore the standard stimulus with the appropriate hand (i.e., appropriate to the condition of response side) and attempt to produce simultaneously an equivalent orientation on the comparison stimulus with his/her other hand. Before commencing each trial in the memory-delay matching condition, the subject was asked to place a finger on the stimulus rod; this enabled the subject 5 full secs. of inspection of orientation. In this way the interval did not pass with the subject merely locating the rod and thereby leaving no time for inspection of its orientation.

With the sound of the alerting auditory cue, the subject (with a specified hand) haptically explored the standard stimulus for 5 secs.; after a 10 sec. delay, the subject endeavored to reproduce (with his/her other hand) the perceived orientation.

Starting modality was randomized such that half of the subjects began this experiment with the visual condition and proceeded onto the haptic condition. For the remaining subjects the reverse was true.

At no time was the subject given feedback regarding his/her performance.

Experiment II: Cross-modal Study

Subjects

The same subjects who served in Experiment I also participated in Experiment II. This experiment took approximately 1 1/2 hours and subjects were again payed on an hourly basis.

Design

A 6x2x2 design was employed, the conditions respectively being orientation, modality, and response comparison condition. In this experiment, the modality conditions were visual-haptic (VH) and haptic-visual (HV); the first modality specified indicates the stimulus inspection mode of the standard stimulus while the second indicates the response mode of the comparison stimulus. In the VH condition, for example, an orientation would be inspected visually and the subject would respond by haptically adjusting the comparison rod to be at an equivalent orientation.

Three repeated measures were taken of each stimulus orientation giving a total of 18 trials per modality under each response comparison condition. Each of the 18 orientations were presented in random order with a different randomly ordered sequence of 18 orientations being used for each modality by response comparison condition.

Stimuli and Apparatus

The stimuli and apparatus of this experiment were identical to those described in Experiment I. In the present experiment, however, the rod connected to the Selsyn motor was positioned on the subject's left and the other rod and frame on his/her right. These positions were maintained throughout the duration of the experiment. In this manner visual stimulation and response invariably occurred on the subject's left and haptic stimulation and response on his/her right.

Procedure

Subjects were introduced to the experiment and apparatus in a manner similar to that in the intramodal study. Speed and accuracy were again emphasized. Half of the subjects began the experiment in the VH modality condition and proceeded onto the HV condition. For the remaining half of the subjects the converse was true.

Visual-haptic Condition. In the simultaneous matching condition subjects visually observed the standard stimulus and simultaneously strived to reproduce it haptically. In the memory-delay matching condition there were 5 secs. exposure to the visual stimulus followed by a 10 sec. interval. Subjects were then required to haptically reproduce the orientation just seen.

Haptic-visual Condition. In the simultaneous matching condition the standard stimulus was explored haptically with the right hand and a visual reproduction was attempted using the remote control unit. In the memory-delay matching condition there was again a 5 sec. period for haptic exploration of the standard followed by a 10 sec. interval. Subjects then attempted to reproduce the haptic stimulus orientation in the visual modality by operating the remote control unit.

Results

Subjects' reproduced orientations were recorded to the nearest half degree. A preliminary statistical analysis was undertaken to test for a possible order effect between Experiment I and Experiment II (the order of the experiments was balanced across subjects). Results of this analysis provided support for the consideration of these 2 experiments as independent studies.

A second preliminary analysis compared absolute mean errors of reproduced orientations with mean errors based on both over- and under estimation of the reproduced orientations (i.e., the sign of direction of error was taken into consideration). When direction of error was considered, overall mean errors of -1.12° and -0.05° were obtained for the intramodal and cross-modal experiments respectively. On the other hand, absolute mean errors for the intra- and cross-modal conditions were 4.81° and 5.04°, respectively. The diminished error when direction, i.e., over- or underestimation, is considered arises from a cancellation effect which occurs when averaging across response errors of opposite sign. Absolute mean error, however, reflects the magnitude of error regardless of sign or direction. As the primary concern of the present experiments is with the accuracy of orientation reproduction, all subsequent data analyses are based on absolute mean errors.

Experiment I: Intramodal Study

A summary of the results of this experiment is depicted by Figure 1 which illustrates the functional relationship of the absolute mean errors of the reproduced orientations for each condition of response comparison by modality. A 2 (response side: right, left) by 2 (response comparison condition: simultaneous matching, memory-delay matching) by 2 (modality: visual, haptic) by 6 (orientation: 0°, 45°, 90°, 135°, 225°, 315°) repeated measures ANOVA was performed on the absolute mean errors of subjects' reproduced orientations (see Table 1). To assess the significance of the difference between specific treatment conditions, Duncan's new multiple range test was also employed to provide separate comparisons of all treatment means.

Significant Main Effects

The orientation main effect proved to be highly significant (*F*(5,2160) = 64.53, $p<.01$) and was largely the result of horizontal and vertical orientations being reproduced reliably more accurately ($p<.01$) than all oblique orientations. The visual and haptic modalities were also found to differ reliably (*F*(1,2160) = 58.98, $p<.01$). Errors of the haptic modality were greater than two times those of the visual modality (mean errors were 6.53° and 3.09°, respectively).

Error changes over trials (repeated trials factor), response side and, more important, the response comparison condition all failed to reach significance.

Significant Interactions

Significant 2 factor interactions included orientation by modality and modality by response comparison condition (F(5,2160) = 6.98, p<.01;F(5,2160) = 6.70, p<.01, respectively).

Significant interactions were also obtained between repeated trials and orientation (F(10,2160) = 5.38, p<.01) and among repeated trials by orientation by modality (F(10,2160) = 4.55, p<.01). Response side, although nonsignificant as a main effect, did reach significance in interaction with orientation (F(5,2160) = 8.25, p<.01) and also in interaction with modality and response comparison condition (F(1,2160) = 5.99, p<.05). One significant 4-way interaction, orientation by modality by response side by response comparison condition, was obtained (F(5,2160) = 3.52, p<.01). All of these higher order interactions, however, lacked systematic patterns of differences and thus are essentially uninterpretable.

Experiment II: Cross-modal Study

Analyses performed on the intramodal data were also repeated for the cross-modal experiment. A 2 (modality: visual-haptic, haptic-visual) by 2 (response comparison condition: simultaneous matching, memory-delay matching) by

6 (orientation: 0°, 45°, 90°, 135°, 225°, 315°) repeated measures ANOVA was applied to the absolute mean errors of subjects' reproduced orientations (see Table 2). Similarly, Duncan's new multiple range test was employed to provide separate comparisons of all treatment means.

Significant Main Effects

An illustrated summary of the ANOVA results is depicted in Figure 2. Orientation, modality, and response comparison condition all resulted in significant main effects ($F(5,1080) = 7.44$, $p<.01$; $F(1,1080) = 5.36$, $p<.05$; $F(1,1080) = 28.57$, $p<.01$, respectively). Again, horizontal-vertical and oblique orientations, with cell means of 3.42° and 5.86° respectively, were found to differ reliably ($p<.01$). The difference between the cell means of the visual-haptic and haptic-visual modalities, 5.02° and 5.07° respectively, although extremely small were, nonetheless, significantly different. Subjects also performed reliably more accurately in the memory-delay matching rather than the simultaneous matching condition (cell means were 4.33° and 5.76°, respectively).

Significant Interactions

Only one significant 2 factor interaction was obtained, orientation by response comparison condition ($F(5,1080) = 2.36$, $p<.05$). Figure 2 illustrates this relationship; averaging over modality conditions, the memory-delay matching condition was reliably more accurate ($p<.05$) than the simultaneous matching condition at 0°, 45°, 90° and 315° but significantly less accurate at 135° and 225°.

Discussion

The present 2 experiments were designed to examine the "oblique effect" within (VV, HH) and across (VH, HV) visual and haptic modalities. Also of interest to this research was the effect of simultaneous vs. successive stimulus matching on the magnitude of the "oblique effect". Three predictions were made: (1) the "oblique effect" would occur across as well as within the visual and haptic modalities, (2) the visual modality would be most accurate in stimulus orientation reproduction, and (3) the simultaneous matching condition would produce superior performance in both modalities. The obtained data, however, although in agreement with the first two predictions were not commensurate with the last prediction.

Experiment I: Intramodal Study

Results showed that both modality and stimulus orientation significantly affected subjects' ability to reproduce stimuli in the selected orientations. Generally, the data trends of significant main effects in intramodal conditions show that: (1) when averaging across modalities, response comparison conditions, and response sides, reliable orientation asymmetries are obtained. Specifically, vertically and horizontally reproduced orientations were reliably more accurate than were subjects' reproductions of oblique orientations; i.e., the "oblique effect" was obtained, and (2) when averaging across orientations, response comparison conditions, and response sides, mean error discrepancies obtained between the visual and haptic modalities are significantly different. In particular, haptic mean errors were more than twice the size of the visual mean errors.

Figure 1 illustrates the lack of a response comparison main effect. The response comparison conditions differed little at horizontal-vertical orientations; however, at oblique orientations the order of accuracy of the 2 temporal conditions in the visual modality is the reverse of that obtained for the haptic modality. In the visual modality, superior orientational reproductions were produced in the simultaneous matching conditon while greater accuracy was obtained by the haptic modality in the memory-delay matching condition. The 2 temporal conditions thus appear to be modality specific in terms of their effects.

Both of the significant main effects are consistent with initial predictions as well as with related experimental and theoretical work. Many of the results obtained in this experiment generally confirm those obtained by Lechelt et al. (1976) in a similar intramodal study examining visual and haptic orientation reproduction. The presence of the "oblique effect" in the visual and haptic modalities, reported by Lechelt et al., is supported by the data collected here; i.e., vertical and horizontal orientations were produced reliably more accurately than any of the remaining oblique stimulus orientations (see

Figure 1).

Neurophysiological evidence of the visual "oblique effect" has been provided by Levanthal and Hirsch (1975) who recently reported that "neurons in the visual cortex that respond preferentially to diagonal contours are present only in cats exposed to diagonal lines early in life". This postion is further corroborated with additional research evidence by Mansfield (1974) who showed that postnatal visual experience appears to determine the development of different populations of orientation-specific neuronal cells as manifested in measures of visual acuity. These experiments, commensurate with that of Annis & Frost (1973) who posit a tuning of orientation specific detectors by the early visual environment, suggest that both neurological factors and experience are involved in visual stimulus orientation perception.

Neurological explanations of the "oblique effect" in the haptic modality are much more speculative. Wall (1970) noted the importance of the dorsal columns which initiate and program motor movements necessary in active haptic exploration (i.e., sequential analysis) for successful discriminition among stimuli. An additional role of the dorsal column, observed by Basbaum & Hand (1973), is the sensory-motor integration of information resulting from haptic stimulus exploration. On the basis of these studies, Lechelt et al. (1976) suggest that haptic orientation analysis is a function of "differential neurological sensitivity to patterns of haptic input varying in tactileproprioceptive composition and resulting from haptic exploration of stimuli in different spatial orientations." From an experiential point of view, the fact that the haptic aesthetics of rectangular form are perceived differentially by congenitally blind and blindfolded-sighted subjects (Hintz & Nelson, 1971) suggests haptic perceptual awareness and discrimination are influenced by differential haptic experiences. Thus at least some haptic discriminations also appear to be a function of both experiential and endogenous factors.

Equally apparent as the obtained "oblique effect" is the reliable difference between the 2 modalities (see Figure 1). Although identical stimuli and stimulus arrangements were employed in both modalities, the differences in mean errors of the 2 modalities suggest a discrepancy in their phenomenal worlds (Cutsforth, 1951). Revesz (1950) suggests the haptic perceptual to function in terms of "successive perception".[1] A total and veridical haptic perception of an object cannot be obtained instantaneously. Haptic perception of a whole form involves taking a number of samples over time; vision in contrast, takes in more information per unit time - objects exist relatively more simultaneously for vision. It is primarily the successive nature of haptic information pickup that makes it less

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[1] Sculptural creativity of the blind provides evidence suggesting haptic production also is based on this same principle. Revesz (1950) demonstrates that the process of modelling by blind students is such "that the sculptural parts are modelled separately and independently of each other."

accurate in its perception of objects.

This differential sensitivity between the 2 modalities has also been specified by Lederman & Taylor (1969) in terms of S. S. Stevens' psychophysical power function. These authors show that the exponent of the power function is larger for touch distance than for visual distance; i.e., "distance perceived tactually increases faster as a function of physical distance than does distance perceived visually." Their touch exponent ranges from 1.1 to 1.3 whereas the visual is approximately 1.0. A second observation made by these authors is that constant errors of touch interpolation of angles are consistently larger than those of vision. The constant errors of touch were, in fact, about twice as large as the visual errors. The similar direction of errors between the 2 modalities is consistent with the results obtained in the present study.

The significance of the main effects must be examined in view of the obtained significant interactions. The orientation by modality interaction indicates reliable differences between the visual and haptic modalities in terms of their abilities to reproduce the different stimulus orientations. Averaging across response comparison conditions and response sides, mean errors of reproduced orientations ranged from 1.55° to 4.84° and from 3.34° to 8.53° for the visual and haptic modalities, respectively. Vision was most accurate at 90° and least accurate at 225° while the corresponding orientations for the haptic modality were 0° and 135°, respectively.

Examination of the response comparison by modality interaction in terms of stimulus orientations is particularly relevant. Despite the nonsignificance of the response comparison main effect, its significant interaction with modality nevertheless indicates that the response errors of the modalities differ as a function of the temporal condition. The response comparison conditions had substantial but opposite effects in the 2 modalities. While visual performance was superior in the simultaneous matching condition (mean simultaneous and memory-delay matching errors were 2.88° and 3.30°, respectively), greater accuracy was obtained by the haptic modality in the memory-delay matching conditon (mean simultaneous and memory-delay matching errors were 6.77° and 6.29°, respectively).

Interesting comparisons may be made between these results and those of Lechelt et al. (1976) who employed a purely memoric rather than a memory-delay matching condition. At horizontal-vertical orientations Lechelt et al.'s subjects performed more accurately in the memory condition of both modalities; at oblique orientations, the simultaneous matching condition was generally most superior. Averaging over orientation (and also over response side in the present study), the results of the 2 studies are congruent - performance was better for the simultaneous matching condition of the visual modality and for the memory demand condition of the haptic modality. This result is inconsistent with those obtained in studies of form matching tasks (Milner & Bryant, 1970; Rudel & Teuber, 1971; Goodnow, 1971a; Rose, Blank & Bridger, 1972; Abravanel, 1973) in which delay was reported to interfer more with tactual functions than with visual thereby suggesting that form perception is easier in vision than in touch (Lobb, 1968).

The results of this experiment and that of Lechelt et al. (1976) suggest a possible distinction between haptic and visual modalities in terms of an internal versus an external representation of stimulus orientation. Perceptual systems in young children are governed by their dependence on external frameworks; however, with increasing perceptual experience as a function of age, in adults external referents can become internalized to form an internal perceptual referent or framework (Bryant, 1974). Modalities would also seem to differ in the extent to which they reflect an internal or an external dependency. Visual perception, which occurs relatively simultaneously, appears to rely on immediately observable cues, i.e., an external framework. The haptic modality, in which perception is successive, appears to rely on an internal framework; the internal framework, however, would be based on visual space in that haptic perception of a particular stimulus attribute will result in that attribute being "processed" with reference to an internalized visual framework. Haptic response, therefore, might reflect a reference to this internal framework (Bryant, 1974). Based on the results of the present study, it appears that the subjects' internal frameworks are lacking veridicality in regard to visual space; hence greater accuracy is obtained by the visual modality in stimulus orientation reproduction which reflects a greater dependency on an external perceptual framework. Response accuracy is diminished in the haptic modality which also intimates a possible internalization of visual space to which subjects are responding rather than making a response to the direct stimulus attributes. In the simultaneous matching condition, the haptic modality has an additional handicap due to the interference of reafferent information with the continuous incoming stream of new information obtained as the hand slides along the stimulus rod. The decreased accuracy of the visual modality and the superior accuracy of the haptic modality in the memory-delay matching condition may have resulted from a tendency of the external framework to be subject to a more rapid decay in memory.

Several subjects of the present experiment appeared to have relied upon an internal framework in conditions involving haptic perception of stimulus orientation. These subjects, during the 5 sec. haptic exposure to the standard stimulus, simply would locate the stimulus rod, determine its orientation on the frame and then remove their hand from the rod immediately upon acquisition of this information. The full 5 sec. interval was not employed in active exploration.[2] This preliminary inspection by these particular subjects may have been merely to determine which

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[2] Upon detection of this tactic, the experimenter would ask the subject to maintain contact with the stimulus rod until the termination of the interval. Active haptic exploration still was not initiated; the subject's hand or finger would merely rest on the stimulus rod.

of the 6 orientations was being tested; fine adjustment when responding would, therefore, be dependent on reference of the internal framework.

Experiment II: Cross-modal Study

Each of the main effects (modality, orientation, and response comparison condition) proved significant in the cross-modal experiment. An examination of mean errors is particularly useful in summarizing the results and comparing the magnitude of errors of the various conditions. Figure 2, illustrating the obtained effects, shows that: (1) a reliable "oblique effect" occurred when averaging across modality and response comparison conditions: the mean horizontal-vertical errors were reliably less than average errors in oblique reproductions (cell means were 3.42° and 5.86°, respectively), (2) when averaging across orientation and modality, orientation reproduction was reliably more accurate in the memory-delay matching condition than the simultaneous matching condition (mean errors were 4.33° and 5.76°, respectively), (3) the VH modality condition was reliably more accurate than the HV condition (mean errors were 5.02° and 5.07°, respectively), and (4) orientation was not independent of response comparison conditions when averaged over modality; for all orientations excepting 135° and 225°, greater accuracy was obtained by the memory-delay matching condition ($p<.05$).

Of greatest significance to the present study is the demonstration of the "oblique effect" in the VH and HV modality conditions (p<.05) (note, however, that the 90° orientation did not differ reliably from the 315° orientation in the VH modality). The presence of the "oblique effect" in cross-modal tests suggests it to be a very robust phenomenon. Although evidence of the extent to which endogenous factors are responsible for cross-modal orientational anisotropies has yet to be specified, the reported results suggest a connection between the 2 intramodal systems. In fact, neurophysiological evidence for cross-modal processing has been recently uncovered. Petrides and Iversen (1975) claim to have located the process of cross-modal matching in the primate prefrontal cortex. Anatomical (Pandya & Kuypers, 1969; Jones & Powell, 1970) and physiological (Albe-Fessard & Besson, 1973) evidence suggest that the arcuate cortex may play an important role in multi-modal tasks. Petrides & Iversen noted an impairment in the ability of monkeys to make cross-modal matches when lesions were made in the arcuate sulcus. These authors suggest poor cross-modal performance as: (1) the result of imperfect integration of information, or (2) the inablilty to use the multi-modal information in order to execute an appropriate response. From an experiential point of view, Bryant (1969), noting the difficulty of children in distinguishing opposite obliques (an apparently easy task for adults) concludes that the reported improvement with age in cross-modal performance occurs as a result of a corresponding improvement in discriminating within modalities. This improvement may be attributed to the development of internal frameworks (Bryant, 1974). Together, the above explanations support Annis & Frost's proposal for the tuning of orientation-specific neuronal detectors by an ecological environment. It would seem, then, that development of the cross-modal system would entail at least a 2 stage process: (1) early tuning of the individual visual and haptic orientation-specific neuronal detectors must first occur in order for (2) a cross-modal neurophysiological connection to develop.

Despite the small mean error difference, the VH and HV modality conditions were found to differ reliably. This result is consistent with that of previous research confirming the variability in accuracy of the 2 cross-modal sequences. The asymmetries in transference errors between VH and HV transfer for form matching have been suggested by Lobb (1968) to be due to poorer learning in the tactual modality. In terms of the present experiment with the haptic standard in the HV sequence, if little "learning" occurs about the standard stimulus, then only as much information as was "learned" could be transferred. This explanation would also account, in part, for the poor performance of the HH modality condition in that little "learning" about the standard would tend to prevent accurate reproductions of stimulus orientation.

Two theories of cross-modal matching have been proposed. Goodnow (1971) postulates an added demand of the transformation of original information about the standard stimulus so that it can be matched with input about the comparison stimulus coming from the other modality. She also proposes that the memory demand in cross-modal conditions may prevent a sufficient amount of haptic input obtained from the brief exposure to the standard from being transformed. (It is important to recall that Goodnow had obtained results in which "memory demands imposed by time or interference appear as limited to information gathered by hand"). Although her initial premise is not invalidated by the present data, her final proposition is inconsistent with results obtained here where memory demands produced superior accuracy for both (VH, HV) cross-modal conditions.

A second theory is posited by Gibson (1969) in which she contends that active exploration (visual and haptic) does not necessarily produce communication between the 2 senses. She further suggests that as a result of active exploration distinctive features of an object are isolated by each sense modality each of which must perceive the same distinctive features for successful cross-modal matching. In a test of preschool children, Jesson & Kaess (1973) obtained results supporting this idea of minimal cross-modal feedback communication between the visual and haptic senses. The present findings are also supportive of this position.

Comparing the results of the 2 experiments in the present study, absolute mean errors of modality in ascending order were 3.09°, 5.02°, 5.07° and 6.53° for the respective VV, VH, HV and HH modality conditions. In congruence with the results of previous studies (Milner & Bryant, 1970;

Rudel & Teuber, 1971; Abravanel, 1972; Rose, Blank & Bridger, 1972), those of the present thesis indicate that cross-modal matches (VH, HV) are intermediate in difficulty between that of their components' intramodal levels (VV, HH) or as difficult as the most difficult intramodal combination.

Extending the comparison of the present 2 studies, several differences may be noted: (1) the overall mean error of the cross-modal experiment, 5.04°, was only slightly larger than that of the intramodal experiment, 4.81°; (2) the response comparison main effect obtained significance in the cross-modal but not the intramodal study in which the 2 temporal conditions were modality specific; and (3) comparisons of modality conditions across both experiments show that accuracy was greatest in the memory-delay matching condition for all (VH, HV, HH) but the VV modality condition.

The superiority of performance in memory demand conditions is somewhat inconsistent with the results of all previous research. It may be that memory "demand" might well be a misnomer and that the increase in accuracy with delay intimates the necessity of a stimulation-free interval permitting cross-modal transfer free of interference of reafferent information with continuous inflowing new information. A brief perception of orientation may be all that is required for accurate reproduction; a stimulation-free interval following would then permit efficient and accurate processing of this information for response purposes. It may be that interference in terms of perceptual-response feedback results in inefficient transfer; i.e., a system overload reduces accuracy. This proposition, however, is contrary to the expectation that continual access to the standard stimulus throughout the trial (simultaneous matching condition) favors corrective responses on the comparison stimulus.

The direction of future research toward a more complete investigation of temporal effects on orientation perception may provide evidence toward a more definitive explanation of the obtained superior performance under conditions of memory for VH, HV and HH modality conditions. The present research may also be extended to children in order to determine the effects of development on stimulus orientation perception and to provide further insight concerning endogenous and experiential factors in orientation perception.

Table 1

Repeated Measures Analysis of Variance Results for Experiment I: Intramodal Study.

Source	SS	df	MS	F
Repeated measures factor (R)	18.15	2	9.07	0.39
Orientation (O)	5067.20	5	1013.44	64.53**
Modality (M)	6828.61	1	6828.61	58.98**
Response comparison condition (T)	0.46	1	0.46	0.03
Response side (H)	1.11	1	1.11	0.04
RxO	131.59	10	13.16	5.38**
RxM	55.69	2	27.84	0.74
OxM	684.63	5	136.93	6.98**
RxT	47.11	2	23.56	1.36
OxT	78.52	5	15.70	0.91
MxT	115.78	1	115.78	6.70**
RxH	0.97	2	0.49	0.02
OxH	445.83	5	89.17	8.25**
MxH	25.10	1	25.10	0.24
TxH	26.16	1	26.16	1.51
RxOxM	182.82	10	18.28	4.55**
RxOxT	24.46	10	2.45	0.14
RxMxT	75.51	2	37.76	2.18
OxMxT	98.11	5	19.62	1.13
RxOxH	108.90	10	10.89	1.39
RxMxH	17.63	2	8.82	2.13
OxMxH	147.08	5	29.42	0.48
RxTxH	54.60	2	27.30	1.58
OxTxH	54.06	5	10.81	0.63
MxTxH	103.57	1	103.57	5.99*
RxOxMxT	40.16	10	4.02	0.23
RxOxMxH	123.48	10	12.35	1.52
RxOxTxH	78.17	10	7.82	0.45
RxMxTxH	8.28	2	4.14	0.24
OxMxTxH	304.61	5	60.92	3.52**
RxOxMxTxH	81.08	10	8.11	0.47
S(ROMTH)	37344.63	2160	17.29	

* $p<.05$
** $p<.01$

Table 2

Repeated Measures Analysis of Variance Results for Experiment II: Cross-modal Study.

Source	SS	df	MS	F
Repeated measures factor (R)	16.56	2	8.28	1.43
Orientation (O)	1801.34	5	360.27	7.44**
Modality (M)	0.97	1	0.97	5.36*
Response comparison condition (T)	588.67	1	588.67	28.67**
RxO	103.23	10	10.32	0.99
RxM	20.94	2	10.47	0.57
OxM	40.77	5	8.15	0.71
RxT	11.57	2	5.79	0.28
OxT	242.10	5	48.42	2.36*
MxT	0.18	1	0.18	0.01
RxOxM	103.28	10	10.33	0.80
RxOxT	104.21	10	10.42	0.51
RxMxT	36.92	2	18.46	0.90
OxMxT	57.59	5	11.52	0.56
RxOxMxT	129.62	10	12.96	0.63
S(ROMT)	22175.09	1080	20.53	

* p<.05
** p<.01

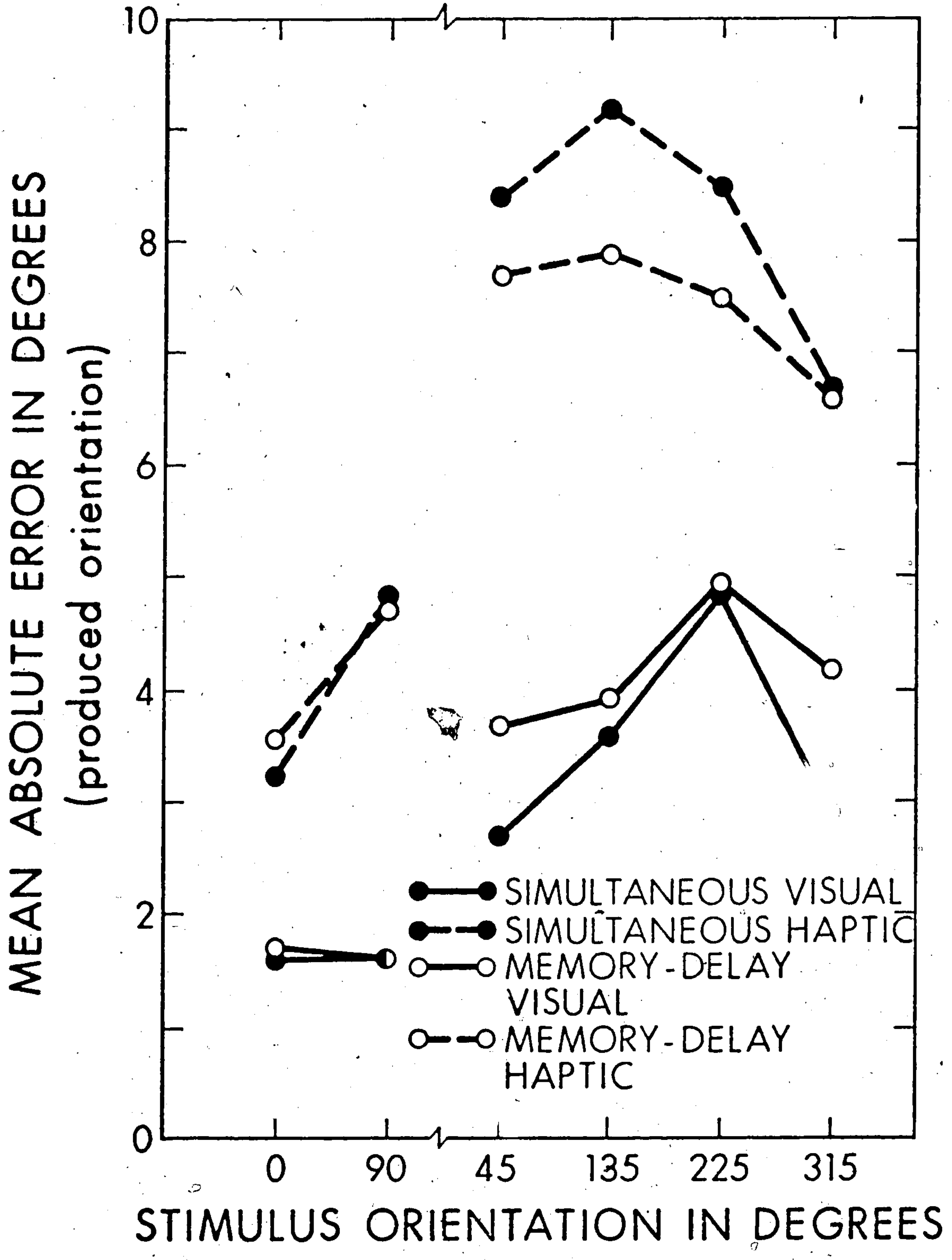

Figure 1: Experiment I: Intramodal Study. Mean absolute error of product orientations shown as a function of stimulus orientation for all conditions of response comparison and modality.

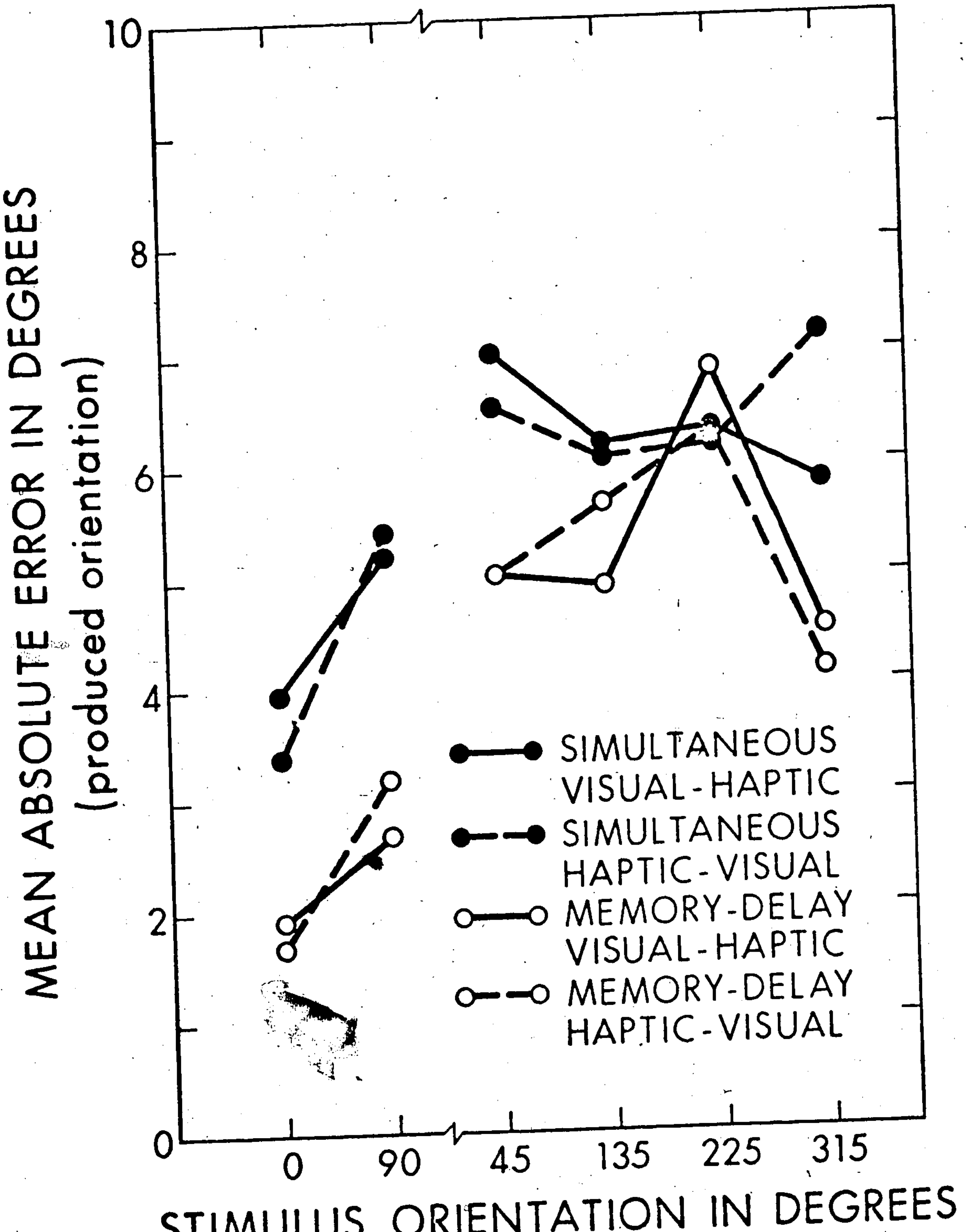

Figure 2: Experiment II: Cross-modal Study. Mean absolute error of produced orientations shown as a function of stimulus orientation for all conditions of response comparison and modality.

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Appendix

Instructions

Set A

The following instructions were read to those subjects who began with Experiment I followed by Experiment II.

Experiment I: Intramodal Study

First of all let me welcome you to the experiment. It is a follow-up of an experiment conducted by Doctor Lechelt last year for the determination of perceptual accuracy of the average individual. The experiment will last approximately 2 1/2 hours; we hope you will find it interesting and perhaps enjoyable. I would like to assure you, however, that we are not trying to assess how "different" you are from others. On the contrary - we do not have a standard of comparison as yet. Your honest effort in this experiment and that of other students will help us determine one. This standard may then be used by other researchers for further exploration of human abilities.

Last year we conducted an experiment in which we had students reproduce an orientation by either vision or touch. In the current experiment you will be doing the same. In those trials involving touch you will feel a rod at a particular orientation for 5 seconds; a 10 second interval will follow. Your task is to reproduce, with the alternate rod in front of you, the orientation that you had seen just 10 seconds earlier. As you can see both rods and frames are essentially identical. As an example of your task, if you feel an orientation for 5 seconds with your right hand, you would (after the 10 second interval) produce the same orientation with your left hand. There will, however, be other times when you will feel the rod on your left and attempt to reproduce its orientation on your right. Before each of these trials involving the use of your memory, I will ask you to first locate the rod with your finger such that the full five seconds can be used to explore its orientation. In this way no time will be wasted in merely trying to locate the rod. There will be no time limit when you are reproducing the orientation. Now, why don't you put one of your hands through the sleeve in order that you will know what to expect when the experiment begins. I would like you to note that to get the maximum amount of information about the orientation it is suggested that you run the rod between your thumb and forefinger. Try it. Good.

Now there will be other times when you will be using your sense of vision. On these trials I will, for example, expose to you an orientation on your right for 5 seconds; a 10 second interval will follow subsequent to when you will attempt to make a reproduction on your left using the remote control unit which is resting on your lap. This unit allows both backwards and forwards motion of the rod. Try the unit and see how it works.

Good.

Again the order will change such that in some cases you will see a rod on your right and reproduce it on your left and at other times you will look at the rod on your left and reproduce it on your right. The beginning and ending of each interval will be marked by a loud "click" which sounds like this .... The various stages of each trial will also be verbally announced by myself.

In another part of this experiment you will be working with both rods simultaneously. For example, if you are using your sense of touch, you will feel a particular orientation with one hand and simultaneously attempt to replicate it with your other hand. Both hands will be working at the same time. For trials involving the employment of vision, both boards will be exposed. A particular orientation will be set on one board and you will attempt to match this orientation on the other board using the remote control unit.

Although you will not be timed as you produce the appropriate orientation, please try and be as quick and as accurate as possible in making your response.

I am aware this experiment may sound difficult and complex, but to enable you to become familiar with the procedure, I shall guide you through it.

Experiment II: Cross-modal Study

I would like to welcome you to the second part of this experiment. It will be similar to the first part with one exception: in the last part of the experiment you worked within your senses, i.e., you worked from vision to vision and touch to touch; in this part of the experiment you will work across your senses, i.e., from vision to touch and from touch to vision. In some cases you will see or feel a rod at a particular orientation for 5 seconds; a 10 second interval will follow. After the 10 seconds you will be asked to reproduce the same orientation by the alternate sense. For example, if you observe (i.e., using your sense of sight) an orientation for 5 seconds, after the 10 second interval you will reproduce the same orientation by your sense of touch. In these trials you will be relying on your memory.

There will also be other trials requiring you to use both your senses simultaneously. In some cases you will see one orientation and, while looking at it, try to reproduce the same orientation by touch. The reverse will also occur - you will feel one orientation and, at the same time, try to reproduce it visually. Although you will not be timed as you produce the appropriate orientation, we do ask you to be as quick and as accurate as possible in making your response.

A small reminder - to get the maximum amount of information about the orientation with your sense of touch, it is suggested that you run the rod between your thumb and forefinger.

Don't panic - once again I shall guide you through the experiment.

Set B

This set of instructions was read to those subjects who began with Experiment I followed by Experiment I.

Experiment II: Cross-modal Study

First of all let me welcome you the the experiment. It is a follow-up of an experiment conducted by Doctor Lechelt last year for the determination of perceptual accuracy of the average individual. The experiment will last approximately 1 1/2 hours. We hope you will find it interesting and perhaps enjoyable. I would like to assure you, however, that we are not trying to assess how "different" you are from others. On the contrary - we do not have a standard of comparison as yet; your honest effort in this experiment, and that of other students, will help us determine one. This standard may then be used by other researchers for further exploration of human abilities.

Last year we conducted an experiment in which we had students reproduce an orientation by either vision or touch. In the present experiment you will be using both senses together. In some cases you will see or feel one rod at a particular orientation for 5 seconds; a 10 second interval will follow. After the 10 seconds you will be asked to reproduce the same orientation with your alternate sense via the other rod. As you can see both rods and frames are essentially identical. If you observe, for example, an orientation for 5 seconds, after the 10 second interval following you will produce the same orientation by your sense of touch. You would put your hand in the sleeve directly in front of you and to your right and manually move the rod. For those trials in which you will be going from touch to vision, I will first ask you to locate the rod with a finger on your right hand such that you will have 5 full seconds of exploration. In this way no time will be wasted in merely trying to locate the rod. When reproducing the orientation visually you will use the remote control unit resting on your lap. This unit allows both backwards and forwards motion.

There is no time limit when you are reproducing the orientation. Now, why don't you put your hand in the sleeve and feel the rod behind just so you will know what to expect when the experiment begins. I would like you to note that to get the maximum amount of information about the orientation we suggest you run the rod between your thumb and forefinger. Now try the remote control unit to familiarize yourself with it. Good.

In these memory conditions the beginning and ending of each interval will be marked by a loud "click" which sounds like this .... The various stages of each trial will also be verbally announced by myself.

Now in another part of the experiment you will also be alternating from touch to vision or vision to touch with one difference. This time you will see one orientation and while looking at it try to reproduce the same orientation by touch. The reverse will also occur - you will feel one orientation and at the same time try to reproduce it vusually. Both senses will be operating simultaneously in this part of the experiment.

Although you will not be timed as you produce the appropriate orientation we do ask you to be as quick and as accurate as possible in making your response.

I am aware this experiment may sound difficult and complex. but to enable you to become familiar with the procedure, I shall guide you through the first few trials.

Experiment I: Intramodal Study

I would like to welcome you to the second part of this experiment. It will be similar to the first part with one exception: in the last part of this experiment you worked across your senses, i.e., you worked from vision to touch and from touch to vision; in this part of the experiment you will work within your senses, i.e., from touch to touch and vision to vision. In some cases you will see or feel a rod at a particular orientation for 5 seconds; a 10 second interval will follow. After the 10 seconds you will be asked to reproduce the orientation using the same sense modality. For example, if you observe (i.e., using your sense of sight) an orientation for 5 seconds, after the 10 second interval you will reproduce (via the alternate rod) the same orientation also by sight. Your response will be made by manipulation of the remote control unit resting on your lap. In these trials you will be relying on your memory.

There will, in addition, be other trials requiring you to use both your senses simultaneously. In some cases you will see one orientation and simultaneously attempt to reproduce it (via the other rod) by use of the remote control unit. The reverse will also occur - you will feel one orientation and at the same time try to manually manipulate the other rod to match it. Although you will not be timed as you produce the appropriate orientation, we do ask you to be as quick and as accurate as possible in making your response.

A small reminder - to get the maximum amount of information about the orientation with your sense of touch, it is suggested that you run the rod between your thumb and forefinger.

Don't panic - once again I shall guide you through the experiment.