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# SPATIAL S–R COMPATIBILITY UNDER HEAD TILT *

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Spatial stimulus–response (S–R) compatibility was investigated for different head positions. Subjects reacted with their right or left hand to a light presented to the right or left of a fixation point, pressing the spatially compatible or the spatially incompatible response key. Responding hands were either held in normal right or left position or were crossed. Three conditions of head posture were tested: Subjects responded (1) with upright head, (2) with the head tilted 90° to the right, and (3) tilted 90° to the left. Results showed a spatial compatibility effect for the upright-head condition. In the tilted-head conditions the spatial compatibility effect significantly decreased from the uncrossed-hands to the crossed-hands condition but did not shift to the opposite. These findings are discussed in relation to Ladavas and Moscovitch's (1984) results and interpreted with respect to a hierarchical model of spatial S-R compatibility.

## Introduction

Spatial S–R compatibility effects represent robust and stable experimental phenomena in choice reaction tasks. Reaction time advantages for spatially compatible over incompatible S–R relationships have been

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demonstrated under various experimental conditions, for bimanual choice reactions as well as for unimanual two-finger choice reactions, both for relevant stimulus location (e.g., Brebner et al. 1972; Nicoletti et al. 1982; Heister et al. 1986) and irrelevant stimulus location (e.g., Umiltà and Nicoletti 1985; Heister et al., 1987). One of the main theoretical models, which is supported by much experimental data, is the hypothesis of *spatial coding*. According to this hypothesis the relative spatial positions of stimuli and responses are related to each other in a spatial code, with the incompatible S–R pairings requiring an additional step of translation and thus yielding longer reaction times (Wallace 1971; Nicoletti et al. 1982; for the discussion of alternative hypotheses see Heister et al. 1986).

However, the reaction time advantage for certain S–R pairings, which is characteristic of spatial compatibility, takes place even when no spatial right/left cues are present for the response positions and the stimuli are still oriented along the spatial right/left dimension. For example, it still obtains when subjects press, with their right or left hand, the same key which is mounted in a middle position (Klapp et al. 1979), or, for unimanual two-finger choice reactions,when the responding hand is turned by 90° and the response buttons are oriented in the midsaggital plane perpendicular to the stimuli (Ehrenstein et al. 1988). This suggests that in addition to the coding of response position a coding of anatomically defined response organs as right or left may also be effective. To avoid terminological confusion we propose to denote the coding in the latter sense, i.e., the natural association of response organs as spatially right or left, by *spatio-anatomical mapping*, in short: *mapping*. In the following, when we simply speak of *coding*, we always mean the spatial coding of response *positions*.

In order to deal uniformly with the range of phenomena Heister et al. (1989) developed a hierarchical model of spatial S–R compatibility. According to this model spatial compatibility effects result from an interaction of various factors including spatial coding and spatio-anatomical mapping. Spatial coding normally dominates spatio-anatomical mapping and therefore accounts for the results of 'standard' experimental designs of S–R compatibility. However, in cases where spatial coding of stimuli and responses along the same spatial dimension is impeded or impossible (as in arrangements where the spatial dimensions of stimuli and responses are perpendicular to each other), the mapping factor becomes stronger or even dominant.

In the present study this hypothesis was tested under conditions in which spatial coding of stimulus and response positions is impeded by having subjects respond with the head tilted to the right or to the left. In this case one has to take into account that stimulus and response positions can be represented in *different* ways, i.e., in the environmental or physical frame of reference and in the egocentric or retinal frame of reference. Both are identical when the subject's head is in the upright position, but differ when the head is tilted (see Attneave and Olson 1967; Attneave and Reid 1968).

Ladavas and Moscovitch (1984) hypothesized that the association of the anatomically right and left hands as spatially right and left (i.e., spatio-anatomical mapping in our sense) becomes effective when subjects respond with the head tilted to the right or left and stimuli and responses are perpendicular to each other. They found reaction time advantages for those stimulus–response relations which are compatible when responding hands are conceived as right or left according to their *anatomical* classification and stimuli are conceived as right or left according to that frame of reference which makes a right/left classification possible. For example, if the head is tilted to the left and stimuli are presented vertically, then the egocentric frame of reference is chosen allowing the coding of the (environmentally) top stimulus as right and the (environmentally) bottom stimulus as left. Correspondingly, the anatomically right hand reacted faster to the egocentrically right (= environmentally top) and the left hand faster to the egocentrically left (= environmentally bottom) stimulus, irrespective of whether responding hands were held crossed or not.

In Ladavas and Moscovitch's (1984) study the conditions of head tilt and of the orthogonality of the stimulus–response arrangement were confounded, since for the tilted-head conditions either the stimuli were arranged horizontally (right/left) and the response buttons vertically (top/down), or vice versa. Therefore their study does not allow to distinguish whether it is essentially the orthogonality condition that causes spatio-anatomical mapping to dominate over coding of response positions or already the unusual head position with the possibility of different frames of reference being involved, or perhaps the combination of orthogonality of stimulus–response arrangement together with unusual head position. In order to resolve this confounding, we used the three head positions upright, right-tilted and left-tilted as in Ladavas and Moscovitch (1984), with stimulus positions and response positions always in the same right/left dimension, and not perpendicular to each other. So, compared to a standard S–R design, the only change was to add the tilted-head conditions.

Summarizing, the question to be answered by the following experiment was: Does the spatial S–R effect change when subjects respond with tilted head? And if there is a change, can it be explained by reference to the concept of spatio-anatomical mapping, either in the sense that the anatomical right/left classification now overrides spatial coding of response positions or in the sense that these different right/left distinctions interfere in some way?

## Method

### *Subjects*

Six female college students (aged 17–18 years) served as paid subjects. They were all right-handed as assessed by a German adaptation of the Edinburgh Inventory (Oldfield 1971), had normal vision and had already participated in a somewhat different reaction task, but were naive as to the purpose of this study.

### *Apparatus*

Subject sat in front of a modified FÖRSTER Perimeter (OCULUS). Their head either rested on a chin rest (upright position) or was positioned on an upholstered wooden board that was adjusted in height so that the midline of the subjects' face matched the height of the fixation point on the perimeter (tilted positions: 90° to the right or to the left). The distance between the subjects' eye and the perimeter plane was 40 cm. The stimuli were presented by two red light-emitting diodes (LEDs; Hewlett-Packard HLMP-6620). The circular LEDs subtended 11′. They were positioned at 10° to the left and right of the fixation point. The fixation point was a white circular field subtending 0.84° on the gray perimeter plane. Luminance, measured by a HAGNER Universal Photometer S2, was 2.2 cd/m$^2$ for the perimeter background, 3.8 cd/m$^2$ for the fixation point, and 33.6 cd/m$^2$ for the LED stimuli. Two shielded lamps provided a dim and diffuse ambient illumination of the experimental room. The ability to maintain fixation properly was tested for each subject in a number of pretrials in which eye movements were monitored by an infrared photoelectric device connected to an oscilloscope. The stimuli were presented for 100 msec and were preceded by an auditory warning with an interstimulus interval that randomly varied between 500 and 800 msec. Response keys were two microswitches (SCHADOW-digitast SE; with electronic rebound suppression) that were connected to an electronic clock which started with the stimulus onset and was stopped by the microswitch contact. The two microswitch boxes were attached to the left and right sides of the experimental desk.

*Procedure*

The subjects attended two sessions on different days. In one session they responded with the hands in normal right or left position. In the other session they responded with the hands crossed. Three subjects started with the uncrossed-hands session, the other three with the crossed-hands session. In each session three conditions were investigated: head upright, head tilted 90° to the right, and 90° to the left. The three conditions were tested in a sequence of six blocks of trials (i.e., two blocks for each condition), separated by short rest periods. In three blocks of each session the subjects made spatially compatible responses (i.e., the hand on the right side responded to right lights and the hand on the left side to left lights). In the other three blocks, subjects made spatially incompatible responses (i.e., the hand on the right responded to left lights and the hand on the left to right lights). After each block, both head position and (compatible vs. incompatible) S–R relation were changed. This procedure determines six possible orderings of blocks, with each of the six subjects obtaining one such ordering. Each block began with 6 practice trials followed by 60 test trials. Half of them consisted of stimuli on the right of the fixation point, the other half of stimuli on the left of the fixation point. Stimuli were presented in a quasi-random order within each block, allowing a maximum of only three consecutive presentations of the same (right or left) stimulus. To avoid any verbally induced set, instructions were given solely by pointing toward the stimulus and to the hand chosen to respond to it. Errors were few, and error trials were repeated at the end of each block.

## Results

Mean reaction times were subjected to a four-way within-subjects analysis of variance with the factors response condition (hands in normal vs. crossed position), head position (upright, tilted to the right, tilted to the left), stimulus location (right, left) and position of responding hand (right, left). The corresponding cell means and standard deviations are given in table 1.

The *grand ANOVA* showed a significant main effect of response condition, $F(1, 5) = 8.33$, $p < 0.05$. Reactions were overall faster with hands in normal position than with crossed hands (275 vs. 313 msec). The interaction between response condition and head positions just failed to reach significance, $F(2, 10) = 3.70$, $p = 0.06$ (multivariate: Wilks' Lambda $= 0.33$, $F(2, 4) = 4.00$, $p = 0.11$). With hands in normal position reactions were fastest with head upright, while with crossed hands reactions were fastest with head tilted to the right. The interaction between response condition and hand position was significant, $F(1, 5) = 15.15$, $p = 0.01$, expressing an advantage of the (anatomically) right over the left hand under both response conditions (288 vs. 301 msec). The interaction between stimulus location and position of responding hand, which expresses the overall spatial S–R compatibility effect, was highly significant, $F(1, 5) = 29.73$, $p < 0.01$. With right field stimulation, responses with the hand held on the right side (irrespective of whether it was the anatomically right or left hand) were faster than responses with the hand held on the left side (273 vs. 311 msec), and with

Table 1
Mean reaction times (in milliseconds) and standard deviations (in parentheses). RH = right hand; LH = left hand.

| | Uncrossed hands | | | | Crossed hands | | | |
|---|---|---|---|---|---|---|---|---|
| | Right light | | Left right | | Right light | | Left light | |
| | Response position: | | | | Response position: | | | |
| | Right (RH) | Left (LH) | Right (RH) | Left (LH) | Right (LH) | Left (RH) | Right (LH) | Left (RH) |
| Head | 246 | 289 | 276 | 258 | 292 | 334 | 350 | 286 |
| upright | (20) | (19) | (21) | (12) | (29) | (26) | (42) | (24) |
| Head | 245 | 310 | 294 | 261 | 301 | 311 | 318 | 293 |
| right-tilted | (15) | (16) | (29) | (2) | (25) | (45) | (58) | (42) |
| Head | 250 | 305 | 291 | 280 | 307 | 317 | 338 | 308 |
| left-tilted | (13) | (13) | (17) | (18) | (34) | (68) | (59) | (31) |

left field stimulation responses with the hand held on the left side were faster than responses with the hand held on the right side (281 vs. 311 msec). Finally, the interaction between response condition, head position, stimulus location and side of responding hand was significant, $F(2, 10) = 10.86$, $p < 0.01$ (multivariate: Wilks' Lambda = 0.13, $F(2, 4) = 13.11$, $p < 0.02$). In order to clarify this four-way interaction, subanalyses were conducted for upright head position and tilted head positions separately.

The three-way analysis for *upright head position* with the factors response condition, stimulus location and position of responding hand yielded a significant main effect for response condition, $F(1, 5) = 29.40$, $p < 0.01$. Responses were overall slower with hands crossed than with hands uncrossed (316 vs. 267 msec). The significant interaction between response condition and responding hand, $F(1, 5) = 28.01$, $p < 0.01$, expresses the advantage of the anatomically right hand, and the interaction between stimulus location and hand position, $F(1, 5) = 103.06$, $p < 0.001$ the normal S–R compatibility effect, compatible reactions being 42 msec faster than incompatible ones (see fig. 1).

The four-way analysis for the *tilted-head positions* with the factors response condition, head position (right tilted vs. left tilted), stimulus location and position of responding hand shows a non-significant tendency to slower reactions with crossed hands, $F(1, 5) = 4.48$, $p = 0.09$ (280 vs. 311 msec). The main effect for head position was significant, $F(1, 5) = 13.08$, $p < 0.05$. Responses were faster when the head was tilted to the right than to the left side (292 vs. 300 msec). There was a tendency to react faster towards right-field stimuli than towards left-field stimuli, $F(1, 5) = 4.46$, $p = 0.09$. Again the interaction between response condition and responding hand was significant, $F(1, 5) = 10.41$, $p < 0.05$, which shows the advantage of the anatomically right hand. The interaction between stimulus location and hand position, i.e. the overall S–R compatibility effect, was significant, $F(1, 5) = 12.09$, $p < 0.05$. Also the three-way interaction between response condition, stimulus location and hand position reached significance, $F(1, 5) = 9.27$, $p < 0.05$. Separate two-way subanalyses for normal and

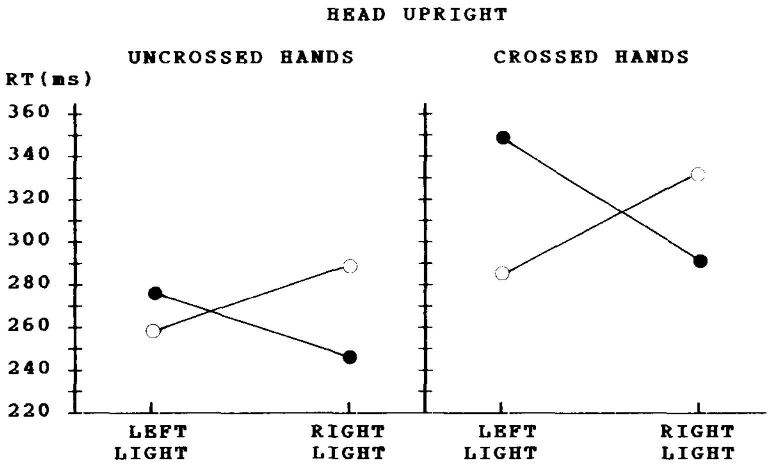


Fig. 1. Mean reaction times for hands held in right position (filled circles) or left position (unfilled circles) to lights on the right or left side of the fixation point under the condition of head held upright.

crossed hand positions showed that a strong S–R compatibility effect (41 msec) was present with normal hand position (interaction between stimulus location and hand position, $F(1, 5) = 42.44$, $p < 0.01$), whereas this interaction did not reach significance

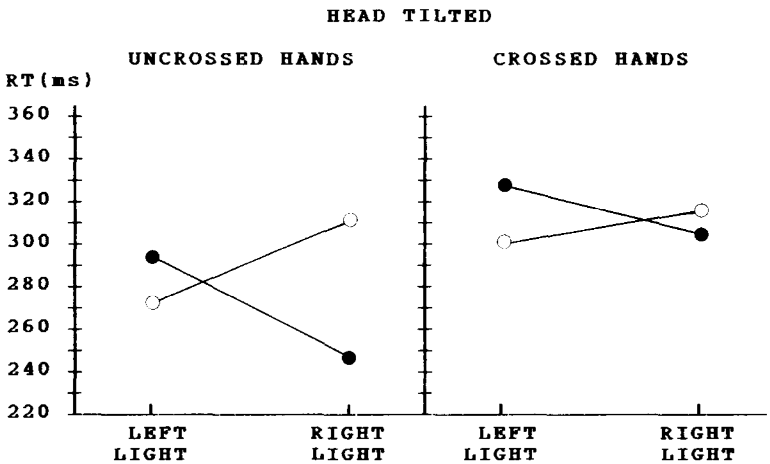


Fig. 2. Mean reaction times for hands held in right position (filled circles) or left position (unfilled circles) to lights on the right or left side of the fixation point under the condition of head tilted (right tilt and left tilt combined).

for crossed hands, $F(1, 5) = 2.64$, $p = 0.17$. Although not reliable, however, the means for the crossed-hands condition show a reaction time advantage of 19 msec for compatible S–R pairings (see fig. 2).

In other words, whereas with head held upright there was no change in S–R compatibility between the response conditions, with tilted head the S–R compatibility effect significantly decreased from the uncrossed-hands condition to the crossed-hands condition, but did not shift to the opposite. This explains the significant four-way interaction in the grand ANOVA.

## Discussion

The purpose of our investigation was to study whether in the case of unusual head posture (head tilt) spatial coding of response positions can still be regarded as the major factor in determining S–R compatibility, or whether it interacts or is even replaced by the association of the anatomically right and left hands as spatially right or left (spatio-anatomical mapping).

For upright head position our experiment shows the usual pattern of spatial S–R compatibility. Spatially compatible reactions were significantly faster than incompatible ones, independent of whether hands are held in normal position or held crossed. This means that the spatial (right vs. left) position of the response and not its anatomical status as right or left was effective, which obviously supports the coding hypothesis.

For tilted-head positions, too, a reaction time advantage for spatially compatible S–R pairings was found. However, this compatibility effect significantly decreased from a highly significant effect of 41 msec for hands held in normal position to a nonsignificant effect of only 19 msec in the crossed-hands condition. It did not shift to the opposite, so that even with tilted head spatial coding is not *replaced* by spatio-anatomical mapping. The *decrease* of spatial S–R compatibility from the uncrossed-hands to the crossed-hands condition could be explained in the following way.

In standard designs for the study of spatial S–R compatibility such as our upright-head condition, spatial orientation and thus spatial coding is facilitated by parcellating the visual space into the right and left hemispace given by the head midline in upright head position. Even if both stimuli and/or responses are on one side of the body midline (as in Nicoletti et al. 1982; Heister et al. 1986), this division requires just a tacit parallel shifting of this line. If the head is tilted to the right or left, but hands are uncrossed, spatial orientation seems to remain easy because the right and left hands are in their normal right and left positions and can thus help in keeping a spatial right/left discrimination. However, when the head is tilted *and* the hands are crossed, then neither the head midline nor the anatomically right and left hands can guide spatial right/left orientation (although this orientation is not completely impossible since one may base it on the body midline). Our hypothesis is that this difficulty leads to a greater uncertainty in coding spatial positions as right and left, which gives spatio-anatomical mapping the chance to manifest itself.

This is in good agreement with the hierarchical model of S–R compatibility of Heister et al. (1989). According to this model both spatial coding and spatio-anatomical mapping may be present in S–R compatibility effects, spatial coding normally being the dominant factor. However, spatio-anatomical mapping can exert some influence if spatial coding is made difficult. The present experimental design with the head tilted would then represent a situation where coding and mapping interfere, their non-coincidence under the crossed-hands condition resulting in a smaller spatial compatibility effect. This situation lies so-to-speak 'in between' standard S–R designs, where spatial coding is easily possible and thus dominant, and the designs of Klapp et al. (1979) and Ehrenstein et al. (1988) (as decribed in the Introduction), in which spatial right/left coding of response positions is excluded and spatio-anatomical mapping becomes dominant.

The experimental design used by Ladavas and Moscovitch (1984) did not permit an answer to the questions of S–R compatibility under head tilt which we were addressing here. Besides head tilt, it differed from 'standard' S–R studies in that the dimensions of stimuli and responses were always perpendicular to each other, so that they could only be aligned by using different frames of reference. From our results it can now be concluded that it is essentially the combination of tilted head with orthogonality of stimulus and response positions and not the tilted head condition alone that caused in their experiment the observed preference for the anatomical right/left distinction.

In summary, our results show that S–R compatibility can only be retained as a uniform phenomenon if it is considered a composite result of various factors that interact under different conditions in different ways.

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