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Effect of an Initiating Action on the Up-Right/Down-Left Advantage for Vertically Arrayed Stimuli and Horizontally Arrayed Responses

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When up and down stimuli are mapped to left and right keypresses or "left" and "right" vocalizations in a 2-choice reaction task, performance is often better with the up-right/down-left mapping than with the opposite mapping. This study investigated whether performance is influenced by the type of initiating action. In all, 4 experiments showed the up-right/down-left advantage to be reduced when the participant's initiating action was a left response compared with when it was a right response. This reduction occurred when the initiating action and response were both keypresses, both were spoken location names, and one was a spoken location name and the other a keypress. The results are consistent with the view that the up-right/down-left advantage is due to asymmetry in coding the alternatives on each dimension, and a distinction between categorical and coordinate spatial codes seems to provide the best explanation of the advantage.

It has been known for nearly 50 years that responses are faster and more accurate in spatial choice-reaction tasks when stimulus and response locations correspond than when they do not (Fitts & Deininger, 1954; see Proctor & Reeve, 1990, for a review). More recently, it has been established that spatial stimulus–response (S-R) compatibility effects also occur when the dimension along which the members of the stimulus set vary is orthogonal to the dimension along which the members of the response set vary. That is, when vertically arrayed stimulus locations are mapped to horizontally arrayed response locations, or vice versa, not all mappings produce equivalent performance. These orthogonal S-R compatibility effects have attracted considerable interest among researchers because they are of both theoretical (e.g., Michaels & Schilder, 1991) and applied (e.g., Andre & Wickens, 1990) importance.

In one of the earliest studies, Bauer and Miller (1982) had participants make a unimanual aimed movement of an index finger from a home key at body midline to a left or right key in response to a stimulus presented above or below a fixation point. Their data showed an up-right/down-left advantage when responses were made with either the right or the left hand. Weeks and Proctor (1990) replicated this up-right/down-left advantage for vertically arrayed stimuli mapped to horizontal unimanual responses and established that it occurs with a variety of other response sets, including bimanual keypresses and "left"–"right" vocalizations. The up-right/down-left advantage and related mapping effects obtained with unimanual responses are amenable to explanations in terms of the motor system (e.g., Bauer & Miller, 1982; Michaels & Schilder, 1991) and hand postures (e.g., Lippa, 1996). For example, Lippa proposed that the unimanual compatibility effects are due mainly to coding the response alternatives along the same dimension as the stimulus alternatives by using the intrinsic axis from fingertip to wrist of the hand as a frame of reference. However, because such explanations are not applicable to the compatibility effects obtained with bimanual discrete keypresses or spoken location words, which are of primary concern in the present study, we will not discuss them further.

Salient-Features Coding Hypothesis

Weeks and Proctor (1990) attributed the up-right/down-left advantage to S-R translation processes and used a variant of Proctor and Reeve's (1985, 1986) salient-features coding principle to explain the effect. According to this principle, translation is fastest when salient features of the stimulus and response sets correspond. The principle has been shown to have considerable explanatory power for four-choice tasks in which the stimulus and response sets have two-dimensional structures (see Proctor, Reeve, & Van Zandt, 1992, and Reeve & Proctor, 1990, for reviews). Across a variety of spatial and symbolic stimulus sets and manual and vocal response sets, performance is best for mappings in which the more salient of the two dimensions for the respective sets match. In the case of orthogonal two-choice tasks, Weeks and Proctor (1990) proposed that the stimuli and responses are coded asymmetrically, with up and right being the salient features of their respective dimensions. They cited evidence from several prior studies (e.g., Chase & Clark, 1971; Farrell, 1979; Olson & Laxar, 1973) indicating that up and right tend to serve as the salient polar referents for the vertical and horizontal dimensions, respectively. According to Weeks and Proctor's (1990) salient-features coding hypothesis, S-R translation is more efficient when the polar referent for the vertical stimulus dimension is mapped to the polar referent for the horizontal response dimension because this mapping preserves the asymmetric feature structure of the S-R sets. Among the evidence Weeks and Proctor (1990) presented as support for this account was the generalizability of the advantage across stimulus types (spatial locations, arrows, and location words) and, as mentioned previously, response modalities.

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With unimanual responses, the up-right/down-left advantage is influenced by the position of the response device on which the responding hand must be placed. When responses by the right hand are made in the right hemispace, the advantage increases in magnitude, but when responses by the left hand are made in the left hemispace, the effect reverses to an up-left/down-right advantage (Michaels, 1989; Michaels & Schilder, 1991). Weeks, Proctor, and Beyak (1995) dissociated the effects of response hand and location by having participants respond by operating a switch left or right with each hand at both ipsilateral and contralateral locations. The position at which the responses were made, and not whether responding was with the left or right hand, was the critical factor. An up-right/down-left advantage occurred when responses were at the body midline, and this advantage increased when the response hand was positioned in the right hemispace. However, it reversed to an up-left/down-right advantage when the response hand was positioned in the left hemispace.

Weeks et al. (1995) extended the salient-features coding hypothesis to explain the reversal of the mapping preference to an up-left/down-right advantage when unimanual responses are made at eccentric locations in the left hemispace. One point stressed by Proctor, Reeve, and colleagues regarding the more general principle from which this hypothesis was derived is that the stimulus and response codes are not fixed and, hence, that the relative salience of the members of the S-R sets is affected by many factors (e.g., Proctor, Reeve, Weeks, Dornier, & Van Zandt, 1991; Reeve, Proctor, Weeks, & Dornier, 1992). Weeks et al. proposed that placing the response set to the left of body midline increases the relative salience of the left response location, tending to counter and reverse the up-right/down-left advantage that is usually evident when the device is at the neutral midline location. In their Experiment 2, Weeks et al. placed a dummy switch to the right or left of a switch centered at body midline with which the unimanual left–right responses were made. When the dummy switch was located to the left, so that the position of the active switch was right relative to it, an up-right/down-left advantage of 20 ms was obtained. But when the dummy switch was located to the right, so that the relative position of the active switch was left, the up-left/down-right mapping showed an advantage of 8 ms. Thus, when the relative location of the response set was left, the up-right/down-left advantage was eliminated, as predicted by Weeks et al.'s salient-features coding explanation.

Dual-Strategy Hypothesis

In a commentary on Weeks and Proctor (1990), Umiltà (1991) accepted the claim that the up-right/down-left advantage is due to asymmetric coding of the members of the stimulus and response sets. However, he restricted this asymmetry to verbal codes, proposing that verbal codes have the salient features of up and right but that spatial codes are symmetric and do not have polar referents. When S-R translation is mediated by verbal codes, the up-right/down-left advantage should appear, but when it is mediated by spatial codes, it should not. The fact that the up-right/down-left advantage was larger with vocal, verbal responses than with manual responses in Weeks and Proctor's (1990) study was cited by Umiltà as evidence that the advantage arises from verbal codes. According to his interpretation, "These [orthogonal] S-R compatibility effects are in general weak, unless the task explicitly favors the use of verbal codes by requiring a verbal response mode" (p. 85).

Adam, Boon, Paas, and Umiltà (1998) recently elaborated Umiltà's (1991) view and provided evidence that they interpreted as support for it. In their Experiment 1, participants were required to respond to vertically arrayed stimuli by pressing one of two keys arranged horizontally. Participants performed under one of two conditions of trial initiation, computer paced and participant paced. In the computer-paced condition, the computer initiated each trial following a 750-ms intertrial interval (ITI). In the participant-paced condition, a prompt was presented after the 750-ms ITI, and the participant had to press the right response key to initiate the trial sequence. The participant-paced condition showed an up-right/down-left advantage of 17 ms, but the computer-paced condition showed no significant difference between the two mappings. In Adam et al.'s Experiment 2, conditions were also included in which the responses were "left" and "right" vocalizations. Overall, an up-right/down-left advantage of 12 ms was evident in the participant-paced condition but not in the computer-paced condition, and this pattern did not interact significantly with response modality (keypress or vocalization).

Adam et al. (1998) explained the presence of the up-right/down-left advantage in the participant-paced conditions but not in the computer-paced conditions in terms of Umiltà's (1991) proposal that the up-right/down-left advantage is due to verbal coding. In their words:

> This finding was interpreted in terms of the dual-strategy hypothesis, which asserts that participants may use the visual or verbal stimulus code and that, depending on the task constraints, a visual or verbal strategy may prevail. With a visual strategy, no compatibility effect arises. With a verbal strategy, the up-right/down-left advantage emerges. (p. 1582)

The ITI was shorter in the computer-paced conditions than in the participant-paced conditions because the timing of trials was the same, except for the additional time to initiate the trial sequence in the participant-paced conditions. Adam et al.'s (1998) initial explanation for why the computer-paced conditions would promote a visual strategy and the participant-paced conditions would not was in terms of the different ITIs. They proposed that "short ITIs allow the response on a just-completed trial to mediate (i.e., guide or cue) the response on the next trial" (p. 1584), precluding the need to retrieve and implement the appropriate verbal mapping rule. However, Adam et al. abandoned this explanation because their Experiment 3 showed no effect of ITI on the magnitude of the up-right/down-left advantage obtained with computer-paced presentation. Instead, they concluded,

> The requirement to actively initiate the trials was the crucial mediating factor in the up-right/down-left advantage. Specifically, the activity to initiate the trial might have a disruptive effect on the previously formed S-R association, possibly provoking participants to retrieve and implement the verbal mapping rule to select the appropriate response. (p. 1589)

In a recent study (Proctor & Cho, 2001, this issue), we were unable to replicate the finding of Adam et al.'s (1998) Experiments 1 and 2 that the up-right/down-left advantage occurs for participant-paced trials but not for computer-paced trials. In two experiments very similar to theirs, we found no significant difference in the magnitude of the up-right/down-left advantage as a function of whether trials were computer or participant paced. However, whereas Adam et al. had found mean reaction time (RT) to be shorter with computer-paced presentation than with participant-paced presentation, we found no difference. In a third experiment, we used a response deadline procedure for both pacing conditions to speed responding and found that neither the participant- nor the computer-paced condition showed an up-right/down-left advantage. Thus, speed of responding, and not the requirement to initiate trials, appears to be the crucial factor, with the advantage being reduced or eliminated when responding is faster on average relative to when it is slower. This outcome is consistent with a third argument pertaining to use of a visual versus verbal strategy made by Adam et al., that the up-right/down-left advantage should be reduced or eliminated when responses are fast because the verbal codes that produce the advantage are slower to form than the visual codes.

Purpose

There is considerable agreement between the accounts of the up-right/down-left advantage provided by Weeks and Proctor's (1990) salient-features coding hypothesis and Umiltà's (1991) dual-strategy hypothesis. Both attribute the advantage to asymmetric coding of the members of the stimulus and response sets and allow that the advantage will not occur under all circumstances. A major difference between the two hypotheses is that the salient-features coding hypothesis views the asymmetric coding as flexible and manipulable, whereas the dual-strategy hypothesis views it as a fixed property of language (i.e., the up-right/down-left advantage is a function of linguistic asymmetries). Thus, the salient-features coding hypothesis implies that it should be possible to affect the magnitude of the up-right/down-left advantage by manipulating variables that influence relative salience of the alternatives, whereas the dual-strategy hypothesis implies that the magnitude should be affected only by whether the task is verbal or nonverbal and by response speed. The purpose of the present experiments was to examine whether a variable that should alter relative salience, type of initiating action, influences the magnitude of the up-right/down-left advantage.

As mentioned previously, Weeks et al. (1995) found that for unimanual responses the up-right/down-left advantage is eliminated when the relative position of the response switch on which the hand is placed is left rather than right. The general idea behind Weeks et al.'s interpretation of this effect is that placement of the response switch (and responding hand) to one side or the other increases the relative salience of the response alternative that corresponds with that side. It is reasonable to think that other response factors may also influence the relative salience of the response alternatives. The requirement of initiating trials with an action that is a member of the set of possible task responses, as for the keypress responses in Adam et al.'s (1998) Experiments 1 and 2, would seem to increase the salience of that response alternative: The response corresponding to the initiating action receives more emphasis in the instructions, occurs more frequently than the alternative response, and on all trials immediately precedes the task sequence. If this assumption is correct, initiating trials with a left keypress would increase the salience of the left response relative to initiating trials with a right keypress, which according to the salient-features coding hypothesis should lead to a reduction in the magnitude of the up-right/down-left advantage. Any such effect of initiating action in the absence of differences in mean RT would be difficult to reconcile with the dual-strategy hypothesis, as the type of initiating action should not have any influence on the asymmetric properties of the verbal codes.

Four experiments were conducted in which within-subject comparisons were made between two types of participant-paced conditions, initiating each trial with a left response or with a right response. In Experiment 1, both the initiating action and task responses were keypresses, as in Adam et al.'s (1998) Experiment 1. For Experiment 2, the initiating action and task responses were both spoken words, "left" or "right." In Experiment 3, the initiating action was the spoken word "left" or "right" and the task responses were keypresses, and in Experiment 4 this relation was reversed. According to the salient-features coding hypothesis, the up-right/down-left advantage should be smaller with left initiation than with right initiation if the response corresponding to the initiating action is increased in salience relative to the other response. According to the dual-strategy hypothesis, the up-right/down-left advantage should be of similar magnitude with left initiation as with right initiation, as long as there are no differences in overall mean RT, because the linguistic properties of "left" and "right" are the same in both initiation conditions.

Experiment 1

The purpose of Experiment 1 was to examine the effect of the type of trial initiation for the task variation in which responses and initiating action are both keypresses. Participants performed a two-choice reaction task for which the stimuli were presented above or below a fixation point and the responses were left and right keypresses. In different blocks of trials, the initiating action was either a right or a left keypress. If it is assumed that the response alternative corresponding to the initiating action is increased in salience relative to the other response alternative, then the salient-features coding hypothesis predicts the up-right/down-left advantage will be clearly evident only in the right initiation condition. In contrast, the dual-strategy hypothesis predicts that the advantage should be equally evident in both initiation conditions.

Method

Participants. A total of 48 undergraduate students enrolled in introductory psychology at Purdue University participated in partial fulfillment of a course requirement. All of the participants were right-handed and had normal or corrected-to-normal visual acuity as determined by self-report. Participants were randomly assigned to the up-right/down-left mapping or the up-left/down-right mapping.

Apparatus and stimuli. The experiment was controlled by software developed with the Micro Experimental Laboratory 2 (MEL 2.0; Schneider, 1995:) system. Stimuli were presented on the display screen of an IBM-compatible 386 microcomputer, and viewing distance was approximately 50 cm. Responses were made by pressing one of two keys, *V* and *N*, on the computer keyboard, which are separated by 2.5 cm, with the index fingers of both hands.

Stimuli were standard uppercase *X*s (0.3 × 0.4 cm; approximately 0.34° × 0.46° of visual angle). They were presented as white characters on a dark background, approximately 2 cm (2.30°) above or below a central fixation point, + (0.25 × 0.3 cm; 0.29° × 0.34°). The response box and computer screen were aligned so that the midpoint between the two response keys and the fixation point were on the participant's sagittal midline.

Procedure. Each participant performed the task with both right initiation and left initiation. The order of the initiation type was counterbalanced across participants. Each participant performed 30 practice trials and 400 test trials for each initiation condition. The test trials were presented in four blocks of 100 trials (50 randomly assigned to each stimulus position), with a 1-min rest interval between trial blocks.

Each trial began when the word READY (1.6 × 0.4 cm; 1.83° × 0.46°) flashed in the center of the screen. To initiate each trial, the participant was required to press the right response key in right initiation condition and the left response key in left initiation condition. After pressing the key, the word READY was replaced by the fixation point for 1 s. The stimulus was presented either above or below the fixation point; both remained on until the participant responded. The READY signal for the next trial came on 750 ms after the response. An incorrect response was followed by a 500-ms feedback tone.

Results

RTs shorter than 125 ms and longer than 1,250 ms were excluded from data in this and the other experiments; 0.69% of the trials were removed from analysis. Mean RTs and percentages of error (PEs) were calculated for each participant as a function of initiation condition (left initiation and right initiation) and response position. Analyses of variance (ANOVAs) were conducted on the mean RT and PE data, with those variables as within-subject factors and mapping rule as a between-subject factor (see Table 1).

Reaction time. The initiation main effect was not significant ($F < 1$). Mean RT was almost the same with right initiation (M = 350 ms) as with left initiation (M = 349 ms). Although responses were 16 ms faster with the up-right/down-left mapping than with the up-left/down-right mapping, this difference was not significant, $F(1, 46) = 1.1$, $p > .29$. However, the interaction between mapping and type of trial initiation was significant, $F(1, 46) = 5.63$, $p = .0219$, $MSE = 992$. The up-right/down-left advantage was 26 ms in the right initiation condition, $F(1, 46) = 17.16$, $p = .0002$, but only 5 ms in the left initiation condition ($F < 1$).

Three terms involving response position were significant. One was the response main effect, $F(1, 46) = 10.99$, $p = .0018$, $MSE = 716$, with right responses being faster than left responses. A second was the Response × Initiation interaction, $F(1, 46) = 18.44$, $p < .0001$, $MSE = 374$ (see Figure 1). Responses were faster when the initiating action corresponded to the response (M = 343 ms) than when it did not (M = 356 ms). The third significant interaction was that of Response × Mapping, $F(1, 46) = 9.45$, $p = .0035$, $MSE = 716$. The up-right/down-left advantage was 27 ms for the left response but only 4 ms for the right response. Although this effect is opposite that of type of trial initiation, which showed a larger advantage with right initiation than with left initiation, it does not bear on the relative salience hypothesis because only the initiating action precedes response selection and could alter relative salience.

An additional analysis was performed with mapping, initiation condition, and RT distribution bin as factors (see De Jong, Liang, & Lauber, 1994). For the bin variable, the RTs for each participant were rank ordered for each mapping and divided into five bins representing the fastest 20%, the next fastest 20%, and so on. There was a main effect of bin, $F(4, 184) = 345.09$, $p < .0001$, $MSE = 2{,}629$, as imposed by the bin classification. The Mapping × Initiation × Bin interaction was also significant, $F(4, 184) = 2.75$, $p = .0299$, $MSE = 277$. This interaction reflects that the up-right/down-left advantage evident with right initiation increased with increasing RT, but there was no consistent mapping effect at any bin with left initiation (see Figure 2).

Percentage of error. Overall PE was 3.21%. Neither the main effect of mapping nor that of initiation was significant ($Fs < 1$). Their interaction also was not significant, $F(1, 46) = 1.33$, $p = .2555$, $MSE = 2.031$. The only significant terms were the Mapping × Response interaction, $F(1, 46) = 25.49$, $p < .0001$, $MSE = 1.820$, and the Initiation × Response interaction, $F(1, 46) = 18.05$, $p < .0001$, $MSE = 4.621$. The former interaction is that for the right response, PE was less for the up-right/down-left mapping (2.92%) than for the up-left/down-right mapping (3.46%), whereas for the left response this relation was reversed (3.85% and 2.52%, respectively). An alternative way of describing this is that more errors were made to the down stimulus (3.70%) than to the up stimulus (2.71%). The latter interaction indicates that fewer errors were made when the initiation position corresponded with the response position (2.54%) than when it did not (3.87%).

Table 1
Mean Reaction Times (RTs; in Milliseconds) and Percentages of Error (PEs) in Experiment 1 as a Function of Mapping, Keypress Response, and Type of Trial Initiation

	"Left" response		"Right" response	
Type of trial initiation	RT	PE	RT	PE
Up-right/down-left mapping				
Right keypress	342	4.52	330	2.57
Left keypress	342	3.37	352	3.27
Up-left/down-right mapping				
Right keypress	382	3.25	344	2.47
Left keypress	357	1.79	346	4.44

Discussion

The up-right/down-left advantage in RT was significantly smaller when the trials were initiated with a left keypress than with a right keypress. This finding is similar to Weeks et al.'s (1995) finding that placement of a response switch in the left hemispace reversed the preferred mapping. In this experiment, execution of the left response to initiate the trial apparently increased the relative salience of the left response location and virtually eliminated the up-right/down-left advantage.

It is important to note that the mean RTs with right and left initiation were almost identical. Consequently, the different patterns of results obtained for the two conditions, that is, an up-right/down-left advantage with right initiation but not with left initiation, cannot be attributed to the time being sufficient to generate a verbal code in the former case but not in the latter.

Independent of the mapping effect, there was a bias to make the same response as the initiating action. That is, the right response was faster and more accurate with right initiation than with left initiation, whereas the left response was faster and more accurate with left initiation than with right initiation. The lack of interaction between the mapping effect and the correspondence effect for

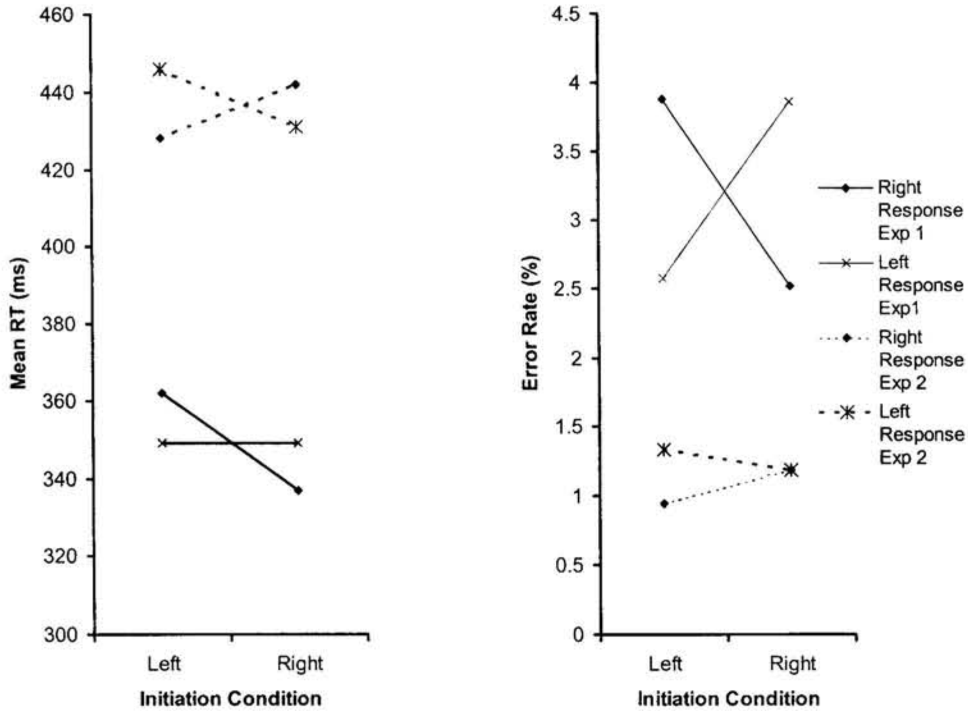

Figure 1. The Initiation × Response Position interaction for reaction time (RT; in milliseconds) and percentage of error in Experiments (Exp) 1 and 2.

initiating action and response implies, using additive factors logic (Sternberg, 1998), that the latter effect has its basis in response-execution, or motor system, processes and not in the response-selection processes that produce the mapping effect.

Experiment 2

Experiment 1 showed that the up-right/down-left advantage was evident when initiated with a right response and absent when

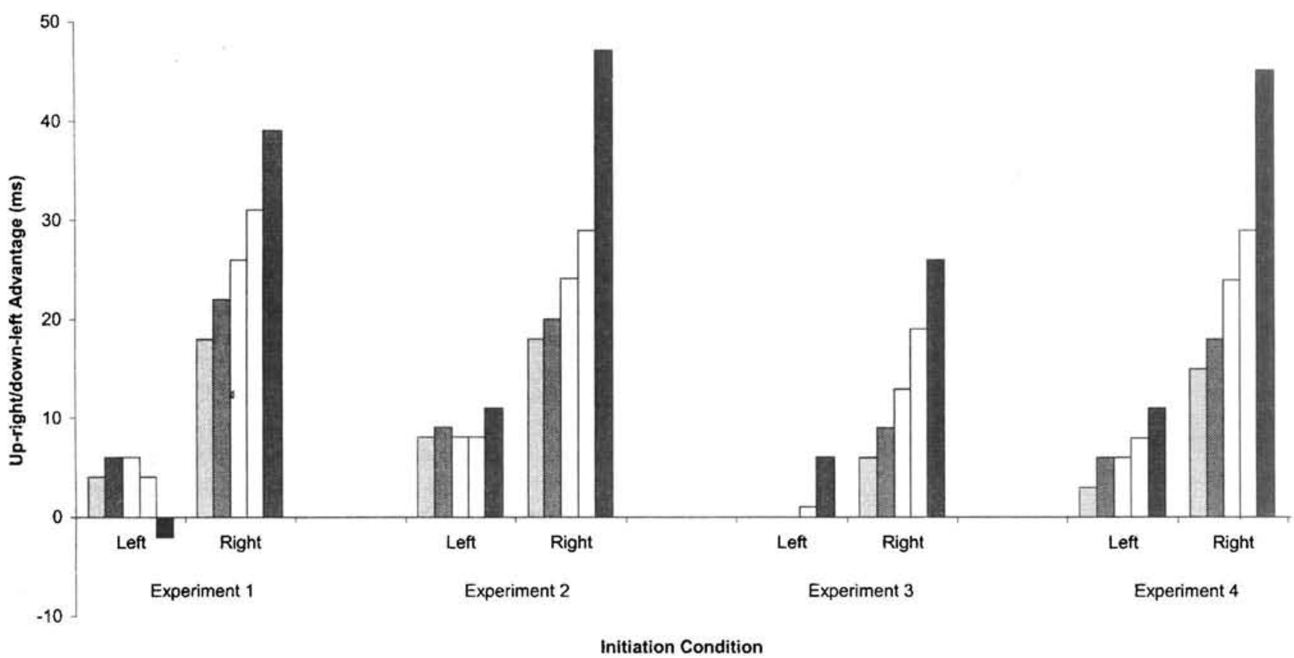

Figure 2. The up-right/down-left advantage as a function of reaction time distribution bin and initiation condition in Experiments 1–4. For each initiation condition, the bars are ordered left to right from the first quintile to the fifth quintile.

initiated with a left response when the initiating action and the response were both keypresses. The up-right/down-left advantage also occurs when the responses are the spoken words "left" and "right" (Adam et al., 1998; Weeks & Proctor, 1990). If the absence of the up-right/down-left advantage with left initiation in Experiment 1 is due to an increased salience for the left response, then a similar result should occur with vocal responses when the spoken word "left" is used to initiate the trial sequence. To test this prediction, Experiment 2 was conducted in a manner similar to Experiment 1, but using vocal "left" or "right" words for trial initiation and vocal responding.

Method

A total of 64 undergraduate students from the same participant pool as in Experiment 1 participated in partial fulfillment of a course requirement. None of the participants took part in the previous experiment.

The apparatus and procedure were similar to Experiment 1, with the exceptions that the interval between the onset of the initiating action and the onset of the imperative stimulus was 1,250 ms,[1] rather than 1 s, and the participant made vocal "left"–"right" responses to vertically arrayed stimuli under two vocal initiation conditions, "left" initiation and "right" initiation. Participants were required to say "left" to initiate each trial in the left-initiation condition and "right" in the right-initiation condition. Vocal responses were made into a microphone interfaced with the microcomputer through a MEL 2.0 response box.

Each participant performed with one mapping, either up-right/down-left or up-left/down-right, using both types of trial initiation. One half of the participants performed with "left" initiation first and then with "right" initiation. The other one half performed in the reverse order. Each participant performed 30 practice trials and 200 test trials for each type of trial initiation.

A trial started when the word READY flashed in the center of the screen. To initiate the stimulus sequence, the participant was required to say "left" in the left-initiation condition and to say "right" in the right-initiation condition. After saying the initiation word, the word READY was replaced by the fixation point + for 1,250 ms. The stimulus was presented either above or below the fixation point. The stimulus and fixation point remained on until the participant responded. The next trial began 1 s after the response. An incorrect response was followed by a 500-ms feedback tone.

Results

Of the trials, 1.11% were removed from analysis by using the exclusion criteria. An ANOVA was conducted on the RT and PE data, with the within-subject variables of location response and type of trial initiation and the between-subject variable of mapping (see Table 2).

Reaction time. The mapping main effect was not statistically significant, $F(1, 62) = 1.47, p = .23, MSE = 14{,}270$, but mean RT was 18 ms faster with the up-right/down-left mapping (M = 428 ms) than with the up-left/down-right mapping (M = 446 ms). The main effect of initiation condition was not significant either ($F < 1.0$), with mean RTs being similar for "left" initiation (M = 439 ms) and "right" initiation (M = 435 ms). The interaction between S-R mapping and trial initiation was significant, $F(1, 62) = 4.82$, $p = .0319$, $MSE = 1{,}153$. The up-right/down-left advantage was larger with "right" initiation (27 ms) than with "left" initiation (9 ms).

The interaction between location response and trial initiation was significant, too, $F(1, 62) = 30.18, p < .0001, MSE = 461$ (see Figure 1). With "right" initiation, RT for the "right" response

Table 2
Mean Reaction Times (RTs; in Milliseconds) and Percentages of Error (PEs) in Experiment 2 as a Function of Mapping, Vocal Location Response, and Type of Trial Initiation

Type of trial initiation	"Left" response RT	"Left" response PE	"Right" response RT	"Right" response PE
Up-right/down-left mapping				
"Right" vocalization	417	1.11	425	0.85
"Left" vocalization	443	1.43	426	1.39
Up-left/down-right mapping				
"Right" vocalization	438	0.77	459	1.51
"Left" vocalization	450	1.23	436	0.98

(M = 442 ms) was longer than that for the "left" response (M = 428 ms), whereas with "left" initiation, RT for the "left" response (M = 446 ms) was longer than that for the "right" response (M = 431 ms). Note that this pattern—mean RT being longer when the response was the same as the initiation action than when the response was different from the initiation action—is the opposite of that found in Experiment 1 for manual initiation and responding.

Bin analysis showed the Bin × Mapping × Initiation interaction to be significant, $F(4, 248) = 4.28$, $p = .0023$, $MSE = 206$. For "right" initiation, the advantage for the up-right/down-left mapping increased from 18 ms in the fastest bin to 47 ms in the slowest bin (see Figure 2). For "left" initiation, the small advantage for the up-right/down-left mapping was constant across RT bins. No other interactions with bin were significant.

Percentage of error. Overall PE was 1.16%. The only significant effect was the interaction of S-R Mapping × Initiation × Location Response, $F(1, 62) = 4.95, p = .0298, MSE = 1.204$. For the up-left/down-right mapping, the error rate was higher when the initiating action and the response were the same (1.37%) than when they were different (0.88%). For the up-right/down-left mapping, the error rate tended to be higher with "left" initiation (1.41%) than with "right" initiation (0.98%), regardless of which response was required.

Discussion

In Experiment 2, participants made vocal responses following initiation with the vocal response "left" or "right". With "right" initiation, mean RT was 27 ms faster with the up-right/down-left mapping than with the up-left/down-right mapping, whereas with "left" initiation this difference was only 9 ms. Thus, as with

[1] An initial experiment performed using a 1-s interval between initiating action and onset of the imperative stimulus showed only a nonsignificant, 4-ms smaller up-right/down-left advantage with left initiation than with right initiation. One difference in using keypress and vocal initiating actions is that a keypress is a relatively discrete event that is completed soon after the response is recorded, whereas production of a spoken word continues for 250–300 ms after the voice-key is triggered (e.g., Balota, Boland, & Shields, 1989). Thus, the interval between completion of the initiating action and onset of the stimulus is shorter when the initiating action is vocal than when it is a keypress. To make the interval between action completion and onset of the stimulus more similar to that of Experiment 1, we added 250 ms to the interval between onsets.

keypress initiation and responding in Experiment 1, there was an interaction between the S-R mapping and the type of trial initiation of the type expected when the salience of the response corresponding to the initiating action was increased.

A correspondence effect for the initiating action and response was also evident. However, this interaction was the opposite of that found with manual responses in Experiment 1. With "right" initiation, "left" responses were 14 ms faster than "right" responses, whereas with "left" initiation, "right" responses were 15 ms faster than "left" responses. Speculation about the nature of this interaction is deferred until the section on response correspondence effects in the General Discussion.

Experiment 3

Experiments 1 and 2 showed that initiating trials with a left response reduced the up-right/down-left advantage relative to initiating trials with a right response, both when initiating action and response were keypresses and when they were spoken location words. Thus, regardless of whether the response mode is manual or vocal, a left-initiating action reduces the up-right/down-left advantage in comparison to a right-initiating action. The salient-features coding hypothesis assigns no special status to the modalities of the stimuli and responses. That is, the mapping preference is presumed to be a function of the relative salience of the respective members of the stimulus and response sets. If the effects of initiating action observed in Experiments 1 and 2 are not modality specific, similar effects should occur when the initiating action is in one modality and the task response is in the other. Experiments 3 and 4 examined this prediction using vocal initiation paired with keypress responding and keypress initiation paired with vocal responding, respectively.

Method

A total of 64 students from the same participant pool as in the previous experiments participated. Of the participants, 32 were tested with the up-right/down-left mapping and 32 with the up-left/down-right mapping. One half of the participants within each mapping group performed four blocks under the left-initiation condition and then four blocks under the right-initiation condition. The other one half performed in the reverse order. Within the initiation conditions, the order of the mapping was counterbalanced across participants. Each participant performed 30 practice trials and 400 test trials for each trial initiation condition.

The word READY was presented until the participant initiated the trial by saying "left" or "right" into a microphone. The word was replaced by the fixation point for 1 s, followed by the onset of the stimulus.[2] It remained on the screen until a response was made by pressing the leftmost or rightmost response button on an MEL 2.0 response box, separated by 6.8 cm. A 750-ms interval occurred prior to the onset of the READY signal for the next trial.

Results

Of the trials, 0.27% were removed as outliers. Mean RTs and PEs, were analyzed as a function of S-R mapping and initiation condition (see Table 3).

Reaction time. Although mean RT was shorter in the up-right/down-left mapping condition (M = 314 ms) than the up-left/down-right mapping condition (M = 321 ms), the mapping main effect was not significant ($F < 1$). In addition, the RTs for "right" initiation (M = 317 ms) were similar to those for "left" initiation (M = 318 ms) ($F < 1$).

Table 3
Mean Reaction Times (RTs; in Milliseconds) and Percentages of Error (PE) in Experiment 3 as a Function of Mapping, Keypress Response, and Type of Trial Initiation

	"Left" response		"Right" response	
Type of trial initiation	RT	PE	RT	PE
Up-right/down-left mapping				
"Right" vocalization	310	2.11	309	1.44
"Left" vocalization	316	2.15	319	1.90
Up-left/down-right mapping				
"Right" vocalization	328	1.57	319	1.73
"Left" vocalization	322	1.50	315	1.88

The interaction between trial initiation and mapping was significant, $F(1, 62) = 4.305$, $p = .0486$, $MSE = 678$. As shown in Table 3, a mapping effect of 14 ms was found in the "right"-initiation condition, $F(1, 62) = 9.59$, $p < .003$, $MSE = 678$, whereas in the "left"-initiation condition, there was no mapping effect ($F < 1$). The Mapping × Response interaction approached standard significance levels, $F(1, 62) = 3.60$, $p = .0623$, $MSE =$ 380. As in Experiment 1, the advantage for the up-right/down-left mapping was larger for the left response (12 ms) than for the right response (3 ms). Alternatively, responses were faster to the down stimulus location (M = 315 ms) than to the up stimulus location (M = 320 ms).

Bin analyses (see Figure 2) showed the Bin × Initiation interaction to be significant, $F(4, 248) = 3.68$, $p = .0062$, $MSE = 189$. There was little difference in the RTs with "left" and "right" initiation, except for the slowest bin, at which the "left"-initiation RT was 10 ms slower than the "right"-initiation RT.

Percentage of error. The overall error rate was 1.79%. The only significant effect was the Mapping × Response interaction, $F(1, 62) = 6.59$, $p = .0127$, $MSE = 1.283$. For the right response the PE tended to be less with the up-right/down-left mapping (1.67%) than with the up-left/down-right mapping (1.80%), but for the left response more errors were made with the up-right/down-left mapping (2.13%) than with the up-left/down-right mapping (1.54%). In other words, more errors were made to the down stimulus (1.97%) than to the up stimulus (1.61%).

Discussion

As in Experiments 1 and 2, type of trial initiation interacted with mapping. A significant up-right/down-left mapping advantage was evident in the RT data with "right" initiation but not with "left" initiation. Thus, vocal initiation of each trial influences the map-

[2] The interval between onset of the initiating action and onset of the imperative stimulus was at the shorter value of 1 s used for keypress initiation in Experiment 1 because Experiment 2, for which we had to lengthen the interval by 250 ms, had not yet been conducted. Note that the difference in magnitude for the up-right/down-left advantage as a function of type of initiation was smaller in this experiment than in any of the others, as would be expected if the amount of time after completion of the initiating action were a critical factor.

ping effect for manual responses in the same way as manual initiation does. In both cases, the results are consistent with the hypothesis that left initiation increases the relative salience of the left response and thus eliminates the up-right/down-left advantage. Again, this difference in mapping effect patterns for "left" and "right" initiation was obtained with no difference in the mean RTs of the two initiation conditions.

It is also interesting to note that, unlike Experiments 1 and 2, there was no interaction between whether the initiating action was "left" or "right" and whether the subsequent response was left or right. With manual initiating actions and responses in Experiment 1, faster and more accurate RTs for responses corresponding to the initiating action implied a bias to repeat the initiating response. Experiment 2 showed the opposite bias for vocal initiating actions and responses. There was no evidence of such a bias in the present experiment, in which the initiating action was vocal and the response was manual, which is additional evidence that the biases observed in Experiments 1 and 2 are based in the motor system.

Experiment 4

In Experiment 3, in spite of the difference between modalities of the initiating action (vocal) and the response (manual), the initiating action affected the mapping preference. This outcome implies that the influence of initiating action on the mapping preference is not restricted to the modality of the initiating action. We examined this possibility further in Experiment 4 by having participants initiate trials with a left or right keypress and respond with a "left" or "right" vocalization. The question of interest was whether the up-right/down-left advantage obtained with vocal responses would be affected by whether the manual initiating action was left or right.

Method

A total of 64 undergraduate students from the same pool as in previous experiments participated. Apparatus and procedure were identical with those of Experiment 3. Participants were asked to press one of two keys located on the MEL 2 response box to initiate each trial. In the left-initiation condition, participants pressed the leftmost key with the left index finger, and in the right-initiation condition, participants pressed the rightmost key with the right index finger. Participants responded to the stimulus by saying "left" or "right" into the microphone interfaced with the microcomputer through a MEL 2 response box.

As in Experiments 1–3, participants were assigned to one of two mapping conditions. Participants in the up-right/down-left mapping group were requested to say "left" to the below stimulus and "right" to the above stimulus, and those in the up-left/down-right mapping group were told to say the opposite. They performed under two initiation conditions. For both conditions, the left index finger was placed on the left response key and the right index finger on the right response key. When the word READY appeared in the center of the screen, the right key was pressed to begin the trial in the right-initiation condition and the left key in the left-initiation condition. The order of type of trial initiation was counterbalanced across participants. All of the participants performed four blocks of 100 trials for each initiation condition. The other parts of the procedure were identical with the previous ones.

Results

Of the trials, 1.0% were removed from analysis using the exclusion criteria. Mean RTs and PEs were analyzed as a function of mapping and initiation (see Table 4).

Table 4
Mean Reaction Times (RTs; in Milliseconds) and Percentages of Error (PE) in Experiment 4 as a Function of Mapping, Vocal Location Response, and Type of Trial Initiation

Type of trial initiation	"Left" response RT	"Left" response PE	"Right" response RT	"Right" response PE
Up-right/down-left mapping				
Right keypress	418	0.47	419	0.53
Left keypress	428	0.73	434	0.65
Up-left/down-right mapping				
Right keypress	446	0.68	444	0.75
Left keypress	437	0.70	438	0.66

Reaction time. Mean RT was faster with the up-right/down-left mapping (M = 425 ms) than with the up-left/down-right mapping (M = 441 ms), but this difference was not statistically significant, $F(1, 62) = 1.50$, $MSE = 11{,}679$. The main effect of trial initiation was not significant either, $F < 1.0$, with the mean RT tending to be slightly faster with right initiation (M = 432 ms) than with left initiation (M = 434 ms).

The interaction between initiation and mapping showed a significant effect, $F(1, 62) = 5.35$, $p = .0241$, $MSE = 1{,}119$. An up-right/down-left advantage of 27 ms was found in the right-initiation condition, $F(1, 62) = 69.17$, $p < .001$, whereas there was no significant difference between the two mappings in the left-initiation condition, $F(1, 62) = 3.09$, $p > .08$.

Bin analysis yielded a significant interaction of Bin × Initiation × Mapping, $F(4, 248) = 7.22$, $p < .0001$, $MSE = 96$ (see Figure 2). The advantage for the up-right/down-left mapping with right initiation increased in magnitude as mean RT increased, and the trend toward an up-left/down-right advantage with left initiation also tended to increase with increases in mean RT.

Percentage of error. The overall error rate was 0.65%. No effects were significant, $Fs(1, 62) \leq 1.61$, $ps > .2097$.

Discussion

As in Experiments 1–3, the interaction of type of initiation with mapping was significant for the RT data. A significant up-right/down-left mapping advantage was evident with right initiation but not with left initiation. The tendency for an up-right/down-left advantage with right initiation but not left initiation was evident in the PE data, too, although not strongly. Thus, the mapping preference with vocal responses is affected by the nature of an initiating manual action in much the same way as that with manual responses.

As in Experiment 3, there was no interaction of initiation type with response. Thus, Experiments 3 and 4 together indicate that when the initiating action is in one modality and the response is in another, the action does not create a bias toward responding with the same response.

General Discussion

Both Weeks and Proctor (1990, 1991) and Umiltà (1991) attributed the up-right/down-left advantage to asymmetric coding of up-down and right-left locations. Weeks and Proctor viewed this asymmetry as a general property of coding in terms of relative salience. They proposed that a bias exists to code right and up as the salient, polar referents for the horizontal and vertical dimensions, respectively. Weeks et al. (1995) extended their salient-features coding hypothesis, in accordance with the broader principle from which it was derived (Reeve & Proctor, 1990), to accommodate changes in the relative salience of the responses in certain situations. Specifically, in their study, coding the location of a unimanually operated response switch as left increased the relative salience of the left response alternative, eliminating the up-right/down-left advantage.

Umiltà (1991), in contrast, viewed the asymmetric coding as restricted to verbal codes. According to his dual-strategy account, the verbal code has a polar referent for each dimension, which is up for the vertical dimension and right for the horizontal dimension, and the up-right/down-left advantage occurs when S-R translation is based on verbal codes but not on spatial codes. Umiltà suggested that because verbal codes should take longer to form than spatial codes, the magnitude of the up-right/down-left advantage should be a positive function of mean RT. Adam et al. (1998) extended the dual-strategy hypothesis to account for the presence of the up-right/down-left advantage in a participant-paced condition but not in a computer-paced condition in their Experiments 1 and 2. Their interpretation was that the act of initiating the trial has a disruptive effect on the S-R association formed for the previous trial, causing participants to retrieve and implement the verbal mapping rule to select the appropriate response.

A major distinction between the salient-features coding hypothesis and the dual-strategy hypothesis is that the former views the coding that produces the up-right/down-left advantage as flexible, whereas the latter views the coding as a fixed linguistic property of the verbal codes. It is well documented that the up-right/down-left advantage obtained for unimanual responses increases when the response device is placed to the right of the participant and is eliminated or reversed when it is placed to the left (Lippa & Adam, in press; Michaels, 1989; Michaels & Schilder, 1991; Weeks et al., 1995). However, the flexibility implied by this outcome may lie in spatial coding and therefore not argue strongly against the dual-strategy hypothesis, because left and right unimanual responses may be spatially coded as up and down relative to the frame of reference provided by placement of the effector (Lippa, 1996). With bimanual, discrete keypresses and vocal responses, however, effector placement is not a factor, and any modification of the up-right/down-left advantage that cannot be attributed to a difference between verbal and spatial coding strategies would be difficult to reconcile with the dual-strategy hypothesis.

Although an initiating action by the participant is not necessary to obtain the up-right/down-left advantage, the salient-features coding hypothesis makes a relatively specific prediction about the effect that type of initiating actions should have if the reasonable assumption is made that the response used as an initiating action is increased in salience relative to the other response. This prediction is that the up-right/down-left advantage will be reduced when the initiating action is a left response in comparison to when it is a right response. In contrast, the dual-strategy hypothesis predicts no influence of type of initiating action, unless it leads to differences in mean RT. In the present study, therefore, we examined the *influence of initiating* action on the up-right/down-left advantage for bimanual keypresses and vocal location words.

Influence of Initiating Action on the Up-Right/Down-Left Advantage

In Experiment 1, the responses were left and right keypresses, and the initiating action was a right keypress in some blocks of trials, as in Adam et al.'s (1998) study, and a left keypress in others. An up-right/down-left advantage of 26 ms was evident when the trials were initiated with a right keypress, but only a nonsignificant 5-ms advantage was evident when the trials were initiated with a left keypress. This difference in mapping effects was obtained even though the overall mean RT for the two initiation conditions was the same. Therefore, the interaction of mapping with initiation condition cannot be attributed to use of distinct coding strategies that require different amounts of time. This outcome is as predicted by the salient-features coding hypothesis if pressing the left key increases the relative salience of the left response.

In Experiment 2, vocal initiation was paired with vocal responding. This experiment also showed a significant interaction between S-R mapping and type of trial initiation: The up-right/down-left advantage of 9 ms in the "left" initiation condition was smaller than that of 27 ms in the "right" initiation condition. Experiment 2 thus established that the reduction of the up-right/down-left advantage with a left initiating action is not restricted to manual responses.

In Experiment 3, trials were initiated by saying "left" or "right" and responses were left or right keypresses, whereas in Experiment 4, trials were initiated by pressing a left or right key and responses were "left" or "right" vocalizations. Again, the up-right/down-left advantage was obtained when the initiating action was right (14 ms in Experiment 3 and 27 ms in Experiment 4) but not when it was left (1 ms in Experiment 3 and 7 ms in Experiment 4), even though there was no overall difference in mean RT for the two initiation conditions in both experiments. The results imply that initiating trials with a left response increases the relative salience of the left response even when the initiating action and task responses are in different modalities, indicating that the effect of initiating action is at a more abstract level than the specific physical response.

Speed of Responding

The findings summarized to this point indicate that an initiating action is not necessary to obtain the up-right/down-left advantage with bimanual keypresses (Proctor & Cho, 2001) and that the type of initiating action affects the magnitude of the advantage in several situations. A third finding is that speed of responding seems to be crucial to the up-right/down-left advantage, as Umiltà (1991) originally suggested. According to Umiltà, because it takes longer to form verbal codes, the up-right/down-left advantage should be larger when RT is long than when it is short. Adam et al. (1998) noted that there was a positive correlation between overall RT and the size of the up-right/down-left advantage in Weeks and Proctor's (1990) study. This correlation is not particularly strong support for the view that speed of responding is important because the different experiments in that study varied in terms of the response mode (unimanual aimed movements, bimanual keypresses, and vocal words) and the stimulus mode (physical locations, arrows, and words). Proctor and Cho found stronger evidence for this view: Computer- and participant-paced conditions with manual responses that produced the up-right/down-left advantage with a typical RT procedure did not when a response deadline procedure that reduced mean RT was used. Moreover, a correlational analysis across experiments that used bimanual keypresses showed a positive correlation between mean RT and size of the up-right/down-left advantage. Elimination of the up-right/down-left advantage when mean RT is relatively fast, as in Proctor and Cho's deadline experiment, is predicted by the dual-strategy hypothesis, assuming that verbal codes take longer than visual codes to form. Although this result is not specifically predicted by the salient-features coding hypothesis, it can be accommodated by it with a similar assumption that a period of time is required for the asymmetric coding to occur.

Adam et al. (1998) also cited RT distribution bin analyses as evidence that the size of the up-right/down-left advantage increases as RT lengthens. Specifically, they found that for the participant-paced conditions in which the up-right/down-left advantage occurred, the effect size increased across the 20% RT bins. All of the conditions in the present study and in Proctor and Cho's (2001) study that yielded an up-right/down-left advantage likewise showed the advantage to increase as RT lengthened. Adam et al. interpreted the divergence of the RT functions for the two mapping conditions as RT bin increased as reflecting a greater likelihood of verbal coding for trials on which RT was long. However, as emphasized by Proctor and Cho, the pattern of diverging functions is not very strong evidence in support of this implication of the dual-strategy hypothesis because the pattern is not restricted to situations in which the stimulus and response sets are orthogonal and seems to be a general characteristic of S-R mapping effects (e.g., De Jong et al., 1994, Experiment 1; Roswarski & Proctor, 1996, Experiment 4).

Effect Magnitude

The primary evidence that Umiltà (1991) originally used to support the argument that asymmetric coding, and hence the up-right/down-left advantage, is restricted to verbal codes was that in Weeks and Proctor's (1990) study the advantage was much larger for the experiments in which responding was vocal rather than manual. The present Experiments 2 and 4 showed overall up-right/down-left advantages of only 18 and 17 ms, respectively, and Proctor and Cho's (2001) Experiment 2 showed only a 16-ms advantage. Moreover, when response modality was manipulated within an experiment, Adam et al. (1998, Experiment 2) did not find the up-right/down-left advantage to be any larger for vocal responses than for keypress responses. Also, large effects in the range of 40–50 ms have been reported for some experiments using bimanual keypresses (Dutta & Proctor, 1992) and unimanual finger movements with a neutral hand position (Lippa, 1996, Experiment 5). Thus, the up-right/down-left advantage is not consistently larger for vocal responses than for manual responses.

Response Correspondence Effects

Whether a trial was initiated with a left or right response had an effect in addition to its influence on the up-right/down-left advantage. With keypress initiation and responding in Experiment 1, the initiating action interacted with the response so that performance was faster and more accurate when the response matched the keypress used to initiate the trial than when it did not. In contrast, with vocal initiation and responding in Experiment 2, performance was better when the response on the trial did not match the vocalization used to initiate the trial than when it did. Both of these effects did not interact with the mapping effects and were not evident when the initiating action and response were in different modalities in Experiments 3 and 4. These findings imply that the effects are motoric in nature.

We can only speculate on the exact reason why repetition was beneficial for keypresses but harmful for vocalizations. When people make repeated attempts to reproduce the same movement distance in a linear positioning task, the distances become longer with repetition (Marshall, Anderson, & Kozar, 1992). This suggests some difficulty in repeating motor acts that is likely to be more of a factor for complex movements such as those required for articulation than for simple movements of the type required for discrete keypresses. The difference could also possibly reflect that both keypresses may be controlled by a single motor program that requires only specification of a hand parameter (e.g., Rosenbaum, 1980), whereas the two vocal responses require different motor programs. A final possibility arises from the fact that the word "left" is a strong associate of the word "right," and vice versa. Consequently, saying "right" to initiate a trial may prime the "left" vocal response and saying "left" may prime the "right" response. Because these associations are verbal, they would not affect keypress responses.

Status of the Salient-Features Coding and Dual-Strategy Hypotheses

The salient-features coding and dual-strategy hypotheses are similar in that both accept that the up-right/down-left advantage arises from asymmetries in the coding of the two stimulus and response alternatives on their respective dimensions. However, whereas the salient-features coding hypothesis does not limit asymmetric coding to any particular code format, the dual-strategy hypothesis restricts asymmetric coding to verbal codes. In this section, we consider the evidence with regard to each of these hypotheses.

Salient-features coding hypothesis. The salient-features coding hypothesis is based on the more general salient-features coding principle of Reeve and Proctor (1990; see also Proctor et al., 1992) and indirectly derives some support from the evidence on which that principle is based. That is, Reeve and Proctor have shown in a variety of four-choice tasks—using spatial and symbolic stimuli, visual and auditory stimuli, and manual and vocal responses—that responses are faster and more accurate when the salient feature of a two-dimensional stimulus set corresponds with that of a two-dimensional response set. The evidence from such tasks also indicates that the relative salience of features can be affected by manipulations that enhance some pairs of alternatives relative to others (e.g., Reeve et al., 1992).

If the salient-features coding principle can be applied to explain the up-right/down-left advantage, as Weeks and Proctor's (1990) hypothesis proposes, one would expect that the up-right/down-left advantage should be obtained across a range of stimulus and response sets and that it should be affected by variables that alter the relative salience of members of the stimulus and response sets. Weeks and Proctor (1990) demonstrated that the advantage holds for spatial location stimuli paired with unimanual aimed movements, keypresses, and "left"–"right" vocalizations, as well as for arrow stimuli paired with vocal responses. Subsequent research has shown the effect to still be evident for unimanual responses when hand position is such that it could not provide a frame of reference with respect to which the responses could be coded as up and down (Lippa, 1996) and with keypress responses when a face context is provided that allows the up and down stimulus locations also to be coded as left and right (Proctor & Pick, 1999). The present experiments add to this evidence by showing the effect to occur with both bimanual keypress and vocal response sets in a variety of situations. Therefore, although the advantage is not always large, it does occur across a range of situations.

The up-right/down-left advantage also seems to be susceptible to influence by factors that alter the relative salience of the response alternatives. Although open to alternative interpretations (Lippa & Adam, in press), Weeks et al.'s (1995) finding that the advantage is affected by the eccentricity of the response device with respect to body midline is in accord with the view that the relative salience is increased for the response corresponding to the hemispace in which the device is placed. Less open to alternative interpretations is Weeks et al.'s finding that the up-right/down-left advantage varies systematically for unimanual responses made at body midline as a function of the location of the response device relative to that of another, inactive device. The present Experiment 1 adds to this evidence by showing that the up-right/down-left advantage for bimanual keypresses varies in the manner expected if the relative salience of the response used as the initiating action (left or right keypress) is increased. Experiment 2 confirms that the effect of initiating action occurs when both it and the responses are vocal, and Experiments 3 and 4 confirm the implication that these effects can occur across modalities by showing similar effects of a vocal initiating action on keypress responses and of keypress initiating actions on vocal "left"–"right" responses.

An outcome that is not predicted by the salient-features coding hypothesis is the absence of an up-right/down-left advantage with the response deadline procedure in Proctor and Cho's (2001) Experiment 3. The hypothesis itself says nothing about the time course of coding and thus makes no prediction regarding how the up-right/down-left advantage will vary across time. However, the way in which Weeks and Proctor (1990) characterize the hypothesis is that the asymmetric coding is used to facilitate responding when direct spatial correspondence is absent. The implication is that if asymmetric coding is not evident, then responding should be slow and inaccurate. Not only were participants relatively fast at responding in Proctor and Cho's Experiment 3, but the error rate did not rise dramatically, either: The 450-ms deadline was exceeded on only 2.9% of the trials, and the PE for the remaining trials was just 3.65%. It is not obvious why asymmetric coding would be used if it does not increase the efficiency of response selection.

Dual-strategy hypothesis. On the basis of the fact that Weeks and Proctor's (1990) experiments showed larger effects when responses were vocal than when they were manual, Umiltà (1991) initially proposed that the orthogonal S-R compatibility effects were weak unless the task used a vocal response mode that favored the use of verbal codes. However, as noted earlier, a direct test of this proposal in Adam et al.'s (1998) Experiment 2 showed no significant difference in magnitude of the up-right/down-left advantage between vocal and manual response modalities. Likewise, in many of the experiments reported in this article and by Proctor and Cho (2001), the effect magnitudes were similar for vocal and keypress responses.

Adam et al. (1998) proposed that participant-paced presentation would promote the use of verbal codes, whereas computer-paced presentation would promote the use of spatial codes. Although their Experiments 1 and 2 showed the up-right/down-left advantage only with participant-paced presentation, their Experiment 3 showed the advantage with computer-paced presentation. Dutta and Proctor (1992) reported a large up-right/down-left advantage using computer-paced presentation, and Proctor and Cho's (2001) Experiments 1 and 2 showed significant advantages that did not differ in magnitude between computer- and participant-paced presentation conditions.

Another hypothesis put forward by Adam et al. (1998) was that the longer ITI for their participant-paced conditions than for their computer-paced conditions was the crucial factor responsible for the occurrence of the up-right/down-left advantage in the former situation but not in the latter. Their logic was that the need to apply a verbal mapping rule would be less with a series of rapid S-R actions, as in the computer-paced condition, because the just-completed S-R action could be used to select the next action. They tested this proposal in their Experiment 3 by directly manipulating ITI for computer-paced presentation and found that the up-right/down-left advantage did not increase in magnitude as ITI increased.

Because their Experiment 3 did not show an effect of ITI on the up-right/down-left advantage, Adam et al. (1998) then offered that it is the act of initiating trials that is crucial to the adoption of a verbal coding strategy. As noted above, though, our replications of Adam et al.'s experiments show that the up-right/down-left advantage is not significantly larger with participant-paced presentation than with computer-paced presentation. In addition, because up and right should be salient whenever verbal codes are used, their proposal predicts that the up-right/down-left advantage should be of similar magnitude regardless of whether the initiating action is left or right. Yet, in our Experiments 1–4, the advantage was reduced or eliminated with left initiation.

Umiltà (1991) suggested that "the spatial codes become available sooner than the verbal ones" (p. 85), implying that the up-right/down-left advantage should be more evident for conditions in which responding is slow. In Adam et al.'s (1998) Experiment 1, RT was 25 ms faster with computer-paced presentation than with participant-paced presentation, and the up-right/down-left advantage was absent in the former condition but not in the latter condition. In our replication of their Experiment 1 (Proctor & Cho, 2001, Experiment 1), there was no difference in mean RT for the computer- and participant-paced conditions, and both conditions showed the up-right/down-left advantage. When a response deadline was imposed in our Experiment 3, leading to shorter mean RTs, the advantage was not evident for either condition. However, the relation between response speed and the up-right/down-left advantage seems to be more complex than implied by the dual-strategy hypothesis. In Adam et al.'s Experiment 3, which varied ITI for computer-paced presentation, RT increased by 50 ms from the shortest to longest ITI, yet a small up-right/down-left advantage was obtained that was independent of ITI. In our Experiments 1–4, the up-right/down-left advantage differed significantly in magnitude for conditions with similar mean RT that differed in the action used to initiate the trials.

Another implication of the view that spatial codes become available sooner than verbal codes is that within a condition the up-right/down-left advantage should increase as RT increases. Distributional analyses for RT showed this finding to be evident not only in Adam et al.'s (1998) experiments but also in the present experiments. However, because similar functions occur for parallel stimulus and response dimensions (De Jong et al., 1994; Roswarski & Proctor, 1996), for which an explanation in terms of asymmetric verbal codes is not plausible, the increase of effect size across the RT distribution does not unambiguously indicate an increased contribution of asymmetric verbal codes.

In Adam et al.'s (1998) Experiment 4, which we have not discussed to this point, the mapping rule was varied from trial to trial using visual or verbal precues. The visual precues showed an *X* in each stimulus location and a square in each response location, with lines connecting the stimuli with their assigned responses. The verbal precues consisted of the Dutch equivalents of the words "above-right/down-left" and "above-left/down-right." An up-right/down-left advantage of 52 ms was obtained with the verbal precues, but no advantage was evident with the spatial precues. Kleinsorge (1999) conducted similar experiments in which the visual precues were the upper left and lower right or the upper right and lower left quarters of a circle and the verbal precues were "up → right, down → left" or "up → left, down → right." He, too, obtained an up-right/down-left advantage of 52 ms with the verbal precues and no significant advantage with the visual precues.

However, Kleinsorge (1999) noted that the spatial precue allowed simultaneous coding of both S-R mappings, whereas the verbal precue specified the two mappings in succession. To equate the visual and verbal precues in this regard, he modified both precue types to indicate explicitly only the mapping of one stimulus to one response, with the other S-R mapping being implicit. In this case, an up-right/down-left advantage of similar magnitude was obtained for the visual and verbal precues. Consequently, Kleinsorge concluded that the up-right/down-left advantage is not dependent on verbal coding. He speculated that the difference between successive and simultaneous specifications of the mappings by the precues lies instead in a distinction between categorical and coordinate spatial relations made by Kosslyn (1994). According to Kleinsorge, the up-right/down-left advantage occurs when spatial mappings are specified successively because the locations are coded in terms of categorical spatial relations, but it is absent when the precue explicitly specifies both S-R mappings simultaneously because the precue image is represented in coordinate spatial relations.

A possible resolution. Asymmetric coding of the type proposed by Weeks and Proctor (1990) in their salient-features coding hypothesis and by Umiltà (1991) in his dual-strategy hypothesis is currently the only way to explain the up-right/down-left advantage that often occurs when up and down stimuli are mapped to left and right responses. The salient-features coding hypothesis receives support from the fact that the advantage is obtained with a variety of stimulus and response sets, both nonverbal and verbal. It is also buttressed by the findings indicating that the magnitude of the up-right/down-left advantage changes systematically as a function of variables that can be construed as altering relative salience. Most problematic for the salient-features coding hypothesis is the evidence suggesting that the up-right/down-left advantage does not occur when responding is fast. This finding in turn provides the strongest support for the dual-strategy hypothesis because verbal coding, which is assumed to underlie the advantage, takes time to occur. However, there is little other evidence suggesting that asymmetric coding is restricted to verbal codes. The distinction between categorical and coordinate spatial codes seems to provide the means for resolving the evidence that the up-right/down-left advantage is not restricted to verbal codes but is time dependent. There are two ways of coding spatial information, as incorporated in the dual-strategy hypothesis, but the asymmetric codes that produce the up-right/down-left advantage are categorical and not verbal, consistent with the generalizability of the phenomenon across stimulus and response sets of various types that has been the central focus of the salient-features coding hypothesis.

References

Adam, J. J., Boon, B., Paas, F. G. W. C., & Umiltà, C. (1998). The up-right/down-left advantage for vertically oriented stimuli and horizontally oriented responses: A dual-strategy hypothesis. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 1582–1597.

Andre, A. D., & Wickens, C. D. (1990). *Display–control compatibility in the cockpit: Guidelines for display layout analysis* (ARL-90-12/NASA-A3I-90-1). Savoy: Aviation Research Laboratory, University of Illinois.

Balota, D. A., Boland, J. E., & Shields, L. W. (1989). Priming in pronunciation: Beyond pattern recognition and onset latency. *Journal of Memory and Language, 28,* 14–36.

Bauer, D. W., & Miller, J. (1982). Stimulus–response compatibility and the motor system. *Quarterly Journal of Experimental Psychology, 34A,* 367–380.

Chase, W. G., & Clark, H. H. (1971). Semantics in the perception of verticality. *British Journal of Psychology, 63,* 311–326.

De Jong, R., Liang, C.-C., & Lauber, E. (1994). Conditional and unconditional automaticity: A dual-process model of effects of spatial stimulus–response correspondence. *Journal of Experimental Psychology: Human Perception and Performance, 20,* 731–750.

Dutta, A., & Proctor, R. W. (1992). Persistence of stimulus–response compatibility effects with extended practice. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 18,* 801–809.

Farrell, W. S., Jr. (1979). Coding left and right. *Journal of Experimental Psychology: Human Perception and Performance, 5,* 42–51.

Fitts, P. M., & Deininger, R. L. (1954). S-R compatibility: Correspondence among paired elements within stimulus and response codes. *Journal of Experimental Psychology, 48,* 483–492.

Kleinsorge, T. (1999). Die Kodierungsabhaengigkeit orthogonaler Reiz-Reaktions-Kompatibilitaet [Coding specificity of orthogonal S-R compatibility]. *Zeitshrift für Experimentelle Psychologie, 46,* 249–264.

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

Lippa, Y. (1996). A referential-coding explanation for compatibility effects of physically orthogonal stimulus and response dimensions. *Quarterly Journal of Experimental Psychology, 49A,* 950–971.

Lippa, Y., & Adam, J. J. (in press). An explanation of orthogonal S-R compatibility effects that vary with hand or response position: The end-state comfort hypothesis. *Perception & Psychophysics.*

Marshall, P. H., Anderson, T., & Kozar, B. (1992). Systematic bias in successive movement repetitions. *Journal of Motor Behavior, 24,* 355–358.

Michaels, C. F. (1989). S-R compatibilities depend on eccentricity of responding hand. *Quarterly Journal of Experimental Psychology, 41A,* 262–272.

Michaels, C. F., & Schilder, S. (1991). Stimulus–response compatibilities between vertically oriented stimuli and horizontally oriented responses: The effects of hand position and posture. *Perception & Psychophysics, 49,* 342–348.

Olson, G. M., & Laxar, K. (1973). Asymmetries in processing the terms "right" and "left." *Journal of Experimental Psychology, 100,* 284–290.

Proctor, R. W., & Cho, Y. S. (2001). The up-right/down-left advantage occurs for both participant- and computer-paced conditions: An empirical observation on Adam, Boon, Paas, and Umiltà (1998). *Journal of Experimental Psychology: Human Perception and Performance, 26,* 466–471.

Proctor, R. W., & Pick, D. F. (1999). Deconstructing Marilyn: Robust effects of face contexts on stimulus–response compatibility. *Memory & Cognition, 27,* 986–995.

Proctor, R. W., & Reeve, T. G. (1985). Compatibility effects in the assignment of symbolic stimuli to discrete finger response. *Journal of Experimental Psychology: Human Perception and Performance, 11,* 623–639.

Proctor, R. W., & Reeve, T. G. (1986). Salient-feature coding operations in spatial precuing tasks. *Journal of Experimental Psychology: Human Perception and Performance, 12,* 277–285.

Proctor, R. W., & Reeve, T. G. (Eds.) (1990). *Stimulus–response compatibility: An integrated perspective.* Amsterdam: North-Holland.

Proctor, R. W., Reeve, T. G., & Van Zandt, T. (1992). Salient-features coding in response selection. In G. E. Stelmach & J. Requin (Eds.), *Tutorials in motor behavior II* (pp. 727–741). Amsterdam: North-Holland.

Proctor, R. W., Reeve, T. G., Weeks, D. J., Dornier, L., & Van Zandt, T. (1991). Acquisition, retention, and transfer of response selection skill in choice-reaction tasks. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 17,* 497–506.

Reeve, T. G., & Proctor, R. W. (1990). The salient-features coding principle for spatial- and symbolic-compatibility effects. In R. W. Proctor & T. G. Reeve (Eds.), *Stimulus–response compatibility: An integrated perspective* (pp. 163–180). Amsterdam: North-Holland.

Reeve, T. G., Proctor, R. W., Weeks, D. J., & Dornier, L. (1992). Salience of stimulus and response features in choice-reaction tasks. *Perception & Psychophysics, 52,* 453–460.

Rosenbaum, D. A. (1980). Human movement initiation: Specification of arm, direction, and extent. *Journal of Experimental Psychology: General, 109,* 444–474.

Roswarski, T. E., & Proctor, R. W. (1996). Multiple spatial codes and temporal overlap in choice-reaction tasks. *Psychological Research, 59,* 196–211.

Schneider, W. (1995). Micro Experimental Laboratory (Version 2.0) [Computer software]. Pittsburgh, PA: Psychology Software Tools.

Sternberg, S. (1998). Discovering mental processing stages: The method of additive factors. In D. Scarborough & S. Sternberg (Eds.), *An invitation to cognitive science: Methods, models, and conceptual issues* (Vol. 4, 2nd ed., pp. 703–863). Cambridge, MA: MIT Press.

Umiltà, C. (1991). Problems of the salient-feature coding hypothesis: Comment on Weeks and Proctor. *Journal of Experimental Psychology: General, 120,* 83–86.

Weeks, D. J., & Proctor, R. W. (1990). Salient-feature coding in the translation between orthogonal stimulus and response dimensions. *Journal of Experimental Psychology: General, 119,* 355–366.

Weeks, D. J., & Proctor, R. W. (1991). Salient-feature coding and orthogonal compatibility effects: A reply to Umiltà. *Journal of Experimental Psychology: General, 120,* 87–89.

Weeks, D. J., Proctor, R. W., & Beyak, B. (1995). Stimulus–response compatibility for vertically oriented stimuli and horizontally oriented responses: Evidence for spatial coding. *Quarterly Journal of Experimental Psychology, 48A,* 367–383.

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