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Tailoring perception and action to the task at hand

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Two experiments investigated whether and how task demands affect the way perceptual events and actions are cognitively represented, and how this affects performance. Subjects performed two-dimensional Simon tasks that alternated with, or were embedded into, a logically unrelated "priming task", in which the relevance of horizontal and vertical dimensions varied frequently. Making the horizontal dimension relevant in the priming task increased the horizontal Simon effect, and making the vertical dimension relevant increased the vertical Simon effect. These findings suggest that stimulus and response representations are not invariant but are tailored to the current task demands. This has implications for models of perception and action planning, stimulus–response compatibility, and executive control.

Human performance is not dictated by fixed stimulus–response (S–R) relations but is flexibly adapted to the situation and task at hand. The same external event can give rise to a multitude of actions, for example the presence of a chair, which under appropriate circumstances may tempt people to sit down on it, take it out of the way, smash it, throw it out of the window, point to it, name it, and much more. Likewise, one given movement can be performed for very different reasons, just think of a button press that may switch a light on or off, type a letter on a sheet, launch a rocket, or signal a stimulus on a monitor during a psychological experiment. This flexibility of perception and action suggests that perceived events (stimuli) and produced events (actions) are not represented in a unitary, invariant fashion but, rather, by distributed networks of feature codes that are tuned to the current task goals and the relevant situational constraints (Barsalou, 1999; Cohen, Braver, & O'Reilly, 1998; Hommel, Müsseler, Aschersleben, & Prinz, 2001). That is, we may tailor our cognitive representations of perceived and produced events to the task at hand by emphasising and attending to those stimulus and response features that are crucial for

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realising our intentions—a process that Hommel et al. (2001) called "intentional weighting".

The present study investigated how this intentional-weighting process works in detail. We employed a task introduced by Cotton, Tzeng, and Hardyck (1977) and commonly used to study two-dimensional spatial S–R compatibility (e.g., Nicoletti & Umiltà, 1984) and task-switching (e.g., Meiran, 1996). The task comprises visual stimuli that can appear at the four corners of an imaginary square, that is, at the top-left, top-right, bottom-left, or bottom-right of a display (see Figure 1, Stimuli). These four stimulus locations are mapped onto two, diagonally arranged response keys, hence, keys located at the bottom-left and the top-right (as shown in Figure 1), or at the top-left and the bottom-right. Each of these two keys thus varies on two spatial dimensions and can be alternatively described as, say, either "bottom" or "left", or as "top" or "right". Performance in such a task is known to depend on the spatial compatibility of the S–R mapping: People perform best if stimuli and responses are compatible on both spatial dimensions (e.g., bottom-left key to bottom-left stimulus, top-right key to top-right stimulus) and worst if stimuli and responses are completely incompatible (e.g., bottom-left key to top-right stimulus, top-right key to bottom-left stimulus), while horizontal-only and vertical-only compatible mappings fall in between (e.g., Nicoletti & Umiltà, 1984). This represents a two-dimensional version of the well-known spatial compatibility effect, which is commonly attributed to code sharing between stimuli and responses (e.g., Hommel, 1997; Kornblum, Hasbroucq, & Osman, 1990; Wallace, 1971). As indicated in Figure 1, the top-right response, say, is cognitively represented through the codes "top" and "right". If it is signalled by a

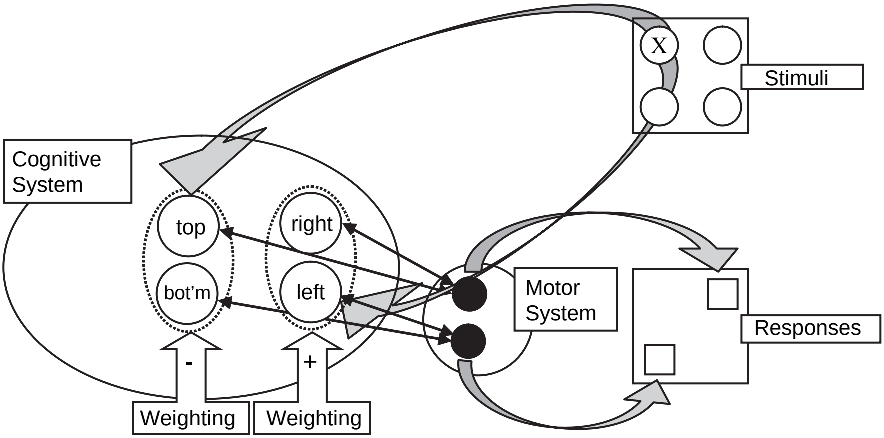

Figure 1. Sketch of the intentional-weighting mechanism. Stimuli and responses are represented by distributed feature codes the dimensions of which are primed by task demands.

stimulus appearing in the top-left corner of the display, as would be the case with vertical S–R compatibility, coding the stimulus will activate both the correct response (via the "top" code) and the incorrect response (via the "left" code). This situation is more beneficial than with a bottom-left stimulus, as in the incompatible condition, but less optimal than with a top-right stimulus in the fully compatible condition.

In their evaluation of two-dimensional S–R compatibility effects Nicoletti and Umiltà (1984) consistently found that the horizontal compatibility effect was larger than the vertical compatibility effect and called this dominance "right–left prevalence". It has been argued that the origins of right–left prevalence may be due to using left and right effectors (Hommel, 1996), to the greater salience of the horizontal dimension (Vu & Proctor, 2001, 2002; Vu, Proctor, & Pick, 2000), or to the greater number of spatial codes for the horizontal dimension (Rubichi, Nicoletti, & Umiltà, 2005). In the present paper we do not suggest or presuppose one particular account but, rather, investigate the possible impact of further, more flexible, task-induced biases.

Some evidence in favour of the idea that performing a task is associated with intentional feature weighting comes from Proctor and colleagues (Marble & Proctor, 2000; Proctor & Vu, 2002; Proctor, Vu, & Marble, 2003). They interleaved a standard one-dimensional S–R compatibility task with a task in which stimulus location was irrelevant (a Simon task, see below). It turned out that the impact of stimulus location on spatially compatible responses increased in this Simon task if the S–R mapping was compatible in the other task but decreased if the mapping was incompatible. Apparently, then, responding to the spatial location of stimuli (as required in the S–R compatibility task) changes the way stimuli and/or responses are represented in a given situation in such a way that location features are somehow more (with a compatible mapping) or less (with an incompatible mapping) prominent than normal and gain or lose impact on action control, respectively—even in the other task.

Indeed, we know from single task studies that instructing subjects to attend to one spatial dimension increases the size of the compatibility effect related to this dimension and decreases the effect related to the other dimension (Hommel, 1996; Vu & Proctor, 2001; Vu et al., 2000). Figure 1 shows how this may work: Attending to the horizontal dimension increases the weights of the codes defined on this dimension ("left" and "right") and decreases those of the vertically defined codes. As a consequence, a top-left stimulus would be coded more as "left" than as "top" and a top-right response more as "right" than as "top", which would increase the impact of horizontal S–R compatibility at the expense of vertical compatibility.

Although the observation of instruction-induced coding biases is consistent with intentional weighting, one would expect more from a mechanism that is assumed to underlie the adaptation of our cognitive system to changing situations and task demands. In particular, one would expect that such a mechanism is flexible enough to switch frequently between alternative weighting patterns (cf. Meiran, Chorev, & Sapir, 2000). Moreover, one would like to see it to be used spontaneously, that is, under conditions that are more natural than urging subjects to ignore an arbitrarily picked S–R dimension. As Vu et al. (2000) have pointed out, such instructions might induce particular inhibitory strategies that, while being successful in meeting the instructed criteria, may not validly reflect the way people would normally deal with the task. Thus, we were interested to see whether evidence of intentional weighting can be gathered under conditions in which (a) weighting was induced in a rather "natural" way, that is, without urging subjects to exclude a particular dimension; and when (b) the weightings were likely to be frequently modified to meet changing task demands. To this effect we carried out three very similar experiments that followed the same logic.

In both experiments we attempted to induce particular weightings by means of a *priming task* (see Figure 2). This task included the presentation of horizontal or vertical arrows appearing at the middle of the display. Vertical arrows required a press of the key that matched the vertical location of the stimulus, e.g., the top-left key for top-left and top-right stimuli and the bottom-right key for bottom-left and bottom-right stimuli, whereas the horizontal arrows called for a press of the key that matched the horizontal location of the stimulus, e.g., the top-left key for bottom-left and top-left stimuli and the bottom-right key for bottom-right and top-right stimuli. We

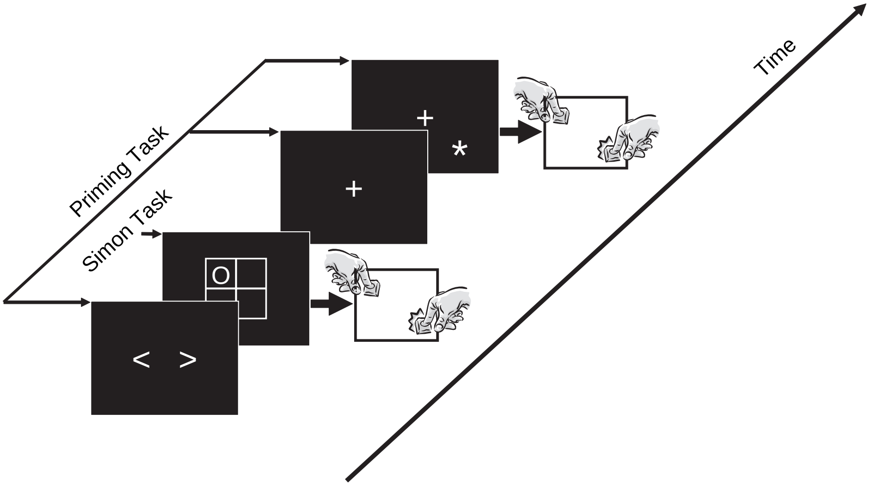

Figure 2. Sequence of events in Experiment 1. See text for further details.

assumed that attending to the dimension as indicated by the arrows would be associated with adopting particular intentional-weighting patterns, that is, responding to the vertical arrows should involve increasing the weights for the vertical dimension to the expense of horizontal weights while responding to the horizontal arrows should have the opposite effect. Then we intermixed this priming task with a two-dimensional Simon task. In a Simon task, people respond to non-spatial stimulus features—the letters "O" and "X" in our case—and ignore the randomly varying stimulus location (see overviews in Hommel & Prinz, 1997; Lu & Proctor, 1995). Nevertheless, spatial S–R compatibility affects performance in much the same way as in the standard S–R compatibility task, that is, both horizontal and vertical compatibility speed up reaction time (RT) and reduce error rates. In other words, two-dimensional Simon tasks produce both horizontal and vertical Simon effects.

Now consider a Simon trial that is preceded and thus primed by a prime-task trial in which vertical arrows were presented. Vertical arrows should be associated with a "vertical set", that is, with a weighting pattern that favours vertical over horizontal spatial codes. If we assume that such sets are inert and decay only slowly (Allport, Styles, & Hsieh, 1994), we would expect the vertical Simon effect to increase relative to the horizontal Simon effect, whereas prime trials involving horizontal should have the opposite effect. Hence, we expected that the primed spatial dimension would show a stronger contribution to the S–R compatibility effect than the unprimed dimension.

In Experiment 1 we were interested to see whether the impact of priming would change if we induced it by means of cues that are also used in more conventional task-switching studies, such as those of Meiran (1996; Meiran et al., 2000). If the outcome was the same, this would provide support for the claim that modifying the weighting of feature dimensions is one part of the processes responsible for task switching (Meiran et al., 2000). In the priming task, we thus cued subjects to respond to the horizontal or the vertical location of the target stimuli—a kind of task-switching design, however with a rather large number of task repetitions (the cued dimension changed every 32 prime trials) to avoid effects peculiar to the switching process itself. The Simon or probe trials were presented between the task cues and the actual prime-task trial, to increase chances that the weightings favouring the cued dimension were in full effect.

Experiment 2 was very similar to Experiment 1 with the exception that the dimension changed more frequently (every four trials). Similar outcomes as in Experiment 1 would provide evidence that the intentional weighting system is indeed very flexible and that the effects are unlikely to reflect long-term associations of overlearned S–R rules (cf. Proctor & Lu, 1999; Tagliabue, Zorzi, Umiltà, & Bassignani, 2000). In the priming task, we cued subjects to respond to the horizontal or the vertical location of the target stimuli—again a kind of task-switching design.

EXPERIMENT 1

Method

Participants. Twenty-four undergraduates from Leiden University participated as paid volunteers. All reported having normal or corrected-to-normal vision and were unaware of the purpose of the experiment.

Apparatus and stimuli. The experiment was conducted in a dimly lit cubicle. Participants were seated in front of PC with a 17-inch monitor; viewing distance was about 60 cm. The software ran under ERTS™ V3.28 (Beringer, 1999). Subjects faced a light-grey two-by-two cell grid of 5.2×5.2 cm, displayed in the middle of the black screen. In the Simon task, the target stimuli consisted of the 24-point letters “O” and “X” appearing in light grey in the middle of the given cell. Responses were given by using the left and right index finger to press one of two diagonally arranged keys of the QWERTY keyboard. Half the participants used a top-left and a bottom-right response key (Esc and right Ctrl), the other half a top-right and a bottom-left key (F12 and left Ctrl). In the priming task, a light-grey, horizontally or vertically oriented double arrow of 4.2 cm length was presented at screen centre to cue the valid S–R rule. Auditory error feedback consisted of an 880 Hz, 300 ms, pure tone.

Procedure. In the instruction it was explained to subjects that the relevant S–R rule would be validly cued by an arrow. With the dimensional priming, and therefore for each trial, the participant had to give two responses. The first response was given in response to the letter presentation and for the second response the participant had to indicate the location of the asterisk according to its horizontal or vertical dimension. Prior to the appearance of the letter the orientation of the arrows indicated which dimension had to be kept in mind. Priming and Simon trials were thus interleaved in the following way: First, an intertrial interval of 1000 ms was presented. Then the arrow cues were presented for 1400 ms. After that the grid containing the target letter appeared and remained on screen until response 1 was given, with a maximum time to respond of 8000 ms. Finally the fixation cross was presented in the middle of the screen accompanied by the target prime until the second response was given with a maximum time to respond of 8000 ms.

Results

The data from one subject was excluded because of an excessive error rate ($>30\%$). Trials with missing ($RT > 1500$ ms) or anticipatory ($RT < 150$ ms) responses were also excluded; they accounted for 3.3% of the data. Mean RT and percentage of errors (PE) were calculated for each combination of priming (horizontal or vertical), horizontal compatibility, and vertical compatibility. These data provided the input for a three-way ANOVA (see Table 1).

The analyses focused on the Simon task.[1] In RTs, main effects were found for horizontal compatibility, $F(1, 22) = 8.2$, $p < .01$, $MSE = 3987.88$, and vertical compatibility, $F(1, 22) = 14.36$, $p < .001$, $MSE = 2989.06$. Horizontal compatibility was modified by priming, showing that horizontal priming increased the horizontal compatibility effect, $F(1, 22) = 4.52$, $p < .05$, $MSE = 7817.99$ (see Figure 3). Vertical compatibility was also modified by priming, showing that vertical priming increased the vertical compatibility effect, $F(1, 22) = 5.92$, $p < .05$, $MSE = 5421.88$ (see Figure 3).

In the errors, there was a main effect of horizontal compatibility, $F(1, 22) = 4.39$, $p < .05$, $MSE = 3.67$. The effect of vertical compatibility, $F(1, 22) = 6.34$, $p < .05$, $MSE = 4.99$, was further modified by priming $F(1, 22) = 12.42$, $p < .005$, $MSE = 2.41$.

Discussion

We sought evidence that the coding of S–R relations or, more precisely, of features in which stimuli and responses overlap, is flexibly adapted to task demands by means of intentional weighting (Hommel et al., 2001). In particular, we were interested to see whether the relative sizes of horizontal

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[1] For the sake of completeness, we also analysed the data from the priming task. Missing and anticipatory responses were excluded and mean RTs and PEs were analysed as a function of primed spatial dimension, the spatial compatibility between response and the stimulus location on the unprimed dimension, and of horizontal and vertical compatibility in the (preceding) Simon task. Reliable main effects were obtained for compatibility in the priming task, $F(1, 22) = 24.26$, $p < .001$, $MSE = 19{,}491.58$, and of horizontal compatibility, $F(1, 22) = 5.15$, $p < .05$, $MSE = 10{,}000.31$, and vertical compatibility, $F(1, 22) = 13.85$, $p < .001$, $MSE = 6525.14$, in the Simon task. All these effects entered into a three-way interaction, $F(1, 22) = 7.07$, $p < .05$, $MSE = 2908.91$, and vertical compatibility was further modulated by priming, $F(1, 22) = 7.79$, $p < .05$, $MSE = 11{,}150.46$. The latter interaction was due to the fact that performance in vertical priming conditions was strongly affected by vertical compatibility in the Simon task (711 vs. 774 ms), whereas performance in horizontal priming conditions was not (759 vs. 759 ms). The three-way interaction reflected that performance on the compatibility effect in the priming task was increased after fully compatible (85 ms) and fully incompatible (89 ms) Simon trials as compared to Simon trials of mixed compatibility trials (63 and 50 ms for vertically compatible/horizontally incompatible and vertically incompatible/horizontally compatible, trials respectively). PEs showed a main effect of compatibility on the unprimed dimension in the priming task, $F(1, 22) = 30.54$, $p < .001$, $MSE = 208.84$, and an interaction of vertical and horizontal compatibility in the Simon task, $F(1, 22) = 7.99$, $p < .01$, $MSE = 49.12$, that was further modified by priming, $F(1, 22) = 13.98$, $p < .01$, $MSE = 32.88$. A four-way interaction, $F(1, 22) = 17.85$, $p < .001$, $MSE = 32.77$, indicated that incompatible priming trials in the vertically primed dimension were modified by compatibility in the Simon trial.

TABLE 1
Reaction times (RT) and percentages of error (PE) in Experiment 1 as a function of horizontal and vertical stimulus–response compatibility, and the type of priming

	Vertical compatibility											
	Horizontal priming						*Vertical priming*					
	Compatible		*Incompatible*		*Δ*		*Compatible*		*Incompatible*		*Δ*	
Horizontal compatibility	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*
Compatible	706	1.3	726	2.0	20	0.7	669	0.9	758	3.8	89	2.9
Incompatible	772	6.5	789	11.1	17	4.6	731	1.4	785	5.8	54	4.4
Δ	66	5.2	63	9.1			62	0.5	27	2.0		

Δ = Effect sizes.

and vertical S–R compatibility effects in a Simon task reflect the frequently changing situational relevance of the given spatial dimensions. In contrast to previous studies (e.g., Hommel, 1993), we did not directly induce intentional weighting by instructing subjects to prefer or ignore a particular feature dimension—in fact, we did not manipulate dimensional relevance in the Simon task at all. Rather, we attempted to prime one or the other feature dimension by manipulating its relative relevance in another, logically unrelated task carried out before or after the Simon task. Experiment 1 provided evidence that this attempt was successful in strongly affecting the

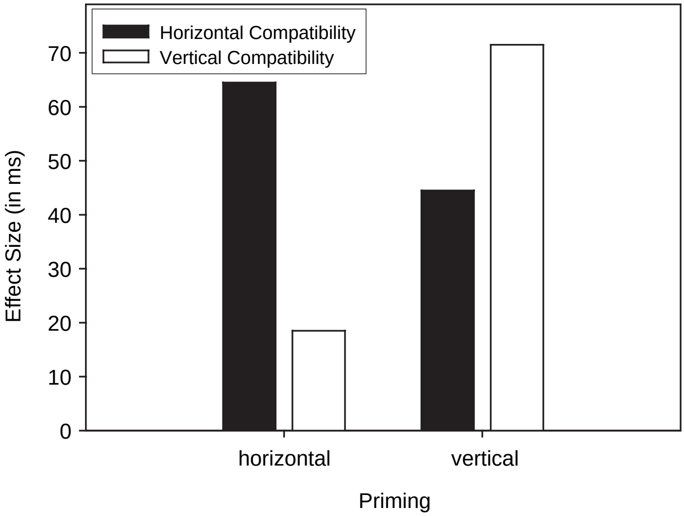

Figure 3. Compatibility effect sizes (incompatible minus compatible) as a function of dimensional priming in Experiment 1.

magnitude of the corresponding compatibility effect in the Simon task: Both horizontal and vertical compatibility effects were increased if the following task rendered the corresponding spatial dimension task relevant.

EXPERIMENT 2

Experiment 1 provides evidence suggesting that a task set adapted for one task can affect performance in another, logically unrelated task, and that this impact is rather immediate. That is, adopting a task set for 32 prime trials was sufficient to bias the compatibility effects in the interleaved Simon task. In Experiment 2 we went one step further and had participants switch to a new set every four trials.

Method

Participants. Twenty-two undergraduates from Leiden University participated as paid volunteers. All reported having normal or corrected-to-normal vision and were unaware of the purpose of the experiment.

Apparatus and stimuli. These were exactly the same as in Experiment 1.

Procedure. It was very similar to the procedure in Experiment 1, except that there was a dimensional switch every four trials. The experimental session consisted of 32 miniblocks of 4 trial triples (priming, priming, Simon) each, amounting to a total of 128 trials. Within a miniblock the primed dimension remained constant.

Results

We again focused on the Simon task.[2] The data from two subjects were excluded because of their excessive RTs (mean RT > 1590 ms as compared to

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[2] RTs and PEs from the priming task were analysed analogously to Experiment 1. Reliable main effects were obtained for compatibility on the unprimed dimension, $F(1, 19) = 12.21$, $p < .005$, $MSE = 76{,}377.24$, and on horizontal, $F(1, 19) = 18.99$, $p < .001$, $MSE = 11{,}844.23$, and vertical compatibility, $F(1, 19) = 6.90$, $p < .05$, $MSE = 36{,}753.19$, in the Simon task. PEs showed a main effect of the primed dimension, $F(1, 19) = 7.03$, $p < .05$, $MSE = 202.61$, and a main effect of compatibility on the unprimed dimension in the priming task, $F(1, 19) = 33.45$, $p < .001$, $MSE = 631.58$. An interaction of priming and vertical compatibility in the Simon task, $F(1, 19) = 11.07$, $p < .005$, $MSE = 57.16$, was found, indicating that more errors were made in the vertically primed condition, following vertically incompatible Simon trials. An interaction of primed dimension and compatibility in the priming task, $F(1, 19) = 5.81$, $p < .05$, $MSE = 177.94$, showed that more errors were made on incompatible trials in the vertically primed condition than in the horizontally primed condition.

737 ms for the rest of the group). Trials with missing (RT > 2500 ms) or anticipatory (RT < 150 ms) responses were also excluded; they accounted for 0.9% of the data. Mean RT and PE were calculated for each combination of priming (horizontal or vertical), horizontal compatibility, and vertical compatibility. These data provided the input for a three-way ANOVA (see Table 2 for means).

In the RTs, main effects were found for horizontal compatibility, $F(1, 19) = 22.39$, $p < .001$, $MSE = 4242.65$, and vertical compatibility, $F(1, 19) = 4.91$, $p < .05$, $MSE = 5924.31$. Only the horizontal compatibility effect was modified by priming, showing that horizontal priming increased the horizontal compatibility effect, $F(1, 19) = 4.55$, $p < .05$, $MSE = 5080.51$ (see Figure 4). In the errors, there were main effects for horizontal compatibility, $F(1, 19) = 15.49$, $p < .005$, $MSE = 56.74$, and for vertical compatibility, $F(1, 19) = 6.56$, $p < .05$, $MSE = 47.37$. There was also an interaction between horizontal and vertical compatibility, $F(1, 19) = 15.81$, $p < .005$, $MSE = 21.83$, indicating that horizontally compatible trials yielded fewer errors than vertically compatible trials, whereas horizontally incompatible trials yielded more errors than vertically incompatible trials.

Discussion

We were interested in how rapid changes in attending to a dimension would affect intentional weighting for that dimension in an unrelated task. Experiment 2 shows that even with as few as four trials the horizontal priming task increased the Simon effect for the horizontal dimension. Vertical priming had no effect on vertically compatible stimuli. On the one hand, given the small main effect of vertical compatibility it is not so

TABLE 2

Reaction times (RT) and percentages of error (PE) in Experiment 2 as a function of horizontal and vertical stimulus–response compatibility, and the type of priming

	Vertical compatibility											
	Horizontal priming						*Vertical priming*					
	Compatible		*Incompatible*		*Δ*		*Compatible*		*Incompatible*		*Δ*	
Horizontal compatibility	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*	*RT*	*PE*
Compatible	683	2.5	725	1.6	42	0.9	707	2.8	741	3.4	34	0.6
Incompatible	764	4.4	790	9.8	26	5.4	746	4.4	752	10.4	6	6.0
Δ	81	1.9	65	8.2			39	1.6	11	7.0		

Δ = Effect sizes.

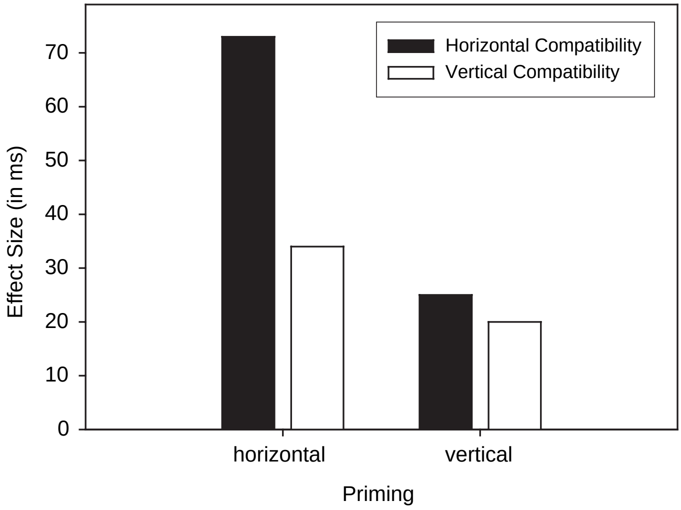

Figure 4. Compatibility effect sizes (incompatible minus compatible) as a function of dimensional priming in Experiment 2.

surprising that it is not further modulated in a reliable fashion. On the other hand, it is not clear why the effect was so much smaller than in Experiment 1. True, prevalence may have played a role, especially given that left and right effectors were used and the horizontal distance between the response buttons was about twice as large as their vertical distance. And yet, why the impact of these factors should increase as people switch between tasks more often is not obvious. In any case, however, the very substantial priming effect on horizontal compatibility demonstrates that frequent switching does not prevent task set effects across tasks. What is more, the fact that priming effects on horizontal compatibility are virtually identical across the two experiments rules out the possibility of any longer-term learning effects.

CONCLUSIONS

The aim of our study was to provide further insights into the inner workings of what Hommel et al. (2001) had called intentional weighting, that is, the task specific tuning of the cognitive system to task-relevant feature dimensions. As predicted, we were able to show that making a particular feature dimension relevant for one task primes the processing of this respective feature dimension (or the feature values coded thereon) in another, unrelated but temporally overlapping task. As pointed out, the fact that our priming effects survive frequent switches between the horizontal and vertical dimension rules out the contribution of stimulus–

response learning, that is, of transfer effects due to overlearned stimulus–response associations acquired in one task to another task (Proctor & Lu, 1999; Tagliabue et al., 2000). Our observations seem more related to the mixing costs reported by Proctor and colleagues (Marble & Proctor, 2000; Proctor & Vu, 2002; Proctor et al., 2003). As mentioned in the introduction, they found that the size of the (one-dimensional) Simon effect is affected by the spatial compatibility of the mapping in an interleaved secondary task. Our findings are consistent with these observations in demonstrating an involuntary transfer of dimensional relevance across tasks. However, the present findings go beyond these results in showing transfer of the *relative weighting* between feature dimensions, as predicted by the intentional weighting account (Hommel et al., 2001). Our findings also show that this transfer can occur extremely fast, that is, in less than four trials.

Taken together, the available observations support the claim that stimulus and response codes—which are represented in a common domain—are not invariant but tailored to the current task demands (Barsalou, 1999; Hommel et al., 2001). That is, event representations are not, or not only unitary symbols but, rather, feature assemblies that can be tuned to a particular situation, so that the goal-related features or affordances receive more attention. Accordingly, our findings suggest that setting up and implementing a task-set to carry out a task involves not only the selection of particular S–R rules (e.g., Cohen et al., 1998; Rubinstein, Meyer, & Evans, 2001) but also the fine-tuning of goal-related stimulus and response representations. As an aside, the fact that introducing a particular dimensional task relevance in one task affected the weighting of the corresponding dimension in another task strongly suggests that top-down control of task set implementation and stimulus–response processing is less complete than available control models imply (e.g., Logan & Gordon, 2001). Finally, our results support Meiran et al.'s (2000) idea that response coding—and the need to recode responses after a switch of the relevant spatial dimension—may contribute to residual task-switching costs. That is, having just performed a top-left response to indicate that a stimulus appeared at the top of a display may make it more difficult to perform the same response to indicate that a stimulus appeared at the left. This points to a central role of the communicative meaning of responses as simple as key presses, as well as to the cognitive demands associated with changing this meaning. At any rate, the present findings demonstrate that stimulus and response coding is more flexible and more sensitive to situational constraints than commonly thought, which provides a challenge for theories of perceptual representation and action planning in general, and for models of S–R compatibility in particular.

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