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Anticipatory affect during action preparation: evidence from backward compatibility in dual-task performance

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ABSTRACT
Upcoming responses in the second of two subsequently performed tasks can speed up compatible responses in the temporally preceding first task. Two experiments extend previous demonstration of such backward compatibility to affective features: responses to affective stimuli were faster in Task 1 when an affectively compatible response effect was anticipated for Task 2. This emotional backward-compatibility effect demonstrates that representations of the affective consequences of the Task 2 response were activated before the selection of a response in Task 1 was completed. This finding is problematic for the assumption of a serial stimulus-response translation stage. It also shows that the affective consequence of a response is anticipated during, and has an impact on stimulus-response translation, which implies that action planning considers codes representing and predicting the emotional consequences of actions. Implications for the control of emotional actions are discussed.

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People experience emotions when anticipating significant events. They to some degree actively “fear” injury, loss, or punishment, and they “hope for” gains, pleasure, or rewards. Affect can thus be triggered anticipatively and people use anticipatory affect for choosing between different actions and related decision making (Damasio, 1998; Knutson & Greer, 2008; Loewenstein & Lerner, 2003; Mellers & McGraw, 2001). Researchers have proposed various theories how anticipations of emotional events might influence the selection, execution, and monitoring of actions (e.g. Baumeister, Vohs, DeWall, & Zhang, 2007; Frijda, 2004). Building on an ideomotor model of action control (Hommel, Müsseler, Aschersleben, & Prinz, 2001), Eder and colleagues hypothesised that (i) affective consequences of action become associated with the producing movements in memory; (ii) affective consequences are automatically retrieved from memory during action selection; and (iii) anticipated affective consequences are causally involved in the production and control of the action (Eder & Hommel, 2013; Eder & Rothermund, 2013).

Supporting evidence for the first two claims comes from studies in which an action produces emotional consequences that are irrelevant for the task at hand (Beckers, De Houwer, & Eelen, 2002; Eder, Rothermund, De Houwer, & Hommel, 2015). In a first learning phase, participants learned to associate two responses with differential affective consequences (e.g. the delivery of an electric shock or the presentation of pleasant and unpleasant pictures). In a subsequent test phase, the same actions were selected in response to a neutral feature of affective stimuli. Results showed that actions with affectively compatible effects were selected faster than those with affectively incompatible effects, irrespective of whether the produced effect was pleasant or unpleasant. These results confirm that (i) affective states become associated with the producing movements, and (ii) affective consequences are retrieved during response selection

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even when this memory trace is not useful for the currently instructed task.

The congruency effect in response latencies also suggests a causal influence of anticipated affect on action-selection processes, albeit the precise underlying process is not clear from this research. Traditional models typically propose a sequence of at least three information processing stages: a *perceptual stage*, responsible for stimulus processing, a *response stage* taking care of movement execution, connected through a *stimulus-response (S-R) translation stage* that uses the output of the perceptual stage to activate the corresponding response (e.g. Sanders, 1980). In modern theories, the S-R translation stage has been further subdivided into a *response-activation* sub-stage that allows for parallel activation of several responses and a *response-selection* sub-stage that identifies and implements the correct response (e.g. Hommel, 1998). According to ideomotor theory, activation of an (affective) action effect in memory should directly prime associated responses, locating the congruency effect in the response-activation sub-stage. However, it has also been considered that compatible action effects (relative to incompatible ones) may facilitate the identification of an already activated response – which would locate the congruency effect in the response-selection stage (cf. Kunde, Koch, & Hoffmann, 2004). Hence, more evidence is needed to determine whether the anticipation of affective consequences is indeed capable of activating associated responses, as ideomotor theory suggests.

Backward crosstalk in dual-task situations

A powerful tool for the study of S-R translation processes is the psychological refractory period (PRP) paradigm. In this paradigm, stimuli for a first and a second task (S1 and S2, respectively) are presented in rapid succession, and participants are asked to perform the responses for Task 1 and Task 2 (R1 and R2, respectively) in this order as quickly as possible. A typical finding is that reaction time to S2 (RT2) is substantially increased if the interval between the onsets of S1 and S2 (a time referred to as the stimulus-onset asynchrony; SOA) is short. This increase in RT2 with decreasing SOA is referred to as the PRP effect (for an overview see Pashler, 1994).

A widespread account of the PRP effect is based on the hypothesis of a structural bottleneck associated with S-R translation. Within bottleneck models, only one stimulus can be translated into its corresponding response at a time while all other pending translations have to wait (McCann & Johnston, 1992; Pashler, 1984; Welford, 1952). Several findings question this idea of strictly serial S-R translation however. Hommel (1998) showed that reaction times in the first task (RT1) are shorter if R1 is compatible with R2 – a finding referred to as the *backward-compatibility effect* (BCE). In one experiment, for example, stimuli were the letters *H* or *S* printed in red or green. Task 1 required pressing a left or right key based on the colour, and Task 2 required saying "left" or "right" based on letter identity. Both, RT1 and RT2 were shorter when the spatial location of R1 matched the verbal meaning of R2, suggesting that R2 must have been activated to some degree before the selection of R1 was completed, which in turn implies that S2–R2 translation did not wait until translation in Task 1 was finished.

Subsequent studies reported comparable BCEs for various kinds of compatibility relations, ranging from physical features, such as spatial correspondence (e.g. Lien & Proctor, 2000) and visual Gestalts (e.g. Ellenbogen & Meiran, 2011), to rather abstract features, such as correspondence in numeric values (e.g. Logan & Schulkind, 2000) and semantic categories (e.g. Thomson, Watter, & Finkelshtein, 2010). BCEs were also obtained with S2–R2 characteristics that are semantically unrelated to Task 1. For instance, Miller (2006) asked participants to respond as quickly as possible to the letters *X* and *O* with key presses using their left hand for Task 1, and to withhold pressing another key with their right hand when a specific tone is played for Task 2 ("no-go"). Withholding the response for Task 2 delayed RT1, even though response inhibition was not required in Task 1 at any time (for additional evidence, see Ko & Miller, 2014; Miller & Alderton, 2006). Important for the present study, Janczyk, Pfister, Hommel, and Kunde (2014) showed that crosstalk could also be based on features of intended (i.e. not yet presented) action effects. In their experiment, R2s switched on lights on left and right locations as response-contingent effects (E2). The anticipated location of E2 could be compatible or incompatible to the relative location of manual responses executed for Task 1. RT1 was shorter with production of spatially compatible relative to incompatible E2s. This result shows that action effects produced in Task 2 were not only used for planning and initiating this particular response (e.g. Kunde, 2001; Pfister & Kunde, 2013; Pfister, Janczyk, Wirth, Dignath, & Kunde, 2014), but that they were even activated during the selection of R1. This means that BCEs can be based on anticipated and intended action effects (i.e. action goals).

To summarise, research on the BCE suggests that the process of response activation is distinct from response selection (Hommel, 1998): response activation is based on task-defined associative structures between stimuli, responses, and their effects, and occurs automatically and in parallel for multiple tasks. Response-selection proper, in contrast, is a capacity-limited act that drives one of the activated responses above threshold for motor execution.

The present research

The present research was motivated by the assumption that investigating an emotionally based BCE in a dual-task setup can clarify whether emotional features of actions are automatically translated into action tendencies. To create an affective BCE, we manipulated the degree of overlap in emotional features between two tasks by presenting emotional stimuli for Task 1 and emotional action effects for Task 2. Figure 1 illustrates the basic design of the experiments. For Task 1, participants were to categorise positive, neutral, and negative pictures as quickly as possible by pressing a button on a keyboard. Thus, S1 were affective pictures and R1 were keypresses performed with the left hand. Neutral tones were presented as stimuli for Task 2 (S2). Participants were to respond to these tones by pressing a left or right mouse button using their right hand (R2). Importantly, the mouse button presses produced pleasant and unpleased sounds as action effects (E2). In each trial, S1 and the upcoming E2 thus were either affectively compatible (same emotional valence) or affectively incompatible (different emotional valence) or neutral.

Based on the research reviewed above, we expected crosstalk between emotional features in Task 1 and emotional features in Task 2. Traditional theorising suggests a compatibility effect in the "forward direction": the compatibility relation between S1 and E2 should affect response latencies in Task 2, with shorter RT2s for compatible than for incompatible S1–E2 combinations. Although the observation of such a "forward compatibility effect" (FCE) in this particular setting would be a novel and interesting finding on its own, we were actually more interested in the question whether the affective compatibility relation also works in a "backward direction". Indeed, a BCE with emotional E2 would provide strong support for the hypothesis that response selection automatically considers codes of predicted emotional consequences of actions.

If the hypothesis of automatic anticipatory affects is correct, then one may also expect more distinctive motivational consequences of anticipated pleasant and unpleasant response effects. There exists a rich animal and human literature showing that the execution of motor responses is inhibited in the context of threatening, aversive stimuli (e.g. Blanchard, Hynd, Minke, Minemoto, & Blanchard, 2001; Wilkowski & Robinson, 2006). Based on this research, one can hypothesise that the anticipations of an unpleasant E2 during Task 1 inhibits the selection of R1 too. Thus, R1 to neutral S1 might be executed slower when E2 is aversive, which would support the hypothesis that the anticipation of an unpleasant consequence automatically inhibits ongoing behaviour.

To summarise, the present research predicted and tested three behavioural effects of emotional action features: (1) A BCE in RT1; (2) an FCE in RT2; and (3) slower RT1 with anticipation of an unpleasant E2. Experiment 1 used a standard BCE paradigm with two embedded forced-choice reaction time tasks. In Experiment 2, we introduced a free response choice for Task 2 to test between two interpretations of the outcome of Experiment 1.

Experiment 1

Methods

Participants

Forty-eight adults from Würzburg (4 left-handed, 36 women, 19–56 years, $M = 25.3$ years) were paid for participation. We planned with a minimum sample size of 46 participants given that comparable experiments obtained significant BCEs with 32 participants in a study (Janczyk et al., 2014). Written informed consent was obtained from all participants before participation. The experiment was approved by an ethics committee.

Apparatus and stimuli

Stimuli for Task 1 (S1) were 48 affective pictures (24 positive and 24 negative) and 24 neutral pictures taken from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005). The pictures were selected according to their valence and arousal norms (see the Appendix for the slide

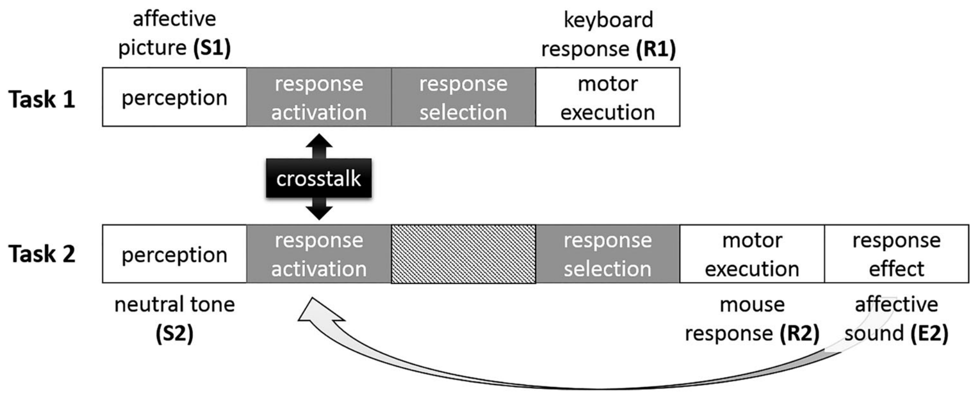

Figure 1. Schematic of information processing stages in a dual-task paradigm with a central response-selection bottleneck (shaded box). Response activation occurs automatically and in parallel for the two tasks. The response selection for Task 2 cannot begin until the response selection for Task 1 has been completed. Features of both tasks crosstalk at the response activation sub-stage. S1, stimulus of the first task; S2, stimulus of the second task; R1, response of the first task; R2, response of the second task; E2, effect contingent upon R2.

numbers). Within each valence category, half of the pictures were low arousing (pleasant: $M_{\text{valence}} = 7.6$ [0.6] $M_{\text{arousal}} = 4.6$ [0.3]; unpleasant: $M_{\text{valence}} = 2.7$ [0.7] $M_{\text{arousal}} = 5.0$ [0.4]) and half were high-arousing (pleasant: $M_{\text{valence}} = 7.2$ [0.4] $M_{\text{arousal}} = 6.3$ [0.5]; unpleasant: $M_{\text{valence}} = 2.9$ [0.8] $M_{\text{arousal}} = 6.4$ [0.4]). Thus, valence and arousal varied orthogonally, with other factors like visual complexity and extremity of valence being controlled for (for corresponding analyses see Robinson, Storbeck, Meier, & Kirkeby, 2004). An additional six pictures per valence category were selected for task practice. Participants categorised the valence of the pictures with the index, middle, and ring finger of their left hand using the buttons "a", "s", and "d" of the keyboard (R1).

Stimuli for Task 2 (S2) were midi tones (Marimba) with a frequency of 400 Hz (low pitch) and 800 Hz (high pitch) and a duration of about 500 ms. Participants responded to high and low tones with mouse button presses using the index and middle finger of the right hand (R2). Pressing one of the mouse buttons always produced a pleasant sound, and pressing the other always an unpleasant as response effect (E2) of about 1 s. The unpleasant sound was a highly aversive noise stimulus that was used in previous research for punishment (Krämer, Büttner, Roth, & Münte, 2008). The pleasant sound was a brief vocal burst of amusement taken from a standardised set of emotional vocalisations (Simon-Thomas, Keltner, Sauter, Sinicropi-Yao, & Abramson, 2009). The acoustic stimuli were presented binaurally to the participant via headphones.

Design

The experiment had a 3 (S1: positive vs. negative vs. neutral) × 2 (S1: low arousal vs. high arousal) × 2 (E2: unpleasant sound vs. pleasant sound) within-subjects design, except that the neutral S1 did not vary in arousal. The following factors were counterbalanced across participants: (1) the picture-response key (S1–R1) assignment; (2) the assignment of the tones to the mouse buttons (S2–R2); and (3) the assignment of the sound effects to the mouse button presses (R2–E2).

Each session consisted of two practice blocks and eight experimental blocks. Each block comprised 36 trials: three occurrences of every instance of the factorial combination of S1 valence, S1 arousal level, and E2 valence. Pictures appeared twice in a trial block, with the restriction that each picture was paired in one trial with a pleasant sound effect and in the other trial with an unpleasant sound effect in Task 2.

Procedure

Participants were instructed to perform the "picture task" (Task 1) before the "tone task" (Task 2). A trial started with the presentation of a fixation cross for 500 ms. Then, a picture (S1) appeared at the centre of the screen and a high or low tone (S2) was played simultaneously via the headphones. The picture stayed on the screen until registration of both responses. A sound effect was played after the mouse button press when both responses were correct and executed in the correct order. In case of an error, a message appeared for 1000 ms indicating the type of committed error (incorrect R1, incorrect R2, incorrect response order). Then the next trial started. After each trial block, a performance summary was displayed that indicated the mean response speed and the number of errors (grand averages across both tasks). Participants were also reminded that they would get a bonus reward (a chocolate bar) for "good" task performance (without further specification).

Results

Five participants were excluded due to excessive error rates (50% and higher). Trials with incorrect order of responses were removed before analyses (0.1%). Tukey (1977) outlier thresholds were computed for each task to identify outliers in RTs. These thresholds removed 7% and 6% of the RTs for Task 1 and Task 2, respectively. Trials with incorrect categorisations (Task 1: 2.2%; Task 2: 6.7%) were also discarded. From the remaining data, mean RTs and percentages of errors (PEs) were computed for each task as a function of S1 valence, S1 arousal, and E2 valence (see Table 1 for means).

We ran separate analyses for affective (positive or negative) and neutral S1, because a full factorial combination was only possibly for affective S1 (see the "Design" section above). Thus, a 2 (S1: positive vs. negative) × 2 (S1: low arousal vs. high arousal) × 2 (E2: pleasant vs. unpleasant) analysis of variance (ANOVA) examined performance in Task 1 for a BCE and performance in Task 2 for an FCE. Furthermore, performance on neutral pictures in Task 1 was analysed for an influence of anticipated pleasant and unpleasant sound effects in Task 2. The significance criterion was set to $p < .05$ for all analyses. Standardised effect sizes (Cohen's *d*, partial eta-square) are reported when appropriate.

Task 1

In the 2 × 2 × 2 ANOVA the main effect of S1 arousal was significant, $F(1, 42) = 39.69$, $p < .001$, $\eta_p^2 = .486$, indicating faster responses to high-arousing pictures. More important, the interaction between S1 valence and E2 valence reached significance, $F(1, 42) = 4.10$, $p < .05$, $\eta_p^2 = .089$, indexing a BCE. Responses were faster if S1 and E2 were affectively compatible relative to when both were incompatible (see Table 1). No other effect reached significance (largest $F = 1.56$, all *p*s > .20). An analogous analysis of the error rates produced a significant main effect of S1 arousal, $F(1, 42) = 41.64$, $p < .001$, $\eta_p^2 = .498$, indicating responses to high-arousing pictures to be less error-prone than responses to low-arousing pictures. The arousal effect was stronger for positive slides, as indicated by a significant interaction between S1 valence and S1 arousal $F(1, 42) = 4.13$, $p < .05$, $\eta_p^2 = .09$. Other effects did not reach significance (largest $F = 1.80$, all *p*s > .10).

For the analyses of response performance to neutral pictures in Task 1, a *t*-test (one-tailed) indicated no significant difference for reaction times between upcoming unpleasant and pleasant E2s ($|t| < 1$). Descriptively, more errors were produced after a cueing of an unpleasant E2 (see Table 1), but the difference was not statistically significant, $t(42) = 1.64$, $p = .06$ ($d = 0.25$).

Task 2

In the 2 × 2 × 2 ANOVA of the RTs, the main effect of S1 arousal was significant, $F(1, 42) = 27.76$, $p < .001$, $\eta_p^2 = .398$. Again, responses were faster with presentations of high-arousing pictures (see Table 1 for the means). The interaction between S1 valence and E2 valence was also significant, $F(1, 42) = 6.53$, $p < .05$, $\eta_p^2 = .135$, indexing an FCE. The interaction between S1 arousal and E2 valence approached significance, $F(1, 42) = 3.32$, $p = .08$, pointing to faster production of unpleasant sound effects after presentations of high-arousing pictures. No other effect reached or approached significance (largest $F = 2.47$, all *p*s > .10). An ANOVA of the error rates produced similar effects. The interaction between S1 valence and E2 valence was close to significance, $F(1, 42) = 3.67$, $p = .06$, $\eta_p^2 = .080$. The interaction between S1 arousal and E2 valence reached significance in this measure, $F(1, 42) = 5.19$, $p < .05$, $\eta_p^2 = .110$, showing again a facilitated production of unpleasant response effects after presentations of high-arousing pictures. The main effect of E2 valence also reached significance, $F(1, 42) = 7.83$, $p < .05$, $\eta_p^2 = .157$. Errors were less frequent with the generation of pleasant response effects. All other effects were not significant (largest $F = 2.35$, all *p*s > .10).

Performance comparisons after presentations of neutral pictures with *t*-tests (one-tailed) showed no difference between responses producing pleasant and unpleasant sound effects (both $|t|$s < 1).

Discussion

Experiment 1 obtained clear evidence for crosstalk between emotional features in a dual task: RT1 was

Table 1. Mean reaction times (in ms) and error rates (in %) in Experiment 1 as a function of S1 and E2 (standard deviations in parentheses).

		Positive S1		Negative S1		Neutral S1
	Arousal:	low	high	low	high	–
Task 1	Pleasant E2	890 (214)	864 (193)	906 (190)	876 (183)	794 (151)
		4.8 (5.5)	1.6 (2.9)	4.1 (4.2)	2.2 (3.6)	1.7 (2.9)
	Unpleasant E2	906 (203)	865 (187)	888 (180)	851 (152)	800 (164)
		5.7 (5.1)	1.9 (3.6)	4.5 (4.7)	2.4 (3.3)	2.5 (3.8)
Task 2	Pleasant E2	1206 (247)	1190 (251)	1255 (217)	1229 (215)	1109 (182)
		5.7 (6.6)	6.8 (7.0)	7.3 (6.6)	9.8 (8.3)	4.8 (5.7)
	Unpleasant E2	1241 (279)	1187 (222)	1226 (210)	1175 (182)	1107 (183)
		12.3 (9.7)	9.5 (8.8)	9.3 (8.0)	9.1 (8.3)	4.8 (7.3)

shorter when the valence of S1 was compatible with the affective consequence (E2) produced by R2. Thus, the anticipation of the emotional consequence of R2 primed the selection of an affectively compatible R1 in a backward direction. Furthermore, affective categorisations in Task 1 facilitated subsequent R2s with affectively compatible sound effects in a forward direction. Thus, crosstalk between emotional task features was observed in mutual directions, producing FCEs *and* BCEs.

The basis for this crosstalk is somewhat ambiguous, however. According to our theorising, S1 is determined by its emotional stimulus category and R2 defined by (or coded in terms of) its emotional effect, so that the critical crosstalk takes place between the emotional features of S1 and E2. However, an alternative interpretation is possible. Note that the neutral S2 may have acquired the valence of the correlated E2 through evaluative conditioning (Levey & Martin, 1975; for a review see De Houwer, Thomas, & Baeyens, 2001), so that crosstalk between S1 and S2 may also have contributed or even played the major role. Although this would not necessarily rule out crosstalk based on the anticipation of the emotional response effect (Baeyens, Eelen, Van den Bergh, & Crombez, 1992), there is evidence that affective valence can be transferred from an affective US to a neutral CS without invoking a representation of the US (Gast & Rothermund, 2011). The interaction between affective features of S1 and S2 can thus explain our crosstalk effects without assuming contributions from the anticipation of E2. We addressed this ambiguity in Experiment 2 by removing the S2–E2 correlation.

Although Experiment 1 showed a backward influence of the emotional E2 on R1 performance, RT1 was not affected by the subsequent production of an unpleasant E2. The error rates provided some hints to the hypothesised response suppression, but the respective effect did not reach statistical significance. One possible reason for a weak effect is the nature of the forced-choice task. Forcing participants to generate an unpleasant sound effect in a response task likely underestimates its motivational effect because the inhibitory influence needs to counteract the motivational demands imposed by the S-R instruction (cf., Watson, Wiers, Hommel, Ridderinkhof, & de Wit, 2016). In fact, Eder et al. (2015) observed response suppression by contingent unpleasant action consequences only in a free choice but not in a forced-choice task. For Experiment 2, we therefore turned Task 2 into a free-choice task in which participants had a free decision between responses generating pleasant and unpleasant sound effects.

Experiment 2

The setup was as in Experiment 1 but Task 2 was now a free-choice task. After hearing a tone, participants were to decide which mouse button they want to press. The mouse button generated pleasant and unpleasant sound effects as before. Instructions stated that there were no correct and incorrect responses for this task and that participants should decide spontaneously about a button press.

Introducing a free-choice task has two important implications: First, the second stimulus (as a "go-signal") was now uncorrelated with the valence of the E2, at least to the degree that participants would show variable response choices. Accordingly, evaluative conditioning of S2 was not likely to play a role. Second, participants had more control over the delivery of pleasant and unpleasant E2s, which should increase the motivational relevance of the action effects for action selection.

Hypotheses were the same as for Experiment 1, with the only difference that we now analysed choice frequencies for R2 rather than RTs or PEs. We expected an overall preference for pleasant over unpleasant E2s, and FCEs and BCEs due to the compatibility relation between pleasant and unpleasant E2 and positive and negative S1, respectively. It should be noted that systematic comparisons of forced- and free-choice tasks observed no differences in dual-task costs (Janczyk, Nolden, & Jolicoeur, 2015).

Methods

Participants

Participants were 87 adults from Würzburg (10 left-handed, 67 women, 18–63 years, $M = 27.5$ years). None of them participated in Experiment 1. Written informed consent was obtained from all participants before participation and the experiment was approved by an ethics committee. We anticipated a significant dropout of data sets due to the unconstrained procedure of the free-choice task (Task 2), which is why sample size was substantially increased relative to Experiment 1.

Apparatus and stimuli

Apparatus and acoustic stimuli were the same as in Experiment 1. We increased the picture sets to 14 pictures per affective category and to 28 neutral pictures (see the Appendix for the slide numbers and Robinson et al. (2004) for the selection criteria). Additional sets of 28 positive and 28 negative IAPS-pictures were selected for task practice.

Design and procedure

Procedure and design were identical to Experiment 1 with the following exceptions. Task 2 was turned into a free-choice task in which participants decided between mouse button presses generating pleasant and unpleasant sound effects. The 400 Hz tone served as a signal for the response choice, and the 800 Hz tone of Experiment 1 was no longer used. Instructions stated that there was no correct or incorrect response for Task 2 and that participants should decide spontaneously which mouse button they wanted to press after the tone signal (and R1). Instructions also stated that participants should avoid using systematic response strategies (e.g. pressing always the same key or switching between keys in a fixed order) and that the frequency of both key presses should be balanced in total. Participants were informed after each trial block about the ratio of their keypresses so far. Participants worked through 2 practice blocks and 8 experimental blocks. Each block comprised 84 trials. Each picture appeared once in a block in randomised order.

After the experimental blocks, participants rated the pleasure and arousal states elicited by the pictures with 9-point self-assessment manikin (SAM) scales (Bradley & Lang, 1994). The SAM scales were presented at the top and bottom of the screen and the to-be-rated picture at the centre. Responses were entered by clicking with the mouse cursor on fields of the SAM scale. Results of the ratings are presented in Table A1 of the Appendix.

Results

Four data sets were removed due to excessive error rates in Task 1 (20% and higher; rest of the sample: $M = 5\%$, $SD = 3.1$). Three participants always press the same key in Task 2. The remaining 80 data sets were screened for a minimum number of 10 data points for each cell of the S1 valence, S1 arousal level, and E2 valence factorial combination. This screening identified 27 data sets with insufficient data points for analyses of performance in Task 1. Given the high dropout of data sets with this criterion, we decided to collapse the data across the arousal factor for analyses, resulting in a loss of only 18 data sets ($n = 62$). The interested reader is referred to the supplement of this article for detailed analyses on the arousal factor that are based on the strict criterion ($n = 53$). Response performance in Task 1 was analysed for an emotionally based BCE using a 2 (S1 valence) × 2 (E2 valence) ANOVA. Performance to neutral pictures was again analysed for an influence of anticipated pleasant and unpleasant sound effects in Task 2 (based on a sample with $n = 75$). Responses were executed in the wrong order in 0.9% of the trials. Tukey (1977) outlier thresholds for Task 1 removed an additional 5.7% of the RTs before analyses. Table 2 shows the mean RTs and error rates observed for Task 1.

For Task 2, the dependent measure of main interest is the choice of responses generating pleasant and unpleasant sound effects (see Table 3 for means). The proportion of responses generating a pleasant sound effect was analysed using a 2 (S1 valence) × 2 (S1 arousal) ANOVA based on a sample with $n = 80$ participants (after removal of 7 data sets as described above). R2 was omitted in 0.4% of the trials. It was expected that participants generally prefer the generation of pleasant sound effects over unpleasant sound effects. Furthermore, the valence of S1 should bias the participants' response choices, with a preference for

Table 2. Mean reaction times (in ms) and error rates (in %) for Task 1 (standard deviations in parentheses) as a function of S1 and E2 in Experiment 2.

	Positive S1	Negative S1	Neutral S1
Pleasant E2	580 (66)	588 (69)	546 (59)
	3.1 (2.9)	4.7 (7.3)	2.8 (2.9)
Unpleasant E2	586 (69)	585 (69)	551 (65)
	5.4 (6.4)	2.9 (2.7)	3.3 (4.0)

affectively compatible sound effects over affectively incompatible response effects (FCEs).

Task 1

The 2 × 2 ANOVA of the RTs produced only a significant interaction between S1 valence and E2 valence – a BCE. As shown in Table 2, responses in Task 1 were faster when the emotional valence of the response effect anticipated for Task 2 was compatible with the affective valence of the response cue presented for Task 1, $F(1, 61) = 7.67$, $p < .05$, $\eta_p^2 = .112$. The main effects were not significant (*F*s < 1). Analyses of PEs yielded analogous results with a significant interaction between S1 valence and E2 valence, $F(1, 61) = 6.98$, $p < .05$, $\eta_p^2 = .103$, and no main effects (largest $F = 1.58$, *p*s > .20). In short, emotional BCEs were observed in both, reaction times and errors.

Like in Experiment 1, *t*-tests (one-tailed) compared the response performance to neutral pictures depending on a production of unpleasant and pleasant response effects in Task 2. These comparisons showed that R1 was slower and more error-prone when R2 produced an unpleasant sound effect (see Table 2). However, the difference reached significance only for RTs, $t(74) = 2.22$, $p < .05$, $d = 0.26$, but not for errors ($t = 1.17$, $p > .10$).

Task 2

Participants generated the pleasant sound effect more frequently after neutral pictures in Task 1, $t(79) = 2.78$, $p < .05$, $d = 0.31$, confirming an overall preference of the pleasant sound effect (see Table 3 for the means). The proportion of responses generating pleasant sound effects for affective S1 was further analysed using a 2 (S1 valence) × 2 (S1 arousal) ANOVA. This analysis revealed a significant main effect of S1 valence, $F(1, 79) = 45.88$, $p < .001$, $\eta_p^2 = .367$. As displayed in Table 3, participants selected more often a pleasant sound effect for Task 2 after having responded to a positive picture in Task 2, and they selected more often an unpleasant sound effect after a response to a negative picture. Thus, a clear FCE was observed in the response choice. Picture arousal or a combination of picture arousal and valence did not affect R2 choice (largest $F = 1.27$, *p*s > .20).

Given that participants could choose between responses that clearly differed in their attractiveness, it is likely that a response decision was reached in some trials even before the presentation of S1. Advance preparation of the second response may then have primed the perception of congruent and incongruent S1 in the more common forward direction. Planning R2 ahead should also facilitate the execution of the prepared response, producing faster RT2s and shorter time intervals between R1 and R2. Variability in RT2 and in the relative timing of R1 and R2 can therefore be used to diagnose the degree to which response decision was strategic in this sense. If strategic response preparation was indeed the major determinant of the compatibility effects, then the magnitudes of BCE and FCE should be related to these diagnostic measures. However, correlations were not significant in corresponding analyses (see Table 4) and descriptively even in the opposite direction than would be expected if strategic decisions require more time (Janczyk et al., 2015). Furthermore, a quartile analysis of the R1–R2 interval showed that the BCE was relatively stable across R1–R2 distribution quartiles (see the supplement for corresponding analyses). Thus, if the response decisions were strategic, the underlying strategy seems not to have affected the magnitude of crosstalk between the tasks on the trial-level and on the participant-level. Note, in addition, that a strategic R2 decision would not invalidate the conclusion that anticipated action consequences have an impact on parallel S-R translation processes because, obviously, a representation of E2 must have been active during action preparation for Task 1 to produce a systematic crosstalk effect.

Table 3. Proportion of responses generating a pleasant sound effect (standard deviations in parentheses) as a function of S1 in Experiment 2 ($n = 80$).

	Positive S1		Negative S1		Neutral S1
	Low arousal	High arousal	Low arousal	High arousal	–
Pleasant E2	67% (22.7)	68% (22.3)	35% (24.9)	35% (24.4)	56% (18.3)

Table 4. Correlations between RT2, the relative timing of R1 and R2, BCE, and FCE.

	1	2	3	4
1. BCE (RT)	–			
2. BCE (PE)	.25*	–		
3. FCE	.43*	.62**	–	
4. RT2	−.06	−.07	.05	–
5. ΔRT1–RT2	−.17	−.13	.01	.88**

Note: BCE = RT1 and percentage of wrong R1 in incongruent minus congruent trials; FCE = proportion of pleasant E2 (R2) in congruent trials minus incongruent trials; RT2 = mean reaction time in Task 2; ΔRT1–RT2 = mean time interval between R1 and R2.
*Correlation is significant at the .05 level.
**Correlation is significant at the .01 level.

Discussion

The design of Experiment 2 ruled out an interaction between emotional stimulus features (S1–S2) as a basis for a crosstalk between the tasks. As in Experiment 1, RT1 was shorter when the affective categorisation was compatible with the emotional valence of E2. This BCE supports our (S1–E2 based) interpretation of the corresponding interaction between S1 and E2 in Experiment 1 and provides first evidence that a BCE is also obtained with a free-choice task as a second task.

Response frequencies in Task 2 were systematically biased by the affective categorisations performed in Task 2. This FCE resembles earlier findings of a priming of affective response choices (Eder et al., 2015, Experiment 5), with the main difference that a dual-task paradigm was used in the present research.

Finally, RT1 was slower during the anticipation of an unpleasant E2. This behavioural suppression effect was expected on the basis of earlier research that observed an analogous suppression only in a free-choice task and not in a forced-choice task (Eder et al., 2015). In the present experiment, the anticipation of an unpleasant, aversive E2 affected not only the response choice in Task 2 but also reaction times in a formally unrelated response task (Task 1). This finding suggests that behavioural suppression induced by the anticipation of an aversive consequence affects all ongoing responses.

General discussion

The present research obtained clear evidence for a BCE indicating crosstalk between emotional features in a dual-task setting: RT1 was shorter when S1 was affectively compatible to the affective consequence (E2) anticipated for R2. This effect has several important implications.

First, it provides further support for the claim that affective consequences of actions become an integral part of their cognitive representation. As performance in Task 1 was affected by emotional action effects anticipated for Task 2, a representation of these effects (i.e. an anticipation) must have been activated in the process of selecting and planning R2. As argued by Elsner and Hommel (2001), action effects become automatically associated with the producing movement in memory with repeated pairings, which means that the emotional sound effect was linked to a particular mouse button press in memory. With a direct binding of E2 to R2, thinking on a mouse button press for Task 2 preparation should also activate the associated sound effect (and vice versa), so that the affective consequence was active before the actual execution of the response.

Second, performance in a first task was affected by response-selection processes carried out for a formally unrelated, second task. This finding, in combination with previous demonstrations of non-affective BCEs (e.g. Hommel, 1998), is problematic for structural bottleneck models of S-R translation claiming that response selection in dual-task performance is strictly serial and restricted to processing one task at a time (Pashler, 1984; Welford, 1952). Obviously, some degree of S2–R2 translation must have taken place before the processing of S1 and R1 was completed, suggesting that, if there is a bottleneck, it does not reduce the number of concurrent S-R translations to one. To be sure, this does by no means rule out other possible bottlenecks at later stages, such as it was proposed by a subdivision into processes of response activation and response-selection proper (Hommel, 1998). However, it seems clear by now that S-R translation proper is not responsible for secondary-task delays. Rather, stimulus information is translated more or less automatically into the corresponding response activation once a procedural representation of the S-R link in working memory is enabled (Ellenbogen & Meiran, 2008; Hommel & Eglau, 2002; see also Eder, Rothermund, & Proctor, 2010).

Third, and most important for our purposes, we were able to demonstrate the extension of BCE to emotional task features. As noted in the introduction, previous research obtained BCEs with various kinds of compatibility relations, ranging from physical response features to abstract features such as semantic categories. The present research extends this research to the emotional domain, showing that features of stimuli and responses associated with states of pleasantness can cause crosstalk as well. From the present research, it cannot be concluded whether these affective features represent "hot" pleasant and unpleasant sensations or "cold" semantic categories thereof. Interactions at both levels of representation are possible, and they are not mutually exclusive. In fact, one would expect from a modern embodied-cognition perspective that semantic categories of affects are grounded in sensorimotor-affective experiences (see e.g. Moseley, Carota, Hauk, Mohr, & Pulvermüller, 2012), which means that the distinction between hot and cold representations of affect is moot. With respect to this discussion, it should also be noted that the arousal level of S1 did not influence the magnitude of crosstalk. This could mean that high and low arousal of the response-initiating cue does not affect S-R translation processes involved in dual-task performance. It should be noted, however, that participants' judgments of the slides were not perfectly in line with our a priori matching on the basis of the IAPS norms. More precisely, ratings of pleasantness were more extreme than those for arousal, and unpleasant pictures were generally perceived as being more arousing (see Table A1). A stronger manipulation of arousal may hence provide better results. Furthermore, it is likely that RT measurements in dual response tasks with their high time pressures are not very sensitive to arousal effects; motor tasks with continuous behavioural and neurophysiological measures may be better suited to examine such effects (see e.g. Coombes et al., 2009; Schmidt et al., 2009).

The present research suggests that an action becomes associated with the emotional consequences it produces, and that codes of the anticipated emotional consequence are reactivated (at least to some extent) during action selection. This idea fits well with Damasio's (1998) concept of a "somatic marker" that provides or generates a "gut feeling" on the expected merits of a given response. It is also consistent with evidence that brain activities during the anticipation of significant (monetary) outcomes correlate with affective experiences and subsequent behavioural choices (Knutson & Greer, 2008). Finally, the results are also in line with an ideomotor account of action control, which holds that actions become associated with codes of their sensory consequences and that these codes guide action selection (Hommel et al., 2001). According to this model, an action should become associated with any exteroceptive or interoceptive perceptual code that is contingent upon its execution. As argued elsewhere in more detail (Eder & Rothermund, 2013), this should also include affective sensations that are experienced after an action.

Our version of the ideomotor model thus allows emotional features to enter feature networks representing stimuli, movements, and their effects. Feature assemblies related to one task then become loosely integrated into what Hommel et al. (2001) called an "event file" (cf. Hommel, 2004; Lavender & Hommel, 2007). Accessing two event files at the same time enables crosstalk between shared features, explaining congruency effects across tasks in dual-task settings and in the PRP paradigm. Obviously, this explanation requires that event files can be accessed in parallel, which is deemed possible for a response activation stage (Lien & Proctor, 2002).

It should be noted that this explanation of emotionally based crosstalk effects treats emotional features (i.e. representations of affects) as a perceptual category that does not differ from other perceptions in a fundamental way. As argued by Duncan and Barrett (2007), a distinction between affect and cognition is phenomenological rather an ontological. Consequently, emotionally based crosstalk does not require a specialised explanation, the more so as emotions can be considered perceptual representations of interoceptive events. Nevertheless, there may still be functional differences between "emotional" and "cognitive" ingredients of event files.

One possible functional difference is that representations of emotional events are dynamic in the sense that they depend on the current concerns of the individual. While activation of a cognitive event is typically subject to a gradual temporal decay (Hommel, 1994), activation of an emotional event file might even increase with time with the frustration of an emotional concern.

A second important difference is that nearly every event can be imbued with an affective meaning, which does not apply to other perceptual features. In fact, some even claimed that all objects and events evoke somatovisceral reactions and are therefore affectively infused to some degree (Duncan & Barrett, 2007). Affective coding is hence pervasive for a coding of perceptual and behavioural events, which means that a crosstalk between emotional event files is very common. It is tempting to relate a widespread crosstalk between affective features to more generalised motivations to approach and avoid. Many studies showed that appetitive and defensive action is facilitated by stimulation of the same motivational class and inhibited by stimulation of the opposite motivational class, respectively (Rescorla & Solomon, 1967). However, little is known about the cognitive organisation of such appetitive–aversive interaction. A crosstalk between emotional event files can parsimoniously explain such interactions (cf. Eder & Klauer, 2009; Eder, Müsseler, & Hommel, 2012).

Furthermore, activation spread across emotional event files may also establish response coherence in a given emotional episode. There was a long-standing debate in emotion psychology how cognition, behaviour, and physiology is orchestrated during an emotional episode, with some theories claiming tight "emotion packages" and others advocating loose connections (Lench, Flores, & Bench, 2011; Lindquist, Siegel, Quigley, & Barrett, 2013). The present approach can account for those correlations with an overlap between event files constructed for an emotional episode. For instance, pushing a disliked person back in an anger episode and producing a frown at her should crosstalk given their common reference to an unpleasant event (Eder, Rothermund, & Hommel, 2016). This synchrony of action with concomitant physiological preparations, or the situated perception thereof, may intensify the experience of anger (Laird & Lacasse, 2014; Wiens, 2005). Crosstalk between features of emotional event files may thus provide the cognitive basis for the orchestration of emotional responses during an emotional episode.

Third, although the structural basis for BCE may not be different, emotional codes may have distinctive effects on action control. One important effect is a suppression of behavioural responses that are associated with aversive outcomes. A behavioural suppression effect was also observed in our second experiment in which R1 to neutral stimuli were executed slower during the selection of an aversive E2 for the second task. This suppression was only observed in the reaction times to neutral S1 while RT1 to emotional S1 was affected by the backward congruency with the anticipated E2. Translated in our stage logic, this pattern of results means that the execution of a response, and not its activation, is slowed down by the anticipation of an aversive consequence. This explanation fits with the functional argument that the aversive system should be flexible in activating freezing, fleeing, and fighting responses depending on the affordances of an emotional situation, while the execution of a (punished) response is inhibited so that an alternative action could still be implemented (McNaughton & Corr, 2004; Wilkowski & Robinson, 2006). Alternatively, or complementary to emotional suppression, the execution of an action could also be facilitated by the association with positive emotional codes (Marien, Aarts, & Custers, 2013). For the present experiments, we cannot decide whether R1 was slowed down by the anticipation of an unpleasant E2 or expedited by the anticipation of a pleasant E2 (or both). Future research may therefore include neutral E2 for a baseline comparison. In either case, associated emotional codes can help to constrain action tendencies by potentiating actions that produce desired outcomes and/or by inhibiting those that produce undesired outcomes.

To summarise, the present research shows that emotional action consequences anticipated for a second task influence how actions are performed for a first task. This finding confirms that representations of emotional action consequences are automatically reactivated during S-R translation and/or response selection. Furthermore, it also confirms that the action system makes active use of these representations when initiating an action. Thus, people may literally feel the future when thinking of an action, which allows them to behave in a way that fits their current needs and goals.

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Appendix

Table A1. IAPS slide numbers and picture ratings (with standard deviations) collected in Experiment 2 ($n = 87$).

Unpleasant		Pleasant		Neutral
High arousal $n = 14$	Low arousal $n = 14$	High arousal $n = 14$	Low arousal $n = 14$	$n = 28$
1050, 1120, 1300, 1301, 1930, 3130*, 3250, 6260, 6300*, 6510, 6570, 7380, 9300, 9570	1111, 1220*, 2053, 2520, 2800, 3230, 3350, 7361, 9008*, 9290, 9320, 9415, 9421, 9561	4599, 4607, 4608, 4641, 4651, 4652, 4660*, 5621, 8180, 8200, 8370, 8380, 8470*, 8490	1440, 1460, 1750, 1810, 2040*, 2050*, 2057, 2070, 2165, 2352, 2550, 2660, 4606, 8350	7000, 7002, 7004, 7006, 7009, 7010, 7020*, 7025, 7030, 7031*, 7034, 7035, 7040*, 7080, 7090, 7100, 7150, 7160, 7170, 7175, 7185, 7186, 7187, 7190*, 7224, 7233, 7235, 7705
$M_{val} = 2.5$ (0.9)	$M_{val} = 2.7$ (0.9)	$M_{val} = 7.1$ (0.9)	$M_{val} = 7.2$ (0.9)	$M_{val} = 5.1$ (0.7)
$M_{arous} = 5.2$ (1.7)	$M_{arous} = 4.6$ (1.5)	$M_{arous} = 4.4$ (2.0)	$M_{arous} = 3.5$ (1.4)	$M_{arous} = 2.0$ (1.2)

Note: M_{val} = mean valence rating. M_{arous} = mean arousal rating. Ratings were provided on 9-point SAM scales (1 = very negative/low arousing; see text for further explanation). Additional pictures in Experiment 2 are marked with asterisks.