Visuomotor integration of relevant and irrelevant angry and fearful facial expressions

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Abstract

Our brain codes the features of perceptual events in a distributed fashion, raising the question of how information belonging to one event is processed without any interference of features from other events. Hommel (1998) suggested the "event file" concept to elucidate these mechanisms: an episodic memory trace "binding" together perceptual features and actions related to an object. Using a similar paradigm, we designed a pilot experiment and four additional experiments to investigate whether emotion, similarly than perceptual features, could bind with a motor response when the emotion was relevant and irrelevant for the task. Few studies have revealed this to be the case. We investigated how angry and fearful faces expressed by avatars and humans might be subject to a binding phenomenon. Our results show that at least three degrees of visuomotor binding seem to coexist: one implicating the relevant feature of the task with a strong effect on behavior, another implicating the location with a smaller behavioral effect (even if not task related), and a third implicating non-task-related features with behavioral effects only [...]
Visuomotor integration of relevant and irrelevant angry and fearful facial expressions

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A B S T R A C T

Our brain codes the features of perceptual events in a distributed fashion, raising the question of how information belonging to one event is processed without any interference of features from other events. Hommel (1998) suggested the “event file” concept to elucidate these mechanisms: an episodic memory trace “binding” together perceptual features and actions related to an object. Using a similar paradigm, we designed a pilot experiment and four additional experiments to investigate whether emotion, similarly than perceptual features, could bind with a motor response when the emotion was relevant and irrelevant for the task. Few studies have revealed this to be the case. We investigated how angry and fearful faces expressed by avatars and humans might be subject to a binding phenomenon. Our results show that at least three degrees of visuomotor binding seem to coexist: one implicating the relevant feature of the task with a strong effect on behavior, another implicating the location with a smaller behavioral effect (even if not task related), and a third implicating non-task-related features with behavioral effects only under specific conditions in which emotion could play a role. Our adaptation of Hommel’s paradigm showed that emotional percepts can be subject to visuomotor binding effects even if the emotion is not task related confirming the important role of emotional information for the central nervous system. These findings offer new perspective in the investigation of the emotion-action binding at the neuronal level.

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1. Introduction

The primate brain codes the features of perceptual events in a distributed fashion (Hommel, 2004). Thus, color, shape, and location of a visual object are represented in different brain regions in the visual cortices (Hommel, 2004). The distribution of object features in several maps in the brain raises the binding problem (Treisman, 1996): How does the brain integrate the information belonging to one event without mixing it up with elements from other concurrently processed events? One hypothesis proposed by Kahneman, Treisman, and Gibbs (1992, cited by Hommel, 2004) involved the concept of an object file: “an episodic memory trace containing information about the relationship between object features, possibly enriched by object-related knowledge from long-term memory, and addressed via location codes” (pp. 494–495). In their experiment, two, four, or eight letters were presented in eight spatial locations. After a slight interval, a letter appeared in one of the locations. The aim was to designate the letter as quickly as possible. Kahneman et al. (1992) found that in some cases, but not all, participants were faster at naming the letter if it had been previously displayed. However, this effect was much stronger if the letter appeared in the same location. The authors concluded that the letter and location were bound in an object file in their first presentation and that reactivation of one automatically activated the other, facilitating the response.

The concept of an object file is interesting for describing the transient interactions occurring between, for example, the visual brain regions that construct a percept, but this assumption seems too narrow when the response action is also manipulated. In fact, Hommel (1998) showed that integration of distributed codes was not restricted to perception, but could apply to sensorimotor processing as well. In this study, the author designed the following experiments: a cue, represented by an arrow pointing in the right or left direction, was presented before a first stimulus (S1). The latter could be a circle or a cross, red or green, and located in the top or bottom part of the screen. Participants answered with a right or left key according to the direction of the cue and therefore independently of the stimulus. Another stimulus (S2) then appeared on the screen. This time, participants answered according to the shape of the stimulus for the first experiment and the color of the stimulus for the second. For example, in the first experiment, if the object was a circle, they pressed the left key, and if it was a cross, they pressed the right key. Hommel’s assumptions were as follows: Participants would be faster at identifying the relevant feature of S2 if it remained the same in S1 and S2 and the answer was repeated. Indeed,
according to Hommel, perceptual features bind with the motor response in S1. Thus, when one feature is repeated in S2, the other is automatically activated, facilitating the response in the case of a complete repetition. When a full alternation of the features and motor response from S1 to S2 occurred, Hommel assumed that the participant’s response would also be favored. In fact, no previous association disrupted the answer in S2. In contrast, Hommel expected a greater reaction time when only one element was repeated. In this situation, Hommel predicted a partial repetition cost: The component that is repeated activates the previous association, disrupting the establishment of a new action scheme. This is exactly what Hommel found. Participants were faster when the relevant feature and the answer were both repeated and alternated than they were in the case of a partial repetition. It appears that binding exists between perceptual features and actions related to an object, which Hommel suggested calling an “event file” instead of an “object file”.

In consideration of evidence of a memory trace linking together perceptual features and actions related to an object, several investigators examined the impact of emotion on stimulus–response compatibility. For instance, Colzato, van Wouwe, and Hommel (2007) discovered, using the paradigm of Hommel (1998), that presentation of a positive picture between S1 and S2 increased visuomotor binding, whereas a negative picture decreased it. Indeed, the introduction of a picture between stimuli entailed a smaller partial repetition cost for positive than for negative images.

Other experiments even showed that an emotion-action integration was probable by interfering with approach- and avoidance-related responses to emotions. These experiments mainly used an approach-avoidance protocol (see Phaf, Mohr, Rotteveel, & Wicherts, 2014). For example, Lavender and Hommel (2007) presented right- and left-oriented positive and negative pictures to participants and asked some of them to move a doll toward the positive pictures and away from the negative pictures. Other participants received the opposite instructions. Results showed that participants with the former instructions were faster than those with the opposite instructions. According to authors, this phenomenon occurred because in everyday life, people are used to approaching positive events and avoiding or withdrawing from negative events. Therefore, they integrate the “approach” action with a positive valence and the “avoid” action with a negative one. Thus, when valence is reactivated, people automatically activate the action related to it, affecting the reaction time. This observation is in accordance with the concept of action tendencies (Frijda, 1986, 2007), emotion embodiment (Niedenthal, 2007), or motivational theory (Lang & Bradley, 2010) and is integrated in theories of emotion (e.g., Grandjean, Sander, & Scherer, 2008; Scherer, 2001).

1.1. Purpose of the Study

Several studies have investigated the impact of emotion and integration on sensorimotor interactions. Emotions, like perceptual features, are likely related to the concept of action tendencies (Frijda, 1986, 2007) and are part of the event files suggested by Hommel (1998). In the present studies, our first aim was to investigate consequences of the general valence-action binding phenomenon, as previously studied (e.g., Eder & Klauer, 2009; Eder, Musseler, & Hommel, 2012; Lavender & Hommel, 2007), but to examine how emotional information could be the subject of visuomotor binding. In the five studies described below, we used angry, fearful, and neutral facial expressions as emotional information. To our knowledge, only one study has used emotional facial expressions in Hommel’s paradigm, but only as task-irrelevant background stimuli behind S1 and S2. Trubutschek and Egner (2012) discovered then that anger did not affect the integration between perceptual features and motor response when it was irrelevant for the task. However, Trubutschek and Egner did not specifically test the emotion-action integration, as faces remained the same in S1 and S2.

Our second aim was to study how task relevance can affect emotion-action binding, with the hypothesis that an automatic and accurate behavioral response to emotional stimuli in our environment is an important aspect of our survival developed during our ontogenetic and phylogenetic history. Discrepant results have been shown in the literature concerning an influence of emotional stimuli when irrelevant for the task. For instance, Lavender and Hommel (2007), who, as mentioned earlier, interfered with approach- and avoidance-related responses to emotions, did not observe an approach-positive/avoidance-negative facilitation effect when realizing a spatial task with their emotional stimuli. However, Giesen and Rothermund (2011), using uncustomed left and right responses to emotion, showed that emotion could bind with motor responses when the task is not about the emotion. They presented an emotional noun and adjective at the same time. Participants had to indicate whether the noun designated a person or an object. The emotional aspect of the words was irrelevant for the task and their valence varied. After a delay, a new noun-adjective pair awaited the same response appeared on the screen. Results showed that distractor and response integration, as well as recall, was modulated by affective congruence: If the target and the distractor had the same valence, the distractor’s repetition facilitated the response when it was also repeated. These effects occurred, according to the authors, because the distractor, when it had the same valence as the target, bound with the motor response during the presentation of the first noun-adjective pair. Repetition of the distractor then reactivated the previous association, facilitating the answer when it was the same.

In the present studies, we designed one pilot experiment and four additional experiments to investigate the foundations of emotion-action binding with unfamiliar responses to emotions (left and right responses) and emotion as a relevant or irrelevant feature of the task in S2. The pilot experiment was a gender task with angry and neutral facial expressions of human avatars, as in the first, second, and fourth studies. The first experiment was an emotional task. The precise design of this experiment was developed on the basis of the results of the pilot study. The second experiment was a location task. The third experiment was a location task with fearful and neutral facial expressions of real humans (photographs). The fourth study was a color task in which participants had to categorize the color of the eyes of the previous angry and neutral facial expressions. Therefore, in four experiments, the task was not about the emotion (emotion task-irrelevant: pilot study, study 2, study 3 and study 4), whereas in one experiment, the task was about the emotion (emotion task-relevant: study 1). Three effects were expected for the five experiments. First, we predicted binding to occur between perceptual features, as predicted by the object file assumption of Kahneman et al. (1992). We expected participants to be faster for the repetition and alternation of the perceptual features than in the situation of a partial repetition of one or some of these features. Second, we predicted an event file binding between perceptual features and motor actions, in particular an emotion-action integration. As in the object file hypothesis, we predicted our participants to be faster for a repetition and alternation of the perceptual features and the motor response than in the situation of a partial repetition. Finally, we predicted that, if emotion and motor response were in fact bound, this integration would be more important for emotional than for neutral faces. Indeed, numerous studies have shown emotional relevance in various cognitive abilities, such as perception, attention, or memory (e.g., Hodsoll, Vidng, & Lavie, 2011; Ohman, Lundqvist, & Esteves, 2001; Talarico & Rubin, 2003). For instance, Ledoux (1994) revealed a specific cerebral pathway for threat detection: a direct path from the visual pathways to the amygdala, without accessing the visual cortex. This circuit would be implicated in the automatic detection of environmental hazards (Ledoux, 1994). Moreover, other authors, such as Talarico and Rubin (2003), revealed that emotional events, particularly negative events, would be more rooted in memory and then better recalled than neutral events. Motivated by these studies and the potential role played by binding in anxiety disorders such as phobia, obsessive–compulsive disorders or post-
traumatic stress disorders, we decided to focus our studies on emotions related to threat. Indeed, in anxiety disorders, a stimulus previously associated with a traumatic event can reactivate an intense fear or panic. We hypothesize that “emotional bindings” are created when someone is confronted with a traumatic situation and that it can be reactivated by re-exposure to the stimuli present during the initial event. Following our hypothesis of a greater binding for emotional faces, we expected participants to be faster for emotion repetition when an emotional face was repeated rather than a neutral face. Moreover, we predicted participants to be slower for emotion variation, if an emotional rather than a neutral face was bound. Indeed, as emotion is more solidly integrated, the cost of breaking the binding would be larger.

2. Pilot Experiment

The pilot study was designed, based on Hommel’s paradigm (1998), to test whether angry facial expressions could be bound with motor responses to form an event file in a nonemotional task (with task-irrelevant emotion).

2.1. Method

2.1.1. Participants

Twenty people (10 men; M_age = 25.25 years, SD = 2.43) from the University of Geneva and surroundings volunteered for this pilot study. All reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment. Written informed consent was obtained from all participants. The experiment was conducted at the University of Geneva and approved by the local ethics committee.

2.1.2. Apparatus and stimuli

The experiment was controlled by a Dell OptiPlex 9010 Intel Inside Core i7 vPro computer, attached to a Dell 1908FP 19” monitor. Participants wore Philips SBC HP250 headphones, allowing us to present them with auditory feedback when they made a mistake. Stimuli, elaborated with FACSGen software (Roesch, Reveret, Grandjean, & Sander, 2006; Roesch et al., 2011), consisted of 3D colored avatar faces of four men and four women expressing anger or being neutral. They were taken from the study of Roesch et al. (2011), in which 44 participants (men and four) expressing anger or being neutral. They were rated with FACSGen software (Roesch, Reveret, Grandjean, & Sander, 2006; Roesch et al., 2011), consisted of 3D colored avatar faces of four men and four women expressing anger or being neutral. They were taken from the study of Roesch et al. (2011), in which 44 participants evaluated them with 69 other FACSGen stimuli in terms of gender, believability, and intrinsic emotionality. In the same study they were also rated by 20 participants in terms of emotion intensity on a scale from 0 (“not intense”) to 100 (“very intense”). Faces were presented on a black background and horizontally centered in the 25° or 75° portion of the screen vertically, above or under a fixation cross. The response cue for the first face (S1) was presented in the middle of the screen, with rows of three left- or right-pointing arrows indicating left and right keypresses, respectively. Responses to S1 and S2 were made by pressing the left or right arrow of the keyboard with the index and middle finger of the right hand, respectively.

2.1.3. Procedure and design

An overview of the procedure is displayed in Fig. 1. A fixation cross appeared in the middle of the screen for 250 ms, and was then replaced by the cue for 250 ms. Participants were instructed to look at the cue. Next, a second fixation cross was presented with a jitter between 500 and 1000 ms. This jitter was added to the original paradigm of Hommel (1998) mainly to avoid precise expectation effects. S1 then appeared on the screen. It could be a man or a woman, situated in the top or bottom part of the screen, expressing anger or being neutral. Participants responded to that stimulus by giving the direction of the cue with the left or right arrow of the keyboard, a response that was thus independent of the face’s identity (and emotion portrayed). After a 500-ms interval, S2 was presented for 2000 ms. This second face could be the same as S1; could have a different gender, location, or emotion; or could have two different features or be entirely different. Participants responded to that stimulus according to the gender of the face. Half of the participants responded with a right keypress for a man and a left keypress for a woman, and the other half responded with opposite keypresses. Finally, a blank screen appeared on the screen for 1000 ms before the next trial.

Feedback was added to our paradigm to ensure that participants answered correctly, consisting of a sound (a beep) with different messages depending on the mistake. First, participants were told to answer according to the cue when they did not respond or made a mistake in S1. When this situation happened, the trial started again from the beginning. Second, participants were asked to answer according to the task-relevant feature (here gender) when they did not respond or made a mistake in S2. In this case, if they did not respond, participants started the trial again from the beginning, but if they made a mistake, they continued the trial.

The pilot study comprised 256 trials composed of a factorial combination of the cue (left vs. right), location (top vs. bottom), emotion (angry vs. neutral), gender (man vs. woman), and identity of the face (four women: F1 to F4; four men: H1 to H4), as well as repetition versus alternation of location, emotion, and gender. The experiment was divided into four blocks of 64 trials and lasted about 32 min.

2.1.4. Statistical analyses

To test our assumptions, that is, the binding between perceptual features (object file hypothesis), the binding between perceptual features and motor response (event file hypothesis), and the primacy of emotion in visuomotor binding (emotional relevance hypothesis), we used the generalized linear mixed models (GLMMs) statistical method. GLMMs are interesting because they combine properties of linear mixed models, which incorporate random effects, and generalized linear models, which handle non-normal data by allowing specification of different distributions, such as Poisson or binomial (Bolker et al., 2009; McCulloch, 2003). Moreover, with GLMMs, it is not necessary to average the trials of individuals, as is often done when using classic analysis of variance without carefully checking the application conditions, and then modeling the total variance, including that related to the trials within individuals. By using GLMMs, we were also able to control for random effects such as interindividual variability and the influence of the identity of faces on task performance.

To investigate the contribution of each variable and their interaction, we compared different models by using the chi-square difference test. Our fixed effects were emotion repetition (S1 and S2 angry: sameemo vs. S1 and S2 neutral: sameneut vs. S1 angry and S2 neutral: diffemo vs. S1 neutral and S2 angry: diffneutemo), gender repetition (same vs. different), location repetition (same vs. different), and motor repetition (same vs. different). Our random effects were the participant and identity of the face in S2. We kept the latter as a random effect because there was a significant effect of adding it to our models (χ^2(1, N = 20) = 166.43, p < 0.001). There was, however, no significant effect of adding the mean luminance of our faces as a continuous predictor (χ^2(1, N = 20) = 0.97, p = 0.32).

2.2. Results

2.2.1. Preprocessing

Before starting our analyses, we excluded trials with incorrect (16% of total trials), missing (> 2 standard deviations above the mean; 5% of total trials), or anticipatory (< 2 standard deviations under the mean;
0% of total trials) responses. Given the distribution of our reaction time data for S2, we then decided to use a log base 10 transformation. Indeed, our data showed a floor effect, participants being on average quite fast in judging the gender of the faces (mean = 666 ms). With the transformation, we equalized variances and made our data Gaussian like.

2.2.2. Object file hypothesis

For interactions between perceptual features, that is, the object file hypothesis, the only significant effect was the interaction between gender and location repetition ($\chi^2(1, N = 20) = 10.76, p < 0.01, R^2_m = 0.002, R^2_c = 0.40$; see Fig. 2). As shown by simple effects, participants were significantly faster for gender repetition if location was also repeated rather than alternated ($t(4073) = -2.73, p < 0.01$). Furthermore, participants were marginally faster for gender alternation if location was alternated rather than repeated ($t(4073) = 1.90, p = 0.06$).

The interactions between emotion and gender repetition ($\chi^2(3, N = 20) = 6.19, p = 0.10, R^2_m = 0.003, R^2_c = 0.40$) and between emotion and location repetition ($\chi^2(3, N = 20) = 2.64, p = 0.45, R^2_m = 0.003, R^2_c = 0.40$) were not significant, nor was the three-way interaction implicating emotion, location, and gender repetition ($\chi^2(3, N = 20) = 4.27, p = 0.23, R^2_m = 0.006, R^2_c = 0.40$).

2.2.3. Event file hypothesis

Concerning the second assumption, that is, interactions between perceptual features and motor response, gender repetition interacted significantly with motor response repetition ($\chi^2(1, N = 20) = 47.89, p < 0.001, R^2_m = 0.01, R^2_c = 0.41$; see Fig. 3a). Simple effects showed that participants were faster for a motor response variation if gender changed than if it did not ($t(4073) = 5.12, p < 0.001$). Moreover, they were faster for a motor response repetition when gender did not differ than when it varied ($t(4073) = -4.68, p < 0.001$; see Fig. 3b).

We also observed a significant interaction between location and motor response repetition ($\chi^2(1, N = 20) = 15.76, p < 0.001, R^2_m = 0.005, R^2_c = 0.40$). Participants were faster for a motor response repetition if location did not differ than if it changed ($t(4073) = -3.15, p < 0.01$). Moreover, participants were significantly faster for a motor response change if location varied than if it remained the same ($t(4073) = 2.44, p < 0.05$).

None of the interactions between emotion and motor response repetition ($\chi^2(3, N = 20) = 0.61, p = 0.89, R^2_m = 0.005, R^2_c = 0.40$); between gender, emotion, and motor response repetition ($\chi^2(3, N = 20) = 6.40, p = 0.09, R^2_m = 0.01, R^2_c = 0.41$); between gender, location, and motor response repetition ($\chi^2(1, N = 20) = 1.55, p = 0.21, R^2_m = 0.01, R^2_c = 0.41$); or between emotion, location, and motor response repetition ($\chi^2(3, N = 20) = 0.61, p = 0.89, R^2_m = 0.008, R^2_c = 0.40$) were significant, nor was the four-way interaction ($\chi^2(3, N = 20) = 2.51, p = 0.47, R^2_m = 0.02, R^2_c = 0.41$).

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3 We report the effect sizes according to the approach of Nakagawa and Schielzeth (2013), implemented in the “MuMin” R package. The development of methods for the effect size calculation of multilevel regression models is an active field of research (e.g., Johnson, 2014; Nakagawa & Schielzeth, 2013; Ovelien & Edwards, 2008; Xu, 2003). Whereas effect sizes (mainly $R^2$) are routinely reported for linear models and generalized linear models, the implication of random variables in linear mixed models and GLMMs causes theoretical problems (e.g. decreased or negative $R^2$ values in larger models) and/or practical difficulties (e.g. implementation) when using standard methods (Nakagawa & Schielzeth, 2013). Nakagawa and Schielzeth (2013) developed an approach based on two indicators, a marginal and conditional $R^2$ (“$R^2_m$” and “$R^2_c$”, respectively), allowing comparability with standard methods, while taking into account the variance explained by the random effects. $R^2_m$ is the variance explained by the fixed factors, whereas $R^2_c$ is the variance explained by the entire model (both fixed and random effects). We calculated them for each effect in our statistical models.

4 In all figures, ** corresponds to a significance level of 0.001, * to a significance level of 0.01, and # to a significance level of 0.05. Vertical bars represent confidence intervals of 0.95. Pilot experiment. Interaction between gender and location repetition.

5 Untransformed values: $M_{Location-diff\_Gender-diff} = 659.75$, $M_{Location-diff\_Gender-same} = 668.29$, $M_{Location-same\_Gender-same} = 659.09$, $M_{Location-same\_Gender-diff} = 659.72$. 

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Fig. 2. 4

Fig. 1. Overview of the displays and timing of events in the pilot experiment.
2.2.4. Emotional relevance hypothesis
Contrary to our predictions, emotion repetition did not interact with motor response repetition.

2.3. Discussion

Several interesting results emerge from our analyses. First, the relevant feature for the task in S2, gender, significantly integrated an event file with the motor response. As expected from previous results of Hommel (1998), participants were faster for a complete repetition and alternation of these elements than for a partial repetition of them.

Second, location participated in two bindings. Indeed, it interacted in the current experiment, no four-way interactions were significant. What these results suggest is that there is not a single binding that integrates all the information pertaining to an object, but rather several local bindings. As mentioned by Hommel (1998), the event file is probably not a single structure, but more a distributed and differentiated multilayer network of stimulus-response-feature codes with many local and distant interconnections.

Finally, and probably the most interesting results of our pilot experiment: Emotion did not take part in any object file or event file bindings, rejecting in the same time our emotional relevance hypothesis.

Thus, what we can conclude from the pilot experiment concerning our research question is that emotion, contrary to location, cannot bind with a motor response when it is irrelevant for a task. Our aim for a second experiment is thus to investigate whether emotion-action integration can occur when making emotion in S2 task relevant by asking participants to judge the emotion of the faces. This second experiment is also the occasion to address some concerns of the pilot study, as described in detail below.

3. Experiment 1

The pilot study showed us that emotion, contrary to location, could not bind with motor responses when irrelevant for the task. In the present experiment, we wanted to know whether the latter integration could occur when making emotion task relevant, that is to say, when asking participants to judge the emotion of the faces.

3.1. Method

3.1.1. Participants
Twenty students in their second and third year of psychology (five men; Mage = 25.35 years; SD = 7.84) from the University of Geneva took part in this study for course credits. None of them had taken part in the previous pilot study. All participants reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment. Written informed consent was obtained from all participants. The experiment was conducted at the University of Geneva and approved by the local ethics committee.

3.1.2. Apparatus and stimuli
The same apparatus and stimuli as the previous pilot study were used in this experiment, but we adapted them on the basis of the pilot study results. First, instead of controlling the effect of the luminance by adding it as a continuous predictor in our models, we converted our color images to grayscale and used the Matlab SHINE toolbox (Willenbockel et al., 2010). The latter equalized the mean luminance and contrast of our pictures by matching their luminance histogram. This toolbox also controlled for spatial frequency difference by matching the amplitude spectrum of our pictures to a specified target spectrum, using in particular the fast Fourier transform method. Second, in addition to control for identity effect by embedding it as a random variable in our models as previously done,

![Fig. 3. Pilot experiment. (a) Interaction between motor response and gender repetition.](image-url)
we decided to always present the same identity in S1 and S2.\textsuperscript{8} Finally, in order to have a paradigm that was more similar to the classic one used by Hommel (1998), we also removed the jitter that we added in our previous experiment.

3.1.4. Statistical analyses

As explained earlier, we slightly modified our pilot study paradigm (see Fig. 1) to reestablish Hommel’s timings (1998). Thus, the first fixation cross was presented for 1000 ms instead of 250 ms. The cue was displayed for 1500 ms instead of 250 ms, and the jitter for the second fixation cross was replaced by a fixed time of 1000 ms. We also controlled for the influence of identity in the binding by keeping the same identity in S1 and S2. Only emotion and location varied from S1 to S2.

To control for the influence of handedness on performance, we added a questionnaire at the end of the experiment to precisely assess the laterality of our participants. The questionnaire was a French translated version of the Edinburgh Handedness Inventory (Oldfield, 1971). No other changes from the pilot experiment were made.

The first study comprised 256 trials composed of a factorial combination of the cue (left vs. right), location (top vs. bottom), emotion (angry vs. neutral), and identity of the face (four women: F1 to F4; four men: H1 to H4), as well as the repetition versus alternation of location and emotion. The experiment was divided into four blocks of 64 trials and lasted about 32 min.

3.1.4. Statistical analyses

GLMM analyzes were performed to test our assumptions. The fixed effects were emotion (S1 and S2 angry: sameemo vs. S1 and S2 neutral: samenuet vs. S1 angry and S2 neutral: diffneutemo vs. S1 neutral and S2 angry: diffemoneut), location (same vs different), and motor response (same vs different) repetition. The random effect was the participant. The identity of the face in S2 was not kept as a random factor because its effect was no longer significant ($\chi^2(1, N = 20) = 0.04, p = 0.85$).

The Edinburgh Handedness Inventory was added as a continuous predictor. Indeed, there was a significant effect of adding it to our models ($\chi^2(1, N = 20) = 4.51, p < 0.05$).

3.2. Results

3.2.1. Preprocessing

The same preprocessing as in the previous experiment was used in the present experiment (incorrect responses: 6% of total trials; missing responses: 4% of total trials; anticipatory responses: 0.1% of total trials).

3.2.2. Object file hypothesis

Concerning the binding between perceptual features (see Fig. 4), we obtained a significant interaction between emotion and location repetition ($\chi^2(3, N = 20) = 23.18, p < 0.001, R^2_m = 0.01, R^2_c = 0.32$). Simple effects showed that participants were faster for the repetition of angry faces if location was repeated rather than alternated ($\tau(4579) = 2.68, p < 0.001$). The same result was obtained for the repetition of neutral faces if location was repeated rather than alternated ($\tau(4579) = 4.24, p < 0.001$). Moreover, participants were tendenitiously faster for the diffneutemo condition when location was alternated rather than repeated ($\tau(4579) = -1.90, p = 0.06$). This result was not significant in the diffneutemo situation ($\tau(4579) = -0.26, p = 0.80$).

3.2.3. Event file hypothesis

For interactions between perceptual features and motor response, emotion repetition interacted significantly with motor response repetition ($\chi^2(3, N = 20) = 107.62, p < 0.001, R^2_m = 0.03, R^2_c = 0.34$; see Fig. 5). Simple effects showed that participants were faster for an emotion repetition if the motor response was repeated rather than alternated. This was true for the situation in which both faces were angry ($\tau(4579) = 4, p < 0.001$) or neutral ($\tau(4579) = 4.09, p < 0.001$). Participants were also faster for an emotion alternation if the motor response was alternated rather than repeated. This was the case for the diffneutemo ($\tau(4579) = -6.26, p = 0.001$) and the diffemoneut ($\tau(4579) = 6.52, p < 0.001$) conditions.

Neither the interaction between location and motor response repetition ($\chi^2(1, N = 20) = 1.28, p = 0.26, R^2_m = 0.002, R^2_c = 0.31$) nor the three-way interaction between emotion, location, and motor response repetition ($\chi^2(3, N = 20) = 0.09, p = 0.99, R^2_m = 0.03, R^2_c = 0.34$) was significant.

3.2.4. Emotional relevance hypothesis

Emotion repetition significantly interacted with motor response repetition. In accordance with our assumptions, participants were faster

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig4.png}
\caption{Experiment 1. Interaction between emotion and location repetition.\textsuperscript{9} Untransformed values: $M_{\text{Motor response-diff Emotion-diff Location}} = 688.67, M_{\text{Motor response-diff Emotion-same Location}} = 683.67, M_{\text{Motor response-same Emotion-diff Location}} = 679.73, M_{\text{Motor response-same Emotion-same Location}} = 652.60, M_{\text{Motor response-same Emotion-same Location}} = 659.41.$}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig5.png}
\caption{Experiment 1. Interaction between emotion and motor response repetition.\textsuperscript{10} Untransformed values: $M_{\text{Motor response-diff Emotion-diff Location}} = 654.62, M_{\text{Motor response-diff Emotion-diff Location}} = 631.37, M_{\text{Motor response-diff Emotion-same Location}} = 661.29, M_{\text{Motor response-diff Emotion-same Location}} = 683.73, M_{\text{Motor response-same Emotion-diff Location}} = 694.73, M_{\text{Motor response-same Emotion-same Location}} = 654.45, M_{\text{Motor response-same Emotion-same Location}} = 658.91.$}
\end{figure}

\textsuperscript{8} To help the reader get an idea of the identity effect in the pilot study, we ran our GLMM analyses, replacing gender with identity repetition (see Appendix B in the supplementary material section), and we observed a significant identity-motor response repetition interaction ($\chi^2(1, N = 20) = 16.20, p = 0.001$), as well as an identity-emotion interaction ($\chi^2(3, N = 20) = 11.38, p = 0.01$). All of these effects follow the assumptions of Hommel (1998), that is, a faster reaction time for a complete repetition and alternation of the features than for a partial repetition of them.
for an emotion repetition when the motor response was repeated if both faces were angry rather than neutral ($t(4579) = 3.78, p < 0.001$). Moreover, when the motor response was repeated, but not the emotion, participants were slower when the first face was angry than when it was neutral ($t(4579) = −3.64, p < 0.001$).

3.3. Discussion

Several interesting results were obtained in the present experiment. First, in accordance with our previous experiment, the task-relevant feature, here emotion, again integrated an object file with location. As mentioned earlier, this interaction is particularly interesting because it shows the importance of location in the binding of visual stimulus features. Moreover, it is the first object file, since the pilot study, in which emotion took part. However, although participants were faster for an emotion repetition if location was repeated, simple effects for an emotion alternation when location was alternated did not reach significance.

Another interesting observation was that, unlike the case in our pilot study and in the study by Hommel (1998), there was a nonsignificant interaction between location and motor response repetition. It appears that when emotion was the relevant feature for the task, the motor action facilitation by location observed in the previous studies was not significantly different. This may be because emotion diverts an important part of attention, diminishing the impact of the location-motor response interaction.

In the same vein, the three-way interaction between emotion, location, and motor response was not significant (as it was in our pilot study). This observation is another argument in favor of the coexistence of several bindings, instead of a single integrated one.

Finally, the interaction between emotion and motor response was this time significant. Indeed, participants were faster for a complete repetition and alternation of these elements than for a partial repetition of them. Furthermore, in accordance with our emotional relevance assumption, participants showed greater binding for emotional stimuli. Indeed, when emotion and motor response were repeated, they were faster for a repetition of angry faces than of neutral faces. Moreover, they were also faster for a motor response repetition and an emotion alternation when the first face was neutral instead of angry. The latter result shows that participants were more disrupted by a change of emotion if an angry face was bound in S1.

To conclude with our research question, the results of our first study are compatible with binding between emotion and motor response when emotion is relevant for the task. In the second experiment, we aimed to investigate with a new task and addressing the changes from the pilot study (see above) if emotion can integrate binding with the motor response when irrelevant for the task in S2.

4. Experiment 2

We showed with the first study that emotion in our paradigm can bind with the motor response when relevant for the task. We also predicted an impact of emotion even if it is not task relevant given the importance for our survival to react automatically to environmental hazards. Following our pilot study and after implementing several changes (see above), we aimed to test emotion-action binding when emotion is not relevant for the task in S2 in the context of a location task.

4.1. Method

4.1.1. Participants

Twenty students in their second and third year of psychology (three men; $M_{\text{age}} = 24$ years; $SD = 6.64$) from the University of Geneva took part in this study for course credits. All reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment (they did not participate in the pilot or the first study). Written informed consent was obtained from all participants. The experiment was conducted at the University of Geneva and approved by the local ethics committee.

4.1.2. Apparatus and stimuli

The same material as in the first study was used in this experiment.

4.1.3. Procedure and design

The same experimental design and variables as in the previous study were used for the present experiment. The only change was the task in S2. Participants had to decide, by answering with the left and right arrow of the keyboard, whether the face displayed in S2 was situated at the top or bottom part of the screen. Half of the participants responded with a right keypress for a top location and left keypress for a bottom location. The other half had the opposite instructions.

4.1.4. Statistical analyses

GLMM analyzes were run to test our assumptions. Our fixed and random effects were the same as in the first study. We again tested the effects of adding the score of the Edinburgh Handedness Inventory as a continuous predictor. The result was not significant ($\chi^2(1, N = 20) = 1.96, p = 0.16$). We did not keep it in our models.

4.2. Results

4.2.1. Preprocessing

The same preprocessing as in the previous experiments was performed in the present experiment (incorrect responses: 5% of total trials; missing responses: 4% of total trials; anticipatory responses: 0% of total trials).

4.2.2. Object file hypothesis

The interaction between emotion and location repetition was not significant ($\chi^2(3, N = 20) = 4.17, p = 0.24, R^2_m = 0.006, R^2_c = 0.25$).

4.2.3. Event file hypothesis

Concerning the binding between perceptual features and motor response, we obtained a significant interaction between location and motor response repetition ($\chi^2(1, N = 20) = 309.43, p < 0.001, R^2_m = 0.05, R^2_c = 0.30$; see Fig. 6). As shown by simple effects, participants were faster for a motor response repetition if location was also repeated rather than alternated ($t(4605) = 16.74, p < 0.001$). Moreover, they were also faster for a motor response variation if location was alternated rather than repeated ($t(4605) = −8.53, p < 0.001$).

Neither the interaction between emotion and motor response repetition ($\chi^2(3, N = 20) = 1.48, p = 0.69, R^2_m < 0.001, R^2_c = 0.24$) nor the
three-way interaction between emotion, location, and motor response repetition ($\chi^2(3, N = 20) = 1.85, p = 0.60, R^2_m = 0.05, R^2_c = 0.30$) were significant.

4.2.4. Emotional relevance hypothesis

The emotion-action binding was not significant in the second experiment.

4.3. Discussion

In agreement with previous studies, we obtained a significant binding between the relevant feature for the task, here location, and the motor response. Participants were faster for a complete repetition and alternation of these elements than for a partial repetition of them. No binding effects implicating emotion (not relevant for the task in this experiment) were significant. This conclusion applies to our object file and to our event file assumptions.

Moreover, still in accordance with previous experiments, the three-way interaction was not significant. The latter result is another argument in favor of multiple bindings instead of a single integrated one.

Thus, in agreement with the results of our pilot study, emotion did not bind with the motor response when irrelevant for the task. The results of this second study showed that the emotion-action binding predicted is not found when emotion is not relevant for the task. In order to further investigate the possible binding of task-irrelevant emotions, we decided to run another study with the same task in S2 as in the present experiment, but varying the emotion presented to participants. Thus far, our motivation to investigate the integration of stimuli associated with threat focused only on anger in order to highlight the potential role of the emotion-action binding in anxiety disorders. We would like in the following experiment to extend our results to a new threat-related emotion: fear.

5. Experiment 3

The pilot and second study are in agreement with an absence of emotion-action integration when emotion is irrelevant for the task. In order to further investigate this phenomenon, we decided to extend our results, with the present experiment, to a new emotion related to threat: fear.

5.1. Method

5.1.1. Participants

Twenty new participants (five men; $M_{\text{age}} = 25.4$ year, $SD = 3.41$) from the University of Geneva and surroundings took part in this study for financial compensation. All reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment. Written informed consent was obtained from all participants. The experiment was conducted at the University of Geneva and approved by the local ethics committee.

5.1.2. Apparatus and stimuli

The same material as in the second study was used for the present experiment. The only modification that we made was in the stimuli we used. In order to examine non-task-relevant emotion binding, we decided to test how facial expressions of fear can induce such binding. Instead of using avatars, we chose photographs derived from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist, Flykt, & Ohman, 1998). 3D avatar faces were not used this time, because we were not satisfied with their realism. Indeed, local deformations in the form of wrinkles are observed on fearful FACSGen faces. We took this also as an opportunity to improve the ecological validity of our results by using natural facial expressions. Eight identities were taken from the KDEF database: four men and four women. Each identity expressed a fearful and a neutral expression. We added a mask around the stimuli to display the face, without the background, hair, ears, and neck. We then converted the color pictures to grayscale and applied the Matlab SHINE toolbox to equalize luminance and the spatial frequencies of our set of stimuli (Willenbockel et al., 2010). As in the previous studies, faces were presented on a black background and were horizontally centered, in the 25° or 75° portion of the screen vertically, and above or under the fixation cross.

5.1.3. Procedure and design

The same experimental design (see Fig. 5) and variables as in the first and second studies were used in the present experiment.

5.1.4. Statistical analyses

GLMM analyzes were run to test our predictions, as was done previously.

5.2. Results

5.2.1. Preprocessing

The same preprocessing as in the previous experiments was performed in the present experiment (incorrect responses: 7% of total trials; missing responses: 5% of total trials; anticipatory responses: 0.02% of total trials).

5.2.2. Object file hypothesis

The interaction between emotion and location repetition was not significant ($\chi^2(3, N = 20) = 3.08, p = 0.38, R^2_m = 0.007, R^2_c = 0.23$).

5.2.3. Event file hypothesis

The interaction between location and motor response repetition ($\chi^2(1, N = 20) = 228.58, p < 0.001, R^2_m = 0.05, R^2_c = 0.28$; see Fig. 7) was significant, demonstrating binding between perceptual features and motor response. As shown by simple effects, participants were faster for a motor response repetition if location was repeated rather than alternated ($t(4513) = 15.24, p < 0.001$). Moreover, they were also faster for a motor response variation if location was alternated rather than repeated ($t(4513) = -6.36, p < 0.001$).

Neither the interaction between emotion and motor response repetition ($\chi^2(3, N = 20) = 2.78, p = 0.43, R^2_m = 0.003, R^2_c = 0.23$) nor the three-way interaction between emotion, location, and motor response repetition ($\chi^2(3, N = 20) = 3.54, p = 0.32, R^2_m = 0.05, R^2_c = 0.28$) was significant.

5.2.4. Emotional relevance hypothesis

Emotion did not bind with the motor response in the third study.

![Fig. 7. Experiment 3. Interaction between motor response and location repetition.](image)
The results of this third study are similar to those of our previous experiments with task-irrelevant emotions, that is to say the pilot and second study. Binding between the emotional perceptual features were not observed and a clear interaction was revealed between the relevant feature for the task, location, and motor response. Interestingly, this effect was observed in all of our experiments and those of Hommel (1998): Participants were faster for a complete repetition and alternation of the relevant feature and the motor response than for a partial repetition of them.

Moreover, consistent with our previous experiments, the three-way interaction was not significant. This result is another argument in favor of the coexistence of multiple bindings rather than a single integrated one.

In conclusion, we again showed with this experiment that emotion cannot integrate binding with the motor response when it is irrelevant for the task. In the present experiment, we reproduced the results of our pilot and second study by using natural fearful expressions. It seems that the features of the stimuli (i.e., the avatar compared with natural photographs or angry vs. fearful expressions) were not responsible for the absence of emotion-action interaction. In fact, we obtained similar results with these two different sets of stimuli. A possible explanation of the null findings could be related to the tasks that participants had to perform. In the pilot, second, and third studies, in which we used gender and location tasks, participants needed only to globally analyze the situation to answer correctly. Indeed, they could categorize the gender of the face by comparing only the facial contours or by using global features without sufficiently processing the emotional aspects of the face. The effect is even larger with location, as they did not even need to analyze the face to perform the task. One can argue that we did not obtain the expected results, because our participants did not fully process the local features of the face that might play a role in emotion binding. The fourth study was designed to investigate the extent to which a non-task-relevant emotion would play a role in the binding process when participants have to perform a task that is more focused on local features, and then process the emotional features in a deeper way than in the context of a global task.

6. Experiment 4

To test our hypothesis, we decided to take the stimuli we used for the pilot and the two studies that followed it and to slightly modify them. With Adobe Photoshop software, we lightened and darkened the eyes of each picture of the neutral and angry face of two women and two men from the previous database (see examples in Fig. 8). The participants’ task in S2 was to categorize the eye color of the faces. We predicted that this local task would focus participants’ attention more on the details of the face, and then cause clear emotion-action binding.

Fig. 8. Examples of stimuli in Experiment 4. On the left: a neutral man with light eyes. On the right: the same face with dark eyes.

6.1. Participants
Twenty new participants (seven men; Mage = 26.95 years; SD = 6.95) from the University of Geneva and surroundings took part in this study for financial compensation. All reported having normal or corrected-to-normal vision and were not familiar with the purpose of the experiment. Written informed consent was obtained from all participants. The experiment was conducted at the University of Geneva and approved by the local ethics committee.

6.1.2. Apparatus and stimuli
The same material as in the previous studies was used for this experiment, except for the changes we mentioned earlier.

6.1.3. Procedure and design
The same experimental design as in the previous study was used in the present experiment. The only modification was the task that participants had to perform in S2. We asked them to indicate whether faces in S2 had light or dark eyes by pressing the left or right arrow of the keyboard. Half of the participants answered with the right key for “light” and the left key for “dark”. The other half of the participants had the opposite instructions.

The study comprised 512 trials composed of a factorial combination of the cue (left vs. right), location (top vs. bottom), emotion (angry vs. neutral), eye color (dark vs. light), and identity of the face (two women: F1 and F2; two men: H1 and H2), as well as the repetition versus alternation of location, emotion, and eye color. The experiment was divided into eight blocks of 64 trials and lasted about 64 min.

6.1.4. Statistical analyses
GLMM analyzes were run to test our assumptions. Our fixed effects were emotion (S1 and S2 angry: sameemo vs. S1 and S2 neutral: sameneut vs. S1 angry and S2 neutral: diffemo; S1 neutral and S2 angry: diffneutemo), location (same vs. different), eye color (same vs. different), and motor response (same vs. different) repetition. Our random effect was the participant and identity of the face in S2. The latter was added to our models because its effect was significant ($\chi^2(1, N = 20) = 53.29, p < 0.001$).

6.2. Results

6.2.1. Preprocessing
The same preprocessing as in previous experiments was performed in the present experiment (incorrect responses: 4% of total trials; missing responses: 4% of total trials; anticipatory responses: 0.1% of total trials), except for the log transformation. Indeed, the data in the present experiment were normally distributed.

6.2.2. Object file hypothesis
Concerning the binding between perceptual features, two interactions were significant: the interaction between emotion and color repetition ($\chi^2(2, N = 20) = 20.02$, $p < 0.001, R^2_m = 0.003, R^2_e = 0.24$; see Fig. 9a) and between location and color repetition ($\chi^2(1, N = 20) = 13.77$, $p < 0.001, R^2_m = 0.01, R^2_e = 0.25$; see Fig. 9b). For the former interaction, participants were faster in the diffemo ($t(9334) = -2.64, p < 0.01$) and diffneutemo ($t(9334) = -4.31, p < 0.001$) conditions for color change than for repetition. No significant difference between a color repetition and an alternation was observed in the sameemo ($t(9334) = 1.45, p = 0.15$) and sameneut ($t(9334) = 0.04, p = 0.96$) conditions. Concerning the color-location interaction, participants were faster for a color repetition if location was repeated rather than alternated ($t(9336) = 11.12, p < 0.001$). However, contrary to our predictions, they were faster for a color alternation if location was repeated rather than alternated ($t(9336) = 5.92, p < 0.001$).
Neither the interaction between emotion and location repetition ($\chi^2(3, N = 20) = 4.11, p = 0.25, R^2_m = 0.01, R^2_c = 0.25$) nor the three-way interaction between location, color, and emotion repetition ($\chi^2(3, N = 20) = 3.13, p = 0.37, R^2_m = 0.02, R^2_c = 0.25$) was significant.

6.2.3. Event file hypothesis

Concerning the binding between perceptual features and motor response, color repetition significantly interacted with motor response repetition ($\chi^2(1, N = 20) = 184.48, p < 0.001, R^2_m = 0.02, R^2_c = 0.25$; see Fig. 10b). Participants were faster for a motor alternation if color was also alternated rather than repeated ($t(9336) = −11.55, p < 0.001$). Moreover, they were also faster for a motor response repetition if color was repeated rather than alternated ($t(9336) = 7.76, p < 0.001$).

Neither the interaction between emotion and motor response repetition ($\chi^2(3, N = 20) = 6.88, p = 0.08, R^2_m = 0.002, R^2_c = 0.24$), location and motor response repetition ($\chi^2(1, N = 20) = 3.03, p = 0.08, R^2_m = 0.01, R^2_c = 0.25$), emotion, location and motor response repetition ($\chi^2(3, N = 20) = 1.67, p = 0.64, R^2_m = 0.03, R^2_c = 0.27$), emotion, color and motor response repetition ($\chi^2(3, N = 20) = 3.59, p = 0.31, R^2_m = 0.02, R^2_c = 0.28$), nor the four-way interaction ($\chi^2(3, N = 20) = 5.07, p = 0.17, R^2_m = 0.03, R^2_c = 0.27$) were significant. Note, however, that the first and second results can be considered marginal. Concerning the emotion-motor response repetition interaction (see

![Fig. 9. Experiment 4. (a) Interaction between emotion and color repetition and (b) interaction between color and location repetition.](image)

![Fig. 10. Experiment 4. (a) Interaction between motor response and location repetition, (b) interaction between motor response and color repetition, and (c) interaction between emotion and motor response repetition.](image)
Fig. 10c), simple effects showed that participants were significantly faster for a motor response alternation than for a repetition in the differmoneut ($t(9334) = -2.70, p < 0.01$) and differmoneut ($t(9334) = -3.05, p < 0.01$) conditions. No significant difference was observed between a motor response repetition and an alternation in the same emo ($t(9334) = -1.31, p = 0.19$) and same neu ($t(9334) = 0.27, p = 0.79$) conditions. For the location-motor response repetition interaction (see Fig. 10a), participants were significantly faster for a motor response repetition if location was repeated rather than alternated ($t(9336) = 9.71, p < 0.001$). However, contrary to our assumptions, participants were significantly faster for a motor response alternation when location was repeated rather than alternated ($t(9336) = 7.34, p < 0.001$). Interestingly, the three-way interaction implicating location, color, and motor response repetition was also significant ($\chi^2(1, N = 20) = 7.13, p < 0.01, R^2_m = 0.03, R^2_c = 0.27$; discussed in detail in Appendix G of the supplementary material section).

6.2.4. Emotional relevance hypothesis

Emotion repetition did not significantly interact with motor response repetition in the fourth study.

6.3. Discussion

Several interesting results emerge from this last study. Concerning the object file hypothesis, the relevant element for the task in S2, color, significantly bound with emotion. Participants, in agreement with Hommel’s assumptions (1998), were faster for a complete alternation of emotion and color than for a partial repetition of them. However, no significant difference was observed in a complete repetition situation, whether the faces were emotional or neutral.

Another interesting result for the binding between perceptual features is the interaction between color and location. Participants were faster for a complete repetition of these elements than for a partial repetition of them. Nonetheless, they were not significantly faster for a color alternation when location was alternated rather than repeated. In fact, the opposite result was observed. Binding between the relevant feature for the task and location was also observed in the first study and those of Kahneman et al. (1992) and Hommel (1998). As we mentioned earlier, the interaction between the task-relevant feature and location is particularly interesting because it reflects the importance of location in the event file establishment and recall (Hommel, 2004).

Concerning the event file hypothesis, the relevant feature for the task, here color, interacted significantly with the motor response. We again reproduced the result of all of our studies and those of Hommel (1998). Participants were faster for a complete repetition and alternation of these features than for a partial repetition of them. Still in agreement with our previous results, no interaction implicating all variables, here a four-way interaction, was observed in the present experiment. These results are in line, once again, with the existence of multiple bindings instead of an integrated single one. Nonetheless a three-way interaction between the task-relevant feature (here color), location, and motor response was significant. Participants were generally faster for a complete repetition and alternation of the features than for a partial repetition of them. In fact, this result was significant for all simple effects except two: when we compared a complete alternation to the situation in which location and motor response were only to be repeated, as well as in the situation in which location and color were only to be repeated (see Appendix G in the supplementary material section).

Finally, concerning our research question, that is, the integration of emotion and motor response when the former is task irrelevant, the effect was not significant in the present experiment. Contrary to our predictions, focusing participants’ attention more on the details of the face did not affect, in the way we expected, emotion-action binding. Of note, however, and compared with all of our other studies with task-irrelevant emotions, this interaction for the reaction time analysis was in the present experiment marginal. Indeed, as shown by simple effects, participants were significantly faster for a motor response alternation than a repetition when emotion was also alternated. Nonetheless, no significant difference between a motor response repetition and alternation was observed when emotion was repeated.

7. General discussion

One pilot study and four additional studies were designed to test whether emotion, like perceptual features, could bind with motor responses. Furthermore, we also designed these studies to investigate the extent to which emotional binding can be modulated by the nature of the task by testing whether task-relevant and non-task-relevant emotions are similarly bound with other manipulated features. The pilot study and the second study showed with angry avatar faces that emotional binding was not possible when emotion was irrelevant for the task, that is to say, when the task was not about the emotion. The first experiment revealed emotional binding when emotion was task relevant. The third experiment generalized our results to natural fearful faces, the emotion-action interaction when emotion is task irrelevant being not observed. The last experiment highlighted once again the fact that emotion was not integrated when it was task irrelevant, but it left open the question of the role played by the focus of attention in emotion-action integration with irrelevant emotions, as the interaction was marginal. Indeed, merely asking participants to concentrate more on the details of the face by asking them to categorize a local feature, such as eye color, instead of a global one, such as location, could have generalized our results. Note that the eyes in this experiment were easily discriminable, as shown by the success rate of 97%. Further studies should systematically address the impact of the local versus global aspect of task-relevant features and their discriminability on non-task-relevant emotional binding effects.

Concerning our emotional relevance hypothesis, that is, the prediction of stronger binding for emotional than for neutral stimuli, it was clearly observed when emotion was significantly interacting with the motor response, that is to say in the first study with the emotional task. Participants were faster for an emotion and motor response repetition when both faces in S1 and S2 were angry rather than neutral. Repeating emotional stimuli facilitated the response in S2 compared with the situation in which neutral faces were presented twice. Moreover, they were slower for a motor response repetition and emotion alternation when the first face was emotional, probably because of the cost of breaking the binding in S2 when an emotional rather than a neutral face was bound in S1.

Interestingly, emotion, in our different experiments, not only integrated binding with the motor response, but also took part in two object files. It bound with location in the first study and with color in the fourth. Two studies encouraged participants’ attention on the emotion by the task (experiment 1: emotional task; experiment 4: eye color task). Focusing participants’ attention on the emotion influenced the integration of the emotion not only with motor responses, but also with the other features. Interestingly, these results are in accordance with the literature reporting a vivid recollection of features associated with emotional events (e.g., Dewhurst & Parry, 2000; Kensinger & Corkin, 2003; Kensinger, Garoff-Eaton, & Schacter, 2007).

Although these results seem in line with an object file and event file binding of emotion, we cannot totally discard the interpretation of our findings as the integration of low-level features instead of emotion. Indeed, a great debate has long divided psychologists (e.g., Coelho, Cloete, & Wallis, 2010; Goffaux & Rossion, 2006): What is really processed when attention is directed toward a face in general, or an emotional face in particular: the local features or the face as a whole? Arguments in favor of both sides coexist (e.g., Calvo & Nummenmaa, 2003; Horstmann, Becker, Bergmann, & Burghaus, 2010). Our results seem to go toward the local feature processing hypothesis for emotion integration when the latter is task irrelevant, as emotion-action binding is close to significance only when participants focus on the details of the
faces. However, we cannot discard the possibility that holistic processes intervene when the emotion is task relevant, as in our first study. The question of whether our effects are due to low-level features or holistic processes remains, especially because we cannot separate facial emotional expressions from the low-level features that compose them. Of importance, however, is that the identity of the face presented in S2 was added as a random factor when significant and that we carefully controlled in the following experiments the luminance and the spatial frequency of our stimuli to maximally reduce low-level confounds. Moreover, our results were reproduced with avatars, photographs of natural expressions, and angry and fearful faces, further reducing the possibility of an effect induced only by low-level differences in our stimuli.

Of note also in our studies is the fact that we used only negative emotions. Our choice was motivated by the observation of clinical populations and the potential role played by binding in anxiety disorders: a stimulus previously associated with a traumatic event reactivating an intense fear or panic. By concentrating in our experiments on emotions related to threat and by associating these emotions with unaccustomed motor actions (right and left finger responses) rather than the regular approach-avoidance responses, we were able to investigate the foundations of visuomotor integration with threatening stimuli. One limitation by making this choice in our studies, however, is the impossibility of generalizing our results to other emotions. To overcome this limitation, researchers interested in studying the integration of a broader set of emotions could easily adapt our paradigm to compare, for instance, binding between positive and negative emotions.

Another interesting result in our studies is that the relevant features for the task in S2 always bound with motor responses. In agreement with Hommel’s assumptions (1998), participants were faster for a complete repetition and alternation of the relevant features and the motor responses than for a partial repetition of them. Furthermore, in accordance with Hommel’s (1998) observations, most of the time, location integrated binding with the relevant features and the motor responses.

The former result can be explained, following the idea of Kahneman et al. (1992), by the importance of location in event file establishment and recall in the visual domain (Hommel, 2004). Hommel (1998) interpreted it as the consequence of strong intradomain coupling of location and motor response. We cannot totally discard, however, the possibility that participants had to perform spatial categorizations in our studies (responses to left and right arrows), which may have primed or heightened the location dimension for the face perception as well (e.g., Fagioli, Hommel, & Schubotz, 2007). Regardless, location, after the relevant feature for the task, played an important role in the visuomotor bindings in our experiments. Given our results, we suggest at least three coexisting levels of visuomotor bindings: one implicating the relevant feature for the task; one implicating location, with a smaller behavioral effect; and one implicating irrelevant features, with behavioral effects only under specific conditions.

A last observation that we consistently noted in our experiments was the absence of binding that implicated all features. Indeed, no four-way interactions and only one three-way interaction reached significance in our experiments. The latter effects were observed in two experiments that included four fixed factors, not in situations of a complete single binding. In accordance with Hommel (1998), our results suggest the coexistence of several distributed bindings. Thus, the event file is probably not a single structure as would be presumed in a “uniform–event-file” hypothesis (Hommel, 1998).

8. Conclusion

One pilot study and four additional studies using avatar angry and natural fearful faces showed that emotion, when relevant and irrelevant for a task, could participate in several bindings, including emotion–action integration. Concerning the latter, new studies need to be done to disentangle the role played by the global versus local focus of a participant’s attention when emotion is task irrelevant. Further research is also needed to increase our understanding of how a task-relevant emotion and its feature discriminability affect different kinds of other-relevant feature bindings (such as location).

Our adaptation of Hommel’s paradigm (1998) has proven its utility in testing the integration of emotional stimuli with motor responses at the behavioral level. The precise underlying neuronal mechanisms subserving the observed binding effects at the behavioral level might open a new line of research. For example, the “binding by correlation” hypothesis (e.g., Hommel, 2004; Konig & Engel, 1995) states that the event file is the result of the synchronization of neuronal units coding the different perceptual and motor features. One could investigate how different brain regions are transiently in synchronization by using phase measures and cross-frequency coupling, especially between subcortical brain regions known to be involved in emotion and cortical responses, for instance, related to different modalities. As an example, we assume a transient neuronal synchronization between the premotor and motor cortices, the amygdala, the orbitofrontal cortex, and the fusiform face area in the emotional facial expression perception predicting the related binding effects observed at the behavioral level. The possibly more temporally sustained binding effects might also imply that the basal ganglia initiate more long-term binding between perceptual and motor responses that are finally observed in what some authors have called “habits” (Graybiel, 2008; Peron, Frühholz, Verin, & Grandjean, 2013). How emotional bindings are characterized in other modalities such as emotional prosody perception and related actions are also of interest. The transient neuronal synchronization would in this case involve the so-called emotional voice areas situated in the middle superior temporal gyrus and sulci (Belin, Zatorre, Lafaille, Ahad, & Pike, 2000; Frühholz & Grandjean, 2012; Grandjean et al., 2005) and the above-mentioned brain regions involved in emotional processing.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.actapsy.2016.09.001.

References
