Emotional Semantic Congruency based on stimulus driven comparative judgements

Carlo Fantoni[a,*], Giulio Baldassi[a], Sara Rigutti[a], Valter Prpic[b], Mauro Murgia[a], Tiziano Agostini[a]

[a] Department of Life Sciences, Psychology Unit "Gaetano Kanizsa", University of Trieste, Via E. Weiss 2, 34128 Trieste, Italy
[b] Faculty of Health and Life Sciences, Institute for Psychological Science, De Montfort University, The Gateway, LE1 9BH Leicester, United Kingdom

ARTICLE INFO

Keywords:
Emotion
Facial expressions
Semantic congruency
SNARC effect
Spatial representation
Spatial attention

ABSTRACT

A common cognitive process in everyday life consists in the comparative judgements of emotions given a pair of facial expressions and the choice of the most positive/negative among them. Results from three experiments on complete-facial expressions (happy/angry) and mixed-facial expressions (neutral/happy-or-angry) pairs viewed with (Experiment 1 and 3) or without (Experiment 2) foveation and performed in conditions in which valence was either task relevant (Experiment 1 and 2) or task irrelevant (Experiment 3), show that comparative judgements of emotions are stimulus driven. Judgements' speed increased as the target absolute emotion intensity grew larger together with the average emotion of the pair, irrespective of the compatibility between the valence and the side of motor response: a semantic congruency effect in the domain of emotion. This result undermines previous interpretation of results in the context of comparative judgements based on the lateralization of emotions (e.g., *SNARC-like instructional flexibility*), and is fully consistent with our formalization of emotional semantic congruency: the direct Speed-Intensity Association model.

1. Introduction

Behavioural evidence based on the classification of centrally presented emotions suggests that the mental representation of valence has a similar spatial structure to the mental representation of numbers with a left-to-right mental format (Casasanto, 2009; Casasanto, 2011; Casasanto & Chrysikou, 2011; Dehaene, Bossini, & Giraux, 1993; Holmes & Lourenco, 2011; Pitt & Casasanto, 2017). Such a format produces a SNARC-Like compatibility Effect, SLE, characterized by a negative right-to-left response speed deviation, Δspeed (right-hand responses slower), and a positive Δspeed (right-hand responses faster), for negative (anger), and positive (happiness) emotions, respectively. These strands of evidence are in line with paradigms suited to investigate how the perception of emotions in isolation drives motor reactivity. However, from an ecological stand-point, emotions are more likely to penetrate our perception and decision stage when presented together, rather than in isolation. This is the case of the cocktail party effect (Cherry, 1953) showing our capacity to tune into a single emotionally relevant voice and tune out all others during a crowded party. This type of affective intrusion similarly regulates visual perception of facial expressions of emotions. For instance, emotional faces are more likely to predominate over neutral in binocular rivalry as well as different types of interference paradigms (Alpers & Gerdes, 2007; Alpers & Pauli, 2006; Alpers, Ruhleder, Walz, Muhlberger, & Pauli, 2005; Anderson, 2005; Lim, Padmala, & Pessoa, 2009). Within such a context a debated issue for the emerging field of emotion regulation research regards how bottom-up exogenous (i.e., stimulus-driven), and top-down endogenous (i.e., goal-directed) factors together exert their influence on emotional signals in order to shape motor reactivity to displays characterized by emotions' combinations (Delgado, Nearing, LeDoux, & Phelps, 2008).

Here we consider a paradigmatic case. The lateralized motor response to the simplest emotions' combination: a dyad, as it is the case of two simultaneously presented facial expressions of emotions differing in term of valence only. As put forth by recent studies, it is not clear whether a SLE would hold true in such a case, and in particular, when the task does (direct task), or does not (indirect task) require the processing of valence (Lee, Chun, & Cho, 2016; Holmes & Lourenco, 2011; Shaki, Petrusic & Leth-Steensen, 2012). In its standard form a comparative judgement would indeed consist in the simultaneous

Abbreviations: SLE, SNARC-Like Effect; ESC, Emotional Semantic Congruity; SC, Semantic Congruency; SIA, Speed-Intensity Association; SE, Size Effect; EA, Emotion Anisotropy

* Corresponding author.
E-mail addresses: cfantoni@units.it (C. Fantoni), giulio.baldassi@phd.units.it (G. Baldassi), srigutti@units.it (S. Rigutti), valter.prpic@dmu.ac.uk (V. Prpic), mmurgia@units.it (M. Murgia), agostini@units.it (T. Agostini).

Accepted 16 April 2019

presentation of a stimulus pair differing in the amount of an attribute with the observer deciding which among the two has more or less of the explicitly considered attribute. In particular, recent results have found a difference between the standard comparative judgements of highly overlearned symbolic magnitudes (like numerals), vs. the one of unfamiliar non-symbolic magnitudes (like animal size, people's height, arrays of black dots), with the former one leading into a clear SLE pattern vs. the latter one into a mixed SLE pattern (Lee et al., 2016; Patro & Haman, 2012; Patro & Shaki, 2016; Shaki & Fischer, 2008; Shaki, Fischer, & Petrusic, 2009; Shaki et al., 2012). Such a difference has been so far attributed to the coarse reference frame evoked by non-symbolic intensities that being unfamiliar would be subjected to instructional flexibility (Shaki & Fischer, 2008). Within such a framework, emotion constitutes a key attribute to be studied given its strong link with action (Fantoni & Gerbino, 2014; Gerbino & Fantoni, 2016; Nummenmaa, Glerean, Hari, & Hietanen, 2014). Furthermore emotions being non-symbolic, though highly overlearned should behave like numerals, thus inducing a pattern of motor reactivity consistent with SLE.

In the present study we addressed this question testing whether simultaneously presented highly overlearned non-symbolic magnitudes automatically (directly – Experiment 1 & 2/indirectly – Experiment 3), and depending on a lateralized processing of valence (under tachistoscopic – Experiment 2- /natural free-viewing conditions – Experiment 1 & 3), elicit a pattern of motor reactivity consistent with a SLE, on pairs of simultaneously displayed facial expressions. Emotional pairs were characterized by expressions varying for their valence only as indexed by different degrees of emotional intensity elicited along the anger-to-happiness continuum. Facial expressions of happiness and anger are known to have strongly different hedonic impact leading into clear cut-off difference in behavioural and brain responses when presented to the left and right visual hemifield (Adolphs, 2002; Becker et al., 2012; Davidson, 1984; Fox, 1991; Harmon-Jones, 2004; Lin et al., 2016; Marsh, Ambady, & Kleck, 2005). They thus constitute optimal affects to the purpose of our study. In particular our emotional pairs were either characterized by complete-facial expressions (with one face being half or fully happy and the other angry) or mixed-facial expressions (with one face being neutral and the other fully happy/or angry) pairs. Participants performed two successive though counterbalanced sessions differing only for the type of emotion to be judged comparatively within each pair, either performing a valence comparison task, following the standard comparative judgement paradigm requiring the direct processing of the stimulus dimension that was task relevant (e.g., the valence, choose the "happiest" or the "angriest" face in Experiment 1 and 2), or performing an emotion identification task, following a novel comparative judgement paradigm requiring instead the processing of a stimulus dimension that was task irrelevant (e.g., the emotion, choose the "emotional" or the "neutral" face).

Importantly, our studies are meant to shed light on a debated issue regarding the lateralized perception of emotions and in particular whether a spatial mental representation of valence is mirrored into a corresponding lateralization of motor response (Canli, 1999; Jansari, Tranel & Adolphs, 2000; Reuter-Lorentz & Davidson, 1981). Comparative judgements of emotions, indeed, differently from standard judgements performed on single isolated intensities, include attentional properties that might be critical for SLE occurrence that goes well beyond instructional flexibility. In particular, the simultaneous presentation of a pair of emotional intensities, can just putatively be expected to trigger in a more or less automatic fashion shifts of attention in a way consistent with a valence-specific lateral bias (e.g., Jansari, Rodway, & Goncalves, 2011). This is particularly true in the categorization of emotional stimuli in which response selection has been shown to be driven by a complex interaction between a goal-directed endogenous attention, voluntarily orienting the observer to detect target stimuli, and a stimulus-driven exogenous attention, capturing observer's behaviour because of motivational significance (Carretié, 2014; Ferrari, Codispotti, Cardinali, & Bradley, 2008; Reeck & Egner, 2015). If the spatial compatibility between the valence of the pair and the response code is not the only predictive factor affecting motor reactivity, then the relationship between Δspeed and the overall intensity of the pair could not follow a standard SLE pattern. For instance, if motor response is shaped by purely stimulus-driven factors due to the perceptual encoding of emotions, an alternative bias might occur: the Semantic Congruency, SC bias (Banks, Clark, & Lucy, 1975; Banks & Flora, 1977; Banks, Fujii, & Kayra-Stuart, 1976; Cantlon & Brannon, 2005; Shaki, Leth-Steensen, & Petrusic, 2006; Zhou, Ho, & Watanabe, 2017). According to SC bias the speed of motor response results to be proportional to the absolute intensity of the target emotion relative to the cut-off of the series (i.e., a neutral valence face in the case of emotional pairs extracted from an anger-to-happiness continuum), irrespective of the side of response, and the congruency with the spatial arrangement of the pair with the left-to-right mental format of valence. Notably the occurrence of such a kind of bias in the domain of emotion, an Emotional Semantic Congruency effect, ESC, would pose a caveat for the current theory of emotion lateralization in general, and for the valence hypothesis in particular. As detailed in Section 1.2 an ESC is indeed fully consistent with a stimulus-driven theoretical framework of the comparative judgement of emotions that contradict the idea that emotion-related stimuli are mentally represented in terms of valence, with negatively- and positively- valenced stimuli associated with the left and right sides of space, respectively (Casasanto, 2009; Root, Wong, & Kinsbourne, 2006). This will show that motor responses in comparative judgements of emotions are more readily driven by purely bottom-up exogenous attention as pivoted by emotional salience of facial expression of emotion independently of task demands as well of lateralized stimulus presentation.

1.1. Spatial arrangement of a pair and spatial congruency with the left-to-right mental format

Performing a standard comparative judgement on a pair of facial expressions involves visual spatial attention, which is a key component for the processing of emotional stimuli. The perception of affective images is indeed modulated by spatial factors according to emotional lateralization in both humans and animals (Adolphs, Jansari, & Tranel, 2001; Pessoa, Kastner, & Ungerleider, 2002; Quaranta, Siniscalchi, & Vallortigara, 2007; Reuter-Lorenz & Davidson, 1981; Reuter-Lorenz, Givis, & Moscovitch, 1983; Root et al., 2006; Vallortigara, Chiandetti, & Sovrano, 2011; Wedding & Stalans, 1985). Furthermore, studies on clinical and healthy humans supported the idea that the representation of emotions, and specifically of the valence dimension of emotions, is lateralized, with positive valence being elaborated by the left side of the brain, and vice-versa for negative valence (Adolphs, Damasio, Tranel, & Damasio, 1996; Davidson, 1995; DeKosky, Heilman, Bowers, & Valenstein, 1980; Heilman, Scholes, & Watson, 1975; Kolb & Taylor, 1981; Landis, Assal, & Perret, 1979; McKeever & Dixon, 1981; Morrow, Vrtunski, Kim, & Boller, 1981; Robinson & Price, 1982; Robinson & Szetela; 1981; Silberman & Weingartner, 1986; Smith, Lee, Fountas, & King, 2006; Tucker, Watson, & Heilman, 1977). Notably, the lateralization of emotions produces effects linked to visual spatial attention, with faster responses for emotional displays presented in a spatially congruent position (Reuter-Lorenz & Davidson, 1981; Root et al., 2006). Effects of spatial congruency on the behavioural performance have been largely demonstrated using a variety of paradigms, like the divided visual field (Alves, Aznar-Casanova, & Fukusima, 2009; Everhart & Harrison, 2000; Wedding & Stalans, 1985), the comparison task (Jansari et al., 2011; 2000; Reuter-Lorenz & Davidson, 1981; Reuter-Lorenz et al., 1983), and the chimeric faces task (Bourne, 2010; Natale, Gur, & Gur, 1983; Prete, Laeng, Fabri, Foschi, & Tommasi, 2015).

These results suggest that the spatial congruency of image pairs in comparative judgements should be determinant for the regulation of the link between the mental representation of different types of magnitudes and the side of motor response. Nevertheless, no studies up to date investigating the SLE with comparative judgements used spatial congruency as a predictor variable: the type of direct comparison task is used in its place instead (Fischer, 2003; Jansari, at al., 2000; Lee et al., 2016; Patro & Haman, 2012; Patro & Shaki, 2016; Shaki et al., 2012), with the Δspeed calculated over the same target intensity when presented in the left and right visual hemifields (i.e., RTs for large magnitudes in congruent/right hemifield - RTs for large magnitudes in incongruent/left hemifield). Remarkably, the SLE pattern predicted by the effect of spatial congruency under the occurrence of a lateralized representation of intensities[1] has never been observed in previous studies on comparative judgements of non-symbolic attributes (Damjanovic & Santiago, 2016; Patro & Shaki, 2016; Shaki et al., 2012). In these studies, indeed a mixed SLE pattern was observed, arguably accounted for by instructional flexibility: SLE was in the standard direction when participants were asked to select the smallest member of a pair, vs. null (though weakly reversed) in the opposite type of task (Lee et al., 2016; Patro & Shaki, 2016; Shaki & Fischer, 2008; Shaki et al., 2012). Such a mixed SLE pattern generally found on non-symbolic magnitudes is in part compatible with a general SC bias, regardless of how well the spatial format of the representation of the considered attribute is well formed in memory (Shaki & Fischer, 2008).

1.2. Semantic Congruency: A novel stimulus-driven framework for comparative judgements of emotions

SC consists in a general tendency for extreme, rather than intermediate, magnitudes to be detected more readily amongst a pair of elements belonging to the same semantic category (i.e., small magnitudes-amongst globally small pairs/ large magnitudes-amongst globally large pairs) when the comparison task requires judging largest/smallest. Following Banks et al. (1976) such a bias might have goal-directed endogenous origin, linked to the prior distribution of the likelihood of encountering a given target intensity over the average magnitude of a pair. Such a likelihood function is inevitably biased toward larger values when the task requires searching for the large magnitudes within a pair and vice-versa when searching for small magnitudes. These opposed biases lead into a well-defined pattern of RTs of the judgements of the responses associated to the smallest vs. the largest choice: when RTs are plotted against the average magnitude of a pair they cross-over in a full interaction with the RT belonging to the smallest choice being below the RT belonging to the largest choice at low intensities, vice-versa at high intensities.

Inspiring from pioneering studies on comparative judgements (Audley & Wallis, 1964; Banks et al., 1975; 1976; Clark, Carpenter, & Just, 1973), we expect the SC bias (not the SLE) to affect the performance on facial expressions of emotion, thus producing an ESC. However, differently from classic studies, we modelled the expected ESC through a stimulus-driven (not goal-directed) theoretical framework of the comparative judgements of emotions.

Consider the two mixed-facial expressions pairs used in the current experiments and shown in Fig. 1: neutral-fully happy and neutral-fully angry with positive and negative average valence, $\mu_{valence}$, respectively, in congruent (Fig. 1A, contingency table, top row), and incongruent (Fig. 1A, contingency table, bottom row) spatial positions relative to the left-to-right mental format of valence. In these pairs, opposite emotions are coupled with the same intermediate intensity (i.e., a neutral facial expression), which is likely to elicit the cut-off of the emotional series[2].

According to the standard goal-directed interpretation of SC (e.g., Banks et al., 1976), ESC could rise given that when the task is to search for the angriest face the average target emotion intensities is negative (-50), with target emotions being 0, for the [0, 100] tuple-2, and -100, for the [0, -100] tuple-2, and positive ($+50$) when the task is to search for the happiest face, with target emotions being 100, for the [0, 100] tuple-2, and 0, for the [0, -100] tuple-2. It is likely that this polarity unbalance produced by the task will systematically bias the performance by pre-activating feature-based processing for negative or positive facial emotional features (Ahs, Davis, Gorka, & Hariri, 2014), thus determining a general tendency for emotional, rather than neutral, to be detected more readily amongst mixed-facial expressions pairs belonging to the same $\mu_{valence}$ domain ($\mu_{valence} = -50$ and $\mu_{valence} = +50$). Importantly, one major implication of ESC is a reversed SLE pattern for pairs of emotional magnitudes displayed in spatially incongruent position (Fig. 1A, C, purple lines and dots), but not for pair of emotions displayed in spatially congruent position (Fig. 1A, C, green lines and dots). However, given that this pattern of predictions produces a positive relationship between absolute emotion intensity and expected judgements' speed (Fig. 1B, black continuous line), it can similarly be accounted for by purely exogenous attentional factors assuming a fully stimulus-driven comparative judgement in the domain of emotion, with the Δspeed predicted by the difference between the absolute emotional intensity encoded from the right and the left image of each pair. We named such a direct Speed-Intensity Association, SIA-model being fully constrained and totally independent of the association (congruent/incongruent) between the code of motor response (left/right) and the spatial mental representation of valence (negative ↔ left; positive ↔ right). Notably, SIA is immaterial on the type of task and predicts ESC occurrence also with the indirect emotion identification task used in Experiment 3. Importantly, no such a prediction would rise from a standard goal-directed interpretation of a possible ESC pattern given that the two instructions involved in our indirect emotion identification task both lead to an unbiased likelihood function of target emotion intensities. Average target emotion intensities are indeed null both when the instruction is to search for an emotional face (with target emotions being $+100$ and -100, for the [0, 100] tuple-2 and the [0, -100] tuple-2, respectively), and when the instruction is to search for a neutral face (with target emotions being always null). Importantly, the occurrence of a task independent ESC would be consistent with a great amount of evidence showing a

[1] Let us consider two different types of mixed-facial expressions pairs with opposite average valence (negative: neutral-fully angry vs. positive: neutral-fully happy) presented in both spatially congruent and spatially incongruent condition, and the direct comparison task we used in Experiment 1 and 2: "choose the angriest", or the "happiest" between the two. According to spatial congruency, if we consider the responses belonging to the “choose the angriest” instruction, a negative Δspeed is expected for responses associated to negative average valence pair. The selection of the angry face is indeed facilitated when displayed in the left spatial congruent position with the left-to-right mental format of emotion, rather than the right spatial incongruent position. A null Δspeed is instead expected for responses associated to positive average valence pair as the target in these cases correspond to a neutral face which should not elicit any response speed bias. If we consider the responses belonging to the "choose the happiest" instruction, the spatial congruency effect predicts a similar increasing relationship between the Δspeed and the average valence of the pair, though globally shifted towards positive values. Note that, the SLE we described for comparative judgements of emotions is a by-product of a spatial congruency effect and should at least include two major main statistical effects: (a) average valence of the pair, with an increasing Δspeed as the average valence increases; (b) Type of Task, with a larger Δspeed when the instruction requires to choose the happiest rather than the angriest face.

[2] Throughout the paper the overall intensity of a pair is operationalized by its $\mu_{valence}$, keeping the valence of each emotion of a pair signed according to the absolute polarity of affects (positive for happiness, negative for anger), while fixing the extreme emotional intensity value to 100 (Fig. 1B, x-axis). For instance, a neutral-fully happy pair (Fig. 1A or C, right, top quadrant of contingency table) is mapped into a tuple of length 2 [0, $+100$] with the ordering encoding the spatial position of each image (first number-left; second number-right), and with positive $\mu_{valence} = 50$, i.e., $(0+100)/2$; a neutral-fully angry pair maps into a [0, -100] tuple-2, with negative $\mu_{valence} = -50$ (Fig. 1A or C, left, bottom quadrant of contingency table).

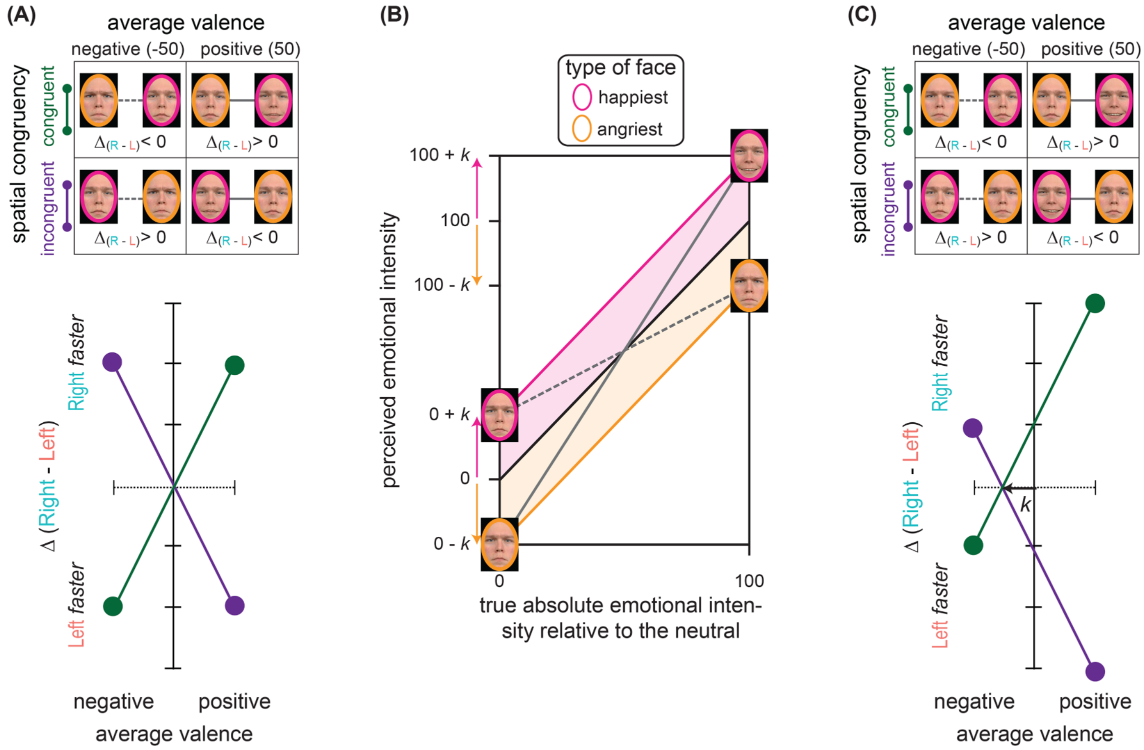

Fig. 1. ESC-pattern resulting from a stimulus driven framework for comparative judgements of emotions (mixed-facial expressions pairs considered). A and C: Predicted ESC in the $\mu_{valence} \times \Delta$speed Cartesian space resulting from the 2 Spatial Congruency (in rows and coded by colour) × 2 $\mu_{valence}$ (in columns) conditions depicted in the contingency table at the top of each graph in absence (A) and presence (C), respectively, of an unbalanced perception (anisotropy) of the type of face to be judged within the pair (happiest/angriest as coded by pink and orange coloured surrounding ellipse in the legend in B). The Δspeed is calculated according to the difference between the absolute emotional intensity of the right and the left image of each pair. In (A and C) according to ESC, but not SLE, in mixed-facial expressions pairs with spatially incongruent pairs with negative average intensities ([0, −100] tuple-2) right-sided responses should be faster than left sided responses, being the extreme emotion (angry facial expression) displayed on the right and the neutral on the left, thus leading into a positive $\Delta\text{speed} = |-100| - |0| = +100$ (purple dot in the top-left Cartesian quadrant). The opposite occurs in mixed-facial expressions pairs with large average magnitudes ([+100, 0] tuple-2) and $\mu_{valence} = +50$: left-sided responses are faster than right sided responses, being the extreme emotion (happy facial expression) displayed on the left and the neutral on the right, thus leading into a negative Δspeed (purple dot in the bottom-right Cartesian quadrant). Following the ESC, a standard SLE pattern should instead be expected for spatially congruent pairs, with faster right side responses for pairs with positive $\mu_{valence}$ (green dot in the top-right Cartesian quadrant), being the extreme emotion (happiness) now displayed on the right, and faster left side responses for pairs with negative $\mu_{valence}$ (green dot in the bottom-left Cartesian quadrant), being the extreme emotion (anger) now displayed to the left. In (B) exemplar re-mapping producing the emotional intensity with either negative or positive valence of the same intensities to be perceived either closer or farther from an unbiased solution predicting a one-to-one matching (black continuous line) between true and perceived absolute emotion intensity relative to the cut-off (the neutral), depending on the perceptual unbalance between the face within the pair that appear happiest (bounded by pink ellipses and connected by the pink continuous line) or angriest (bounded by orange ellipses and connected by the orange continuous line): this re-mapping produces the pattern of predictions in (C) which is consistent with an emotion anisotropy in the direction of a happiness advantage. The grey continuous and discontinuous lines in (B) connects faces belonging to mixed-facial expression pairs with positive and negative $\mu_{valence}$, respectively, while the pink and orange lines represent how the true intensity associated to the angriest or the happiest emotion within a pair relates with perceived emotion intensity, when their relationship is kept linear, and the angriest or the happiest emotions are perceived more negatively or positively respectively of about a constant factor (k). The oblique continuous black line in (B) instead represents an unbiased relationship between real and perceived emotion intensities and is consistent with the pattern of predictions in (A), in which the response speed for emotional targets is predicted to be the same irrespective from the type of face to be judged within the pair (the angriest or the happiest). Panel (C) shows how the pattern of Δspeed predicted by ESC relates with the anisotropy constant k: with the two lines describing the spatially congruent and incongruent conditions with a positive and a negative intercept, respectively, equal to $2k$ and intersecting in a point with null ordinate and $\mu_{valence} = -k$. Relative to the unbiased/isotropic case shown in (A) such a pattern produces a prediction in which positive and negative Δspeed are equally larger for positive $\mu_{valence}$ and smaller for negative $\mu_{valence}$.

prioritization in early sensory processing of affective emotional over neutral stimuli, with emotional stimuli evoking greater activation in relevant early visual cortical regions (Lane, Chua, & Dolan, 1999; Morris et al., 1998; Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005; Vuilleumier, Armony, Driver, & Dolan, 2003), and being more likely to capture visual spatial attention, drive decision-making and the response selection processes (Fox, 2002; Hansen & Hansen, 1994; Öhman, Flykt, & Esteves, 2001a; Öhman, Lundqvist, & Esteves, 2001b).

An unbalanced distribution of perceived targets' intensities might give rise to a further source of systematic error, as the one generally observed on the stronger SC bias for large (above the cut-off), rather than for small (below the cut-off) intensities (i.e., Banks et al., 1976). This unbalance, namely the *funnel effect* (Audley & Wallis, 1964; Marks, 1972), can be accounted for by considering the representation of symbolic intensities, like numerals, as being not perfectly symmetric relative to the reference frame of the series (Holyoak, 1978). A similar unbalance can rise in the domain of facial expressions of emotions generalizing the response competition model of Wallis & Audley (1964) dealing with the funnel effect in comparative judgements of pitch, and of brightness. In Fig. 1B we add or subtract a constant value (k) to the absolute emotional intensity of each facial expression of emotion of a pair depending on the relative polarity of the emotion to be chosen within the pair: positive for the facial expression that appear happiest (Fig. 1B continuous pink line) vs. negative for the facial expression that

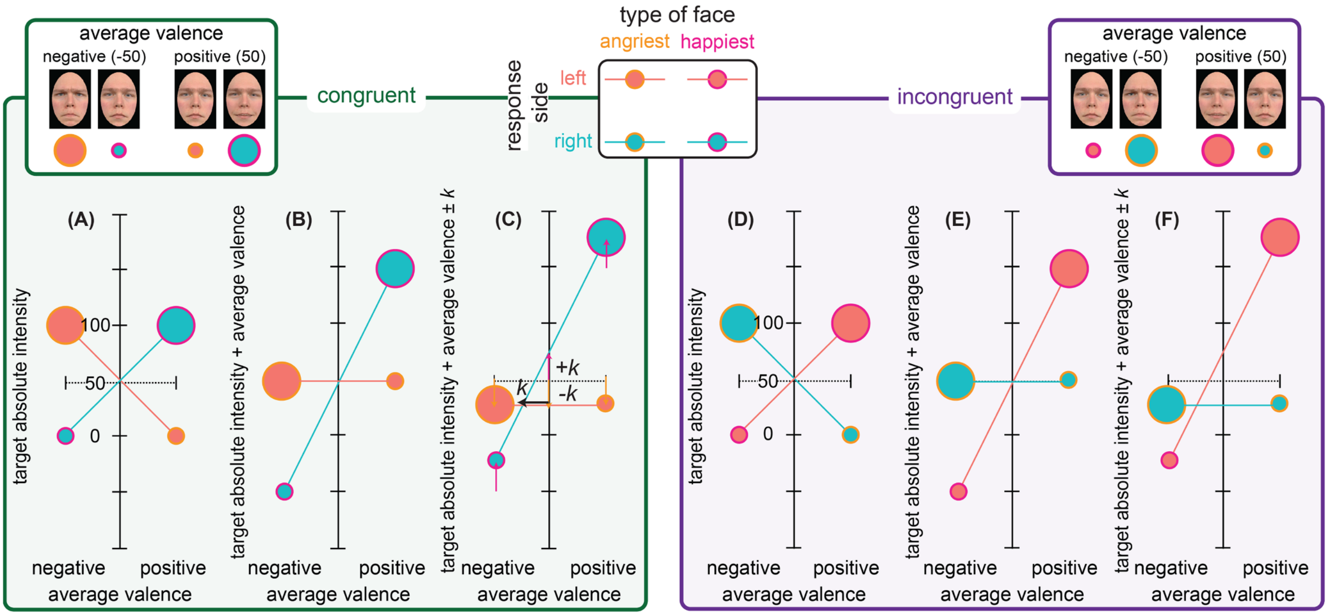

Fig. 2. The direct Speed-Intensity Association model, SIA. Illustrations of the three possible types of three-way interaction rising from the assumption that there is a direct association between response speeds and different sources of intensities intrinsic of stimulus pair used in our experiments in both spatially congruent (A, B, and C, [−100, 0] tuple-2 and [0, 100] tuple-2) and incongruent conditions (D, E and F, [0, −100] tuple-2 and [100, 0] tuple-2), and that they are equally weighted: ESC alone (in A, and D), ESC + SE (in B and E), ESC + SE + EA (in C and F). Emotion Anisotropy in C and F has been modelled including a $k = 25$ in order to be consistent with the pattern of Δspeeds discussed in Fig. 1. In all panels the three possible combinations of intensities are plotted as a function of the $\mu_{valence}$ of the pair with the size of the circles coding for the target absolute emotional intensity (small = neutral; large = emotional), the outline colour of the circles coding for the type of facial expression within the pair (pink = the happiest; orange = the angriest), and the fill colour of the circles coding for the Side of Response (red = left; blue = right). If speed directly corresponds to any one of the three combinations of intensities a Side of Response × Spatial Congruency × $\mu_{valence}$ interaction should raise qualified by well distinct statistical properties.

appear angriest (Fig. 1B continuous orange line). Notably this pairing of k values is task-independent being consistent across our two type of tasks (the direct valence comparison task and the indirect emotion identification task). This is an effective way to remap the facial expressions of emotions along the valence continuum so to produce a stimulus-driven happiness advantage (i.e., *emotion anisotropy*) as the one generally observed with realistic faces as those used in the current experiments (Becker, Anderson, Mortensen, Neufeld, & Neel, 2011; Becker et al., 2012; Fantoni & Gerbino, 2014; Fantoni, Rigutti, & Gerbino, 2016a; Juth, Lundqvist, Karlsson, & Öhman, 2005, Srivastava & Srinivasan, 2010). In particular, relative to the balanced ESC resulting from an isotropic representation of emotion intensity (Fig. 1B, black continuous line), such a remapping produces a reduction of the perceived difference between absolute emotional intensities of mixed-facial expressions pairs with negative $\mu_{valence}$ (Fig. 1C, left quadrants), relative to those with positive $\mu_{valence}$ (Fig. 1C, right quadrants). Under the assumption of a direct SIA the $\Delta speed_{congruent,\ negative} = -100 + 2k$ is expected to be largely smaller than the $\Delta speed_{congruent,\ positive} = 100 + 2k$ and vice-versa the $\Delta speed_{incongruent,\ positive} = -100 - 2k$ is expected to be smaller than the $\Delta speed_{incongruent,\ negative} = 100 - 2k$.

An emotion anisotropy could also lead to a faster discrimination between targets that have to be classified within a pair with globally positive rather than negative $\mu_{valence}$ producing a *size effect* in the domain of emotion (Moyer & Landauer, 1967). The comparative judgement will indeed be more difficult, thus requiring more time to be performed with those pairs that, depending on the representational placement of the cut-off, will be perceived as being more similar: this size effect is known to resemble a similar effect observed when magnitudes of physical stimuli are discriminated (e.g., Buckley & Gillman, 1974).

The operative purpose of our study is to test for the occurrence and nature of ESC (vs. SLE) thus controlling for the possible effect of the spatial congruency of a pair with the left-to-right mental format of an overlearned magnitude domain: facial expressions of emotions depicting affects opposed on the only domain of valence like anger vs. happiness.

2. Material and methods

In order to fulfill the purpose of our study we ran three complementary experiments and asked observers to perform a comparative judgement on emotions expressed by pairs of faces shown side-by-side viewed with (Experiment 1 and 3) or without (Experiment 2) foveation, so to control for the impact of lateralized emotional processes in our task (Bourne, 2006). Furthermore, in order to control whether our pattern of response speeds was pivoted by either an explicit (goal-directed) and/or an implicit (automatic) processing of valence we manipulated the type of task across Experiments. In particular, Experiment 1 and 2 involved a valence comparison task where the valence dimension of emotion was task relevant (choose the “happiest“/”angriest“ face), while Experiment 3 involved an emotion identification task where the valence dimension of emotion was task irrelevant (choose the emotional/neutral face). In all experiments stimulus pairs were balanced across our two fully randomly assigned types: (1) either mixed-facial expressions pairs (i.e., neutral-fully happy or angry pairs) with $\mu_{valence} = +50$ or -50 and target intensity = 0 or ± 100; (2) or complete-facial expressions pairs (i.e., happy - angry pairs) with $\mu_{valence} = 0$ with target emotional intensity relative to the neutral = ± 50 or ± 100. Participants were tested individually in two successive sessions distinguished by tasks requiring to judge faces belonging to facial expressions with opposite valence (happy-positive vs. angry-negative) or type (emotional-present vs. neutral-absent), with the ordering of the Type of Task counterbalanced across participants. In the next subsection we show how the SIA described in Section 1.2 (Fig. 1) can be formalized in order to provide quantitative predictions about the possible patterns of response speed rising from the comparative judgements of emotions elicited by both the direct and the indirect task used in our study, on the basis of the linear combination of intensities intrinsic of our emotional dyads (Fig. 2), likewise:

(1) the target absolute emotional intensity (Fig. 2A, D), formalizing ESC-alone and producing a *full cross-over effect* in the domain of emotion;
(2) the $\mu_{valence}$ formalizing a Size Effect (SE) in the domain of emotion leading overall response speeds to increase as $\mu_{valence}$ gets larger (Fig. 2B, E);
(3) an additive/subtractive constant k formalizing the Emotion Anisotropy (EA) possibly involving a general improvement of the performance for positive relative to negative choices within our real facial stimulus set (Fig. 2C, F), producing a *funnel effect* in the domain of emotion.

2.1. Mixed-facial expressions pairs

The ESC bias, as modelled by the SIA model, is in sharp contrast with SLE. It indeed predicts a cross-over vs. a flat pattern of Δspeed over $\mu_{valence}$ when pooling response speeds as a function of Spatial Congruency (not the Type of Task). Fig. 2 clarifies how, according to SIA, the cross-over pattern expected on the basis of ESC defining a $\mu_{valence}$ × Spatial Congruency interaction on Δspeed (Fig. 1A and C), is further qualified by a three-way $\mu_{valence}$ × Spatial Congruency × Response Side interaction on individual response speeds. In particular, depending on the relative presence of each intensity component (if ESC alone, ESC + SE or ESC + SE + EA) the expected three-way SIA interaction on individual response speeds might be of three different types. Specifically, we will statistically reveal which type (Type I, II or III) most likely account for our pattern of response speeds, as follows:

- Type I) ESC alone (Fig. 2A, D): will be revealed by a three-way $\mu_{valence}$ × Spatial Congruency × Response Side interaction, with no other main effects or interactions (*full cross-over effect*). In particular, the trend of the relationship between speeds and $\mu_{valence}$ for the conditions left-congruent (Fig. 2A, red circles with orange outline), and right-incongruent (Fig. 2D, blue circles with orange outline) will be informative: if characterized by a negative slope then ESC alone will be at work; on the contrary, if speeds are modulated by $\mu_{valence}$ (as in Fig. 2B, C, E, F), the SE and possibly an EA will also affect the performance;
- Type II) ESC + SE (Fig. 2B, E): will be revealed by a main effect of $\mu_{valence}$ (a *size effect*) combined with a three-way $\mu_{valence}$ × Spatial Congruency × Response Side interaction (*full cross-over effect*).
- Type III) ESC + SE + EA (Fig. 2C, F): will be revealed by a main effect of $\mu_{valence}$ combined with a two-way Spatial Congruency × Response Side interaction plus a three-way $\mu_{valence}$ × Spatial Congruency × Response Side interaction. In particular, the point of intersection between the lines describing the relationship between speeds and $\mu_{valence}$ for left- and right-hand responses in spatially congruent and incongruent conditions will be informative: if characterized by a negative $\mu_{valence}$ value then an emotion anisotropy favouring the choice of happiest face in the pair is at work with a strength proportional to k (black arrow in Fig. 2C): a *funnel effect* in the domain of emotion.

Notice that, the Type I and II SIA based combination (Fig. 2A, B, D, E) leads to a pattern of Δspeeds consistent with the unbiased relationship between real and perceived emotion intensities shown in Fig. 1A. Only the Type III SIA (Fig. 2C, F) based combination leads to a pattern of Δspeeds consistent with the biased relationship between real and perceived emotion intensities shown in Fig. 1C (*funnel effect*). Furthermore, Fig. 2 (B, C, E, F) are exemplars of specific Type II and III SIA based combination in which ESC and SE are equally weighted leading to a prediction in which the response speed associated to the neutral face belonging to the positive $\mu_{valence}$ pair should be similar to the response speed associated to the angry face belonging to the negative $\mu_{valence}$ pair. This would produce an almost flat relationship between speeds and $\mu_{valence}$ for left-hand responses in spatially congruent and right-hand responses in spatially incongruent conditions. However, more general predictions based on Type II and III SIA based combination are possible considering the general case of unequal weights. For instance, including a multiplying factor larger than 1 to $\mu_{valence}$ (operationalizing a larger weight of SE over ESC), would proportionally increase the steepness of the relationship between speeds and $\mu_{valence}$ for left-hand responses in spatially congruent and right-hand responses in spatially incongruent conditions, thus leading to the general SIA expectation that the response speed associated to the neutral face belonging to the positive $\mu_{valence}$ pair should be larger than the response speed associated to the angry face belonging to the negative $\mu_{valence}$.

Finally, even if a response encoding based on both spatial and motor congruency is at work in our task a reversal of the SLE pattern in spatially incongruent displays is not contemplated. According to the lateralization of emotion spatial incongruency should globally decrease response speed, relative to spatial congruency. However, given that the $\mu_{valence}$ of a mixed-facial expressions stimulus pair is immaterial on the spatial position of the target emotion, left-hand responses should result to be equally faster than right-hand responses for spatially congruent and incongruent negative pairs; and vice-versa for positive mixed-facial expressions stimulus pair. As a consequence, a response encoding based on spatial and motor congruency with the left-to-right mental format of emotion can lead to a significant main effect of $\mu_{valence}$ on the Δspeed that is accompanied by a $\mu_{valence}$ × Response Side interaction and a main effect of Spatial Congruency on individual response speeds.

2.2. Complete-facial expressions pairs

Complete-facial expressions pairs had a more explorative purpose, as both ESC and SLE predict that with these stimuli (with cross-range intensities over the neutral cut-off) no reliable Δspeeds should be observed, regardless of the spatial congruency of the pair with the right-to-left mental format. According to ESC since both intensities in complete-facial expressions pairs are equally away from the cut-off they should be categorized with the same easiness when belonging to one or the other valence polarity (positive if the target is the happiest vs. negative if the target is the angriest face). This should not produce any systematic performance's bias. However if, as consistent with Type III SIA combination, an emotion anisotropy is at work speeding up responses when the choice requires the selection of happiest rather than angriest faces then right-hand response speeds to spatially congruent and left-hand response speeds to spatially incongruent (both consisting in the selection of the happiest faces of the pair) should be equally faster than left-hand response speeds to spatially congruent and right-hand response speeds to spatially incongruent displays (both consisting in the selection of the angriest faces of the pair). In term of Δspeed this would produce a positive score for spatially congruent displays, opposed to a negative score for spatially incongruent displays.

As regards SLE, no Δspeed is predicted in both spatially congruent and incongruent displays as in the former case the right/left response should be equally facilitated by the presence of emotions in positions that are spatially congruent with the left-to-right mental representation of valence; while in the latter case the right/left response should be equally hindered by the presence of emotions in positions that are spatially incongruent with the left-to-right mental representation of valence. In general, a global slowdown of the response speeds could be observed if emotion lateralization is at work in our task in spatially incongruent relative to spatially congruent displays.

Finally, according to an *analog* representation of emotional intensities elicited by facial expressions, response speeds could increase with the target absolute emotional intensity relative to the neutral, in a way similar to the distance effect generally observed with numerals (Moyer & Landauer, 1967), with the amount of time required to decide which of a pair of emotions is larger (Experiment 1 and 2)/present (Experiment 3) decreasing as the valence difference between them increases.

2.3. Visual spatial attention: Experiment 1 vs. 2

Experiments 1 and 2 involved the same direct valence comparison task, but different visual spatial attention requirements, with Experiment 1 allowing for stimulus foveation, which is characterized by a self-terminating stimulus duration in line with participants' response, vs. Experiment 2 hindering stimulus foveation, through tachistoscopic stimulus presentation time. This latest manipulation was inspired by divided visual field paradigm so to better control for the lateralized presentation of emotional pairs (Bourne, 2006). This was relevant for understanding how hemispheric specialization of visual perception of facial expressions of emotions might relate with performance in our direct valence comparison task. In both Experiments, if ESC holds, no differences between them are expected. In presence or absence of stimulus foveation, indeed, the pattern of response speeds should be similarly consistent with ESC being it independent on the lateralization of emotion. However, if SLE holds then the two experiments should lead to different patterns of response speeds, as responses are expected to be driven by a response encoding based on spatial and/or motor congruency. Such hypothesis includes the idea that the encoding of a stimulus pair is supported by the lateralization of emotion whose effectiveness is maximized by presenting the pair of stimuli to each hemisphere through hindering foveation. Experiment 1 and 2 thus serve the purpose of providing converging evidence on the process governing the encoding of motor responses during comparative judgements of emotions.

The presence or absence of any difference between experiments may also inform about a debated issue on SC, as the one about its locus (Shaki & Algom, 2002): whether it occurs at early stages of decision processing, as showing up under brief and rapid stimulus exposition (e.g., Duncan & McFarland, 1980; Marschark & Paivio, 1979; Marschark & Paivio, 1981), or at latest stages of decision processing, as requiring a sustained stimulus elaboration (e.g., Banks & Flora 1977; Cech, 1995; Cech, Shoben, & Love, 1990). Finally, the brief stimulus exposition used in Experiment 2 should increase the likelihood of orienting attention towards salient and perceptually relevant stimulus features thus reducing the role of endogenous over exogenous attention in shaping responses (Pessoa et al., 2002).

2.4. Task demands: Experiment 1 vs. 3

Observers performing the comparative judgements of emotions in Experiments 1 and 3 underwent the same freeviewing conditions (self-terminating stimulus duration) but under different task demands. In particular, the valence comparison task used in Experiment 1 likely substantiate a controlled effect of valence as an explicit processing of valence was relevant for solving the task at stake (to judge which is the happiest/angriest between the two facial expressions). Vice-versa the emotion identification task used in Experiment 3 likely substantiate an automatic effect of valence as involving its implicit processing being the task irrelevant on the valence dimension. This manipulation is inspired by previous studies on SNARC (e.g., Dehaene et al., 1993; Dehaene, Dupoux, & Mehler, 1990), and SLE in non-numerical domains (Fumarola et al., 2014; 2016; Prpic et al., 2018). These strands of studies consistently show that the explicit processing of a magnitude elicits a strong spatial association with motor response, and that such an association is elicited also by an implicit processing, thus showing its automaticity (for a review see Macnamara, Keage, & Loetscher, 2018).

In both Experiment 1 and 3, if ESC holds and is purely stimulus-driven no differences between them are expected. Independently on task demands (being it implicit or explicit) the response speed should be similarly modulated by the direct association between absolute emotional intensity and motor reactivity. However, if the occurrence of ESC also depends on the biasing effect of explicit semantic elaboration of the task then ESC could be impaired under the indirect task condition of Experiment 3, relative to other intensity components, like the $\mu_{valence}$ involved in SE occurrence, that according to SIA model are more likely to be task independent.

Furthermore, if SLE holds then the two experiments could lead to different patterns of response speeds as responses are expected to be driven by a response encoding which is flexible depending on the task. There is evidence that using explicit comparative instructions such as the direct valence comparison task we used in our Experiment 1 and 2, compared with the indirect emotion identification tasks of Experiment 3 might exert different SNARC-like compatibility effect (e.g., Prpic et al., 2016; 2018). In particular, as regards the spatial mental representation of the valence evoked by isolated facial expressions of emotions, there is contrasting results from Holmes and Lourenco (2011), on the way direct and indirect tasks differently underpin spatial association effects. Authors found that an indirect task leads into a rather strong spatial association effect consistent with a left-to-right mental representation of emotion intensity (with faster right-hand response as happiness or anger grew larger), while a direct task lead into a spatial association effect consistent with a left-to-right mental representation of valence (with faster left-hand response for hangry vs. faster right-hand response for happy faces), only when the task is to explicitly judge the presence/absence of anger (but not happiness).

Experiment 1 and 3 thus serve the purpose of providing converging evidence on the process governing the encoding of motor responses during our direct and indirect comparative judgements, being them automatic and task independent or controlled and task dependent.

2.5. Participants

Data from 125 students of the University of Trieste, all with normal/corrected-to-normal visual acuity, were included in the analysis. All participants were Italian speakers with a left-to-right reading direction, they were naïve to the purpose of the experiment (as confirmed by the result of post experimental questioning on compliance, see the Procedure section), which lasted about 30 min. Participants took part in the current study in exchange for course credit. Our sample of participants included all types of hander (with handedness categorized according to their scoring at the Edinburgh handedness inventory, Oldfield, 1971) according to the idea that a heterogeneous sample should be more informative rather than a specific sub-sample exclusively composed by right-handers, especially in studies involved with brain lateralization and motor response code (Willems, Van der Haegen, Fisher, & Francks, 2014). Seventy-nine participants were randomly assigned to the two conditions of instruction ordering (happy first, angry first) of Experiment 1 or 2. The remaining 46 participants, successively, were randomly assigned to the two instruction ordering conditions of Experiment 3 (neutral first, emotional first).

Experiment 1 (direct valence comparison task with foveation) included data from 40 participants (33 female; mean age = 22.97, SD = 4.46; age range = [18 – 39]; mean handedness = 36.78, SD = 63.40; min. to max. range = [-100 – +100], with 20 participants performing the experiment in the "angry first" ordering condition), Experiment 2 (direct valence comparison task without foveation) included data from 39 participants (36 female; mean age = 20.49; SD = 2.75; age range = [19 – 34]; mean handedness = 76.46; SD = 29.86; min. to max. range = [-66 – +100], with 19 participants performing the experiment in the "angry first" ordering condition), and Experiment 3 (indirect emotion identification task with foveation) included data from 46 participants (26 female; mean age = 22.41; SD = 7.12; age range = [18 – 57]; mean handedness = 53.37;

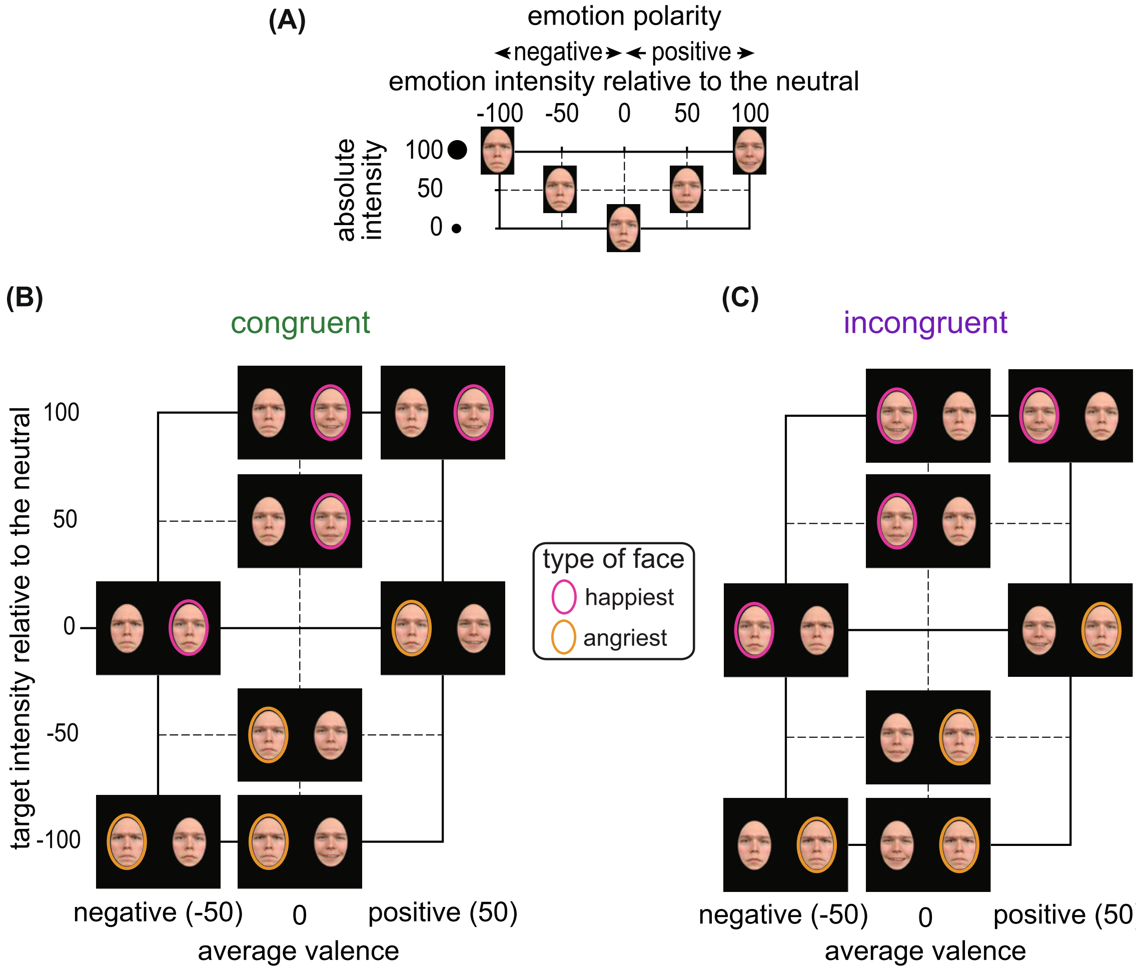

Fig. 3. Facial stimuli and emotional stimulus pairs used in our experiments. (A) Exemplar of facial stimuli (identity not used in our experiments who gave permission for the usage of his image) used for the generation of the 8 types of emotional stimulus pairs used in our experiment (B and C congruent and incongruent Spatial Position, respectively). Stimuli are depicted in a Cartesian space with the per cent morph continuum recoded: (1) according to emotion intensity relative to the neutral (along the x-axis) so that fully angry faces and fully happy faces defines the negative and positive extreme values of the x-axis, respectively; (2) according to absolute emotion intensity (along the y-axis), with the neutral face = 0 and the fully emotional faces (irrespective of the type of emotion) = 100. (B) and (C): emotional stimulus pairs resulting by combining the facial stimuli in A in the $\mu_{valence}$ × target emotion intensity relative to the neutral Cartesian space for the spatially congruent (B, happiest face on the right) and incongruent (C, happiest face to the left) conditions. Our 8 types of stimuli, depending on the type of target face (happiest/angriest coded by pink and orange coloured surrounding ellipses) determined 16 experimental conditions (8 congruent in B and 8 incongruent in C). Notably the colours correspond with the two type of instructions used in the direct valence comparison paradigm of Experiment 1 and 2 (pink for "choose the happiest", orange for "choose the angriest"), but not with the two type of instructions used in the emotion identification paradigm of Experiment 3 (target faces for the "choose the emotional" instruction are surrounded by both pink and orange ellipses, when $\mu_{valence} = +50$ and $\mu_{valence} = -50$, respectively, and vice-versa for the "choose the neutral" instruction). Throughout the paper, stimuli with $\mu_{valence} = 0$ are named complete-facial expressions pairs, while stimuli with $\mu_{valence} = \pm 50$ are named mixed-facial expressions pairs, with complete-facial expressions pairs including values of target absolute emotion intensity of 50 or 100, while mixed- facial expressions pairs including values of target absolute emotion intensity of 0 or 100.

SD = 39.60; min. to max. range = [-100 – +100], with 22 participants performing the experiment in the "neutral first" ordering condition). Data from eight additional participants (two from Experiment 1, two from Experiment 2, and four from Experiment 3) were discarded for having not reached a response accuracy level during the training session beyond the chance level in our 2 Alternative Forced Choice, 2AFC, task (i.e., 0.75). Data from one participant of Experiment 2, and eight participants of Experiment 3 were discarded for they having reached a level of accuracy averaged across the 16 different pairs resulting from our experimental design (see Fig. 3 and Apparatus, Stimuli and Design subsection) below 0.5.

The study was approved by the Research Ethics Committee of the University of Trieste in compliance with national legislation, the Ethical Code of the Italian Association of Psychology, and the Code of Ethical Principles for Medical Research Involving Human Subjects of the World Medical Association (Declaration of Helsinki). Participants provided their oral informed consent prior to inclusion in the study. Participants responses were filed in raw documents.

2.6. Apparatus, stimuli, and design

Participants sat in a dark laboratory and they were positioned on a height adjustable chinrest in order to keep their head stabilized and their eyes centred on a CRT CID421 Barco monitor (19″; 1024 × 768 pixels; 75 Hz refresh rate; 50% brightness and 90% contrast) at a viewing distance of 58 cm. Stimulus presentation and response recording were controlled by a custom made E-Prime 2.0 program installed on a Dell, Optiplex 580, AMD Phenom™ II X2 B57 Processor (3.2 GHz) with Operating System Windows 7 Professional (32 bit). A Five keys Serial Response Box (Psychology Software Tools, Inc.) was positioned on the tabletop between the participants and the monitor along the participants' sagittal axis, with only the two extreme keys being activated during the experiment (keys' distance = 8 cm). The distance of the response box was carefully adapted to the participant harm length in order to ensure a comfortable posture according to previous researches on reaching comfort, at about 40% of the arm length (Fantoni & Gerbino, 2014; Mark, et al., 1997).

Two different sets of emotional facial expressions were utilized to compose our emotional stimulus pairs in the training and in the experimental sessions.

For the training sessions we utilized black and white drawings of facial expressions created according to an online tutorial on human anatomy (Medlej, 2012). A single unisexual model depicting an angry, a happy or a neutral facial expression was used. The full combination of these three facial poses gave rise to 6 pairs resulting from the combination of 3 pair types (angry-happy, neutral-happy, and neutral-angry) × 2 Spatial Congruency. The training session lasted 18 trials including the full random presentation of these 6 pairs each repeated for about 3 times.

For the experimental sessions (in both task conditions) we utilized coloured photographs of human facial expressions taken from the same facial set used by Fantoni et al. (2016a, but see also Fantoni & Gerbino 2014) including 8 Caucasian characters (4 male models: number 20, 30, 46, and 71; 4 female models: number 1, 2, 4, and 19) selected from the Radboud University Nijmegen set (Langner et al., 2010). For each of the 8 characters we utilized faces displaying two basic emotions (fully happy and fully angry), and one neutral facial expression. We followed the exact same morphing technique used by Fantoni et al. (2016a) in order to generate two additional intermediate facial expressions one for each tested emotion. Using a sophisticated morphing algorithm that implements the principles described by Benson and Perrett (1993), for each character two synthetic images were extracted one from the neutral-to-happy morph continuum and the other from the neutral-to-angry morph continuum. Both morphed images contained a 50% mixture of the original neutral expression and either the original expressions of emotion of happiness or the original expression of emotion of anger. Fig. 3A shows an exemplar of the five facial expressions of emotions utilized in our experiments in order to compose our emotional pairs (either complete- or mixed-facial expressions pairs).

All facial stimuli (both drawings and photographs used in the training and experimental session respectively) were treated in the same way in order to include equal geometrical and feature-based properties. They were masked by an oval vignette hiding hair and ears and presented on a black surround. Each vignette was centered on the horizontal axis of the screen, occupied a visual size of 12.0° × 16.8°, and was displayed so that its margin was displaced relative to the centre of the screen of about 3.8°. Such an arrangement defined emotional stimulus pairs in which the horizontal distance between the centres of the two facial expressions of emotions equal 19.6° (nose-to-nose distance). According to results of Bayle, Schoendorff, Hénaff, and Krolak-Salmon (2011), the eccentricity of our target image involved in the simultaneous presentation of our emotional stimulus pairs (9.8°) should guarantee a lateralized encoding of emotion though leading into an emotion detection performance well above chance level, even when the time of simultaneous presentation was below the time needed for foveation, as in the case of our Experiment 2.

As depicted in Fig. 3C-B, each set of 5 facial stimuli belonging to the same character were paired in order to obtain 4 types of mixed-facial expressions pairs resulting from the combination of 2 Spatial Congruency (spatially congruent, spatially incongruent) × 2 $\mu_{valence}$ (negative and positive), and 4 types of complete-facial expressions pairs resulting from the combination of 2 Spatial Congruency × 2 Target Absolute Emotional Intensity (50 and 100 per cent). Combining these 8 types of stimuli with the Side of Response (left/right) determined the 16 experimental conditions of our experimental design.

Fig. 3 shows how all emotional stimulus pairs (n = 8) in both the spatially congruent (Fig. 3B, the angriest-negative facial expression on the left side and the happiest-positive facial expression on the right side), and spatially incongruent condition (Fig. 3C, the angriest-negative facial expression on the right side and the happiest-positive facial expression on the left side), are combined in the Cartesian Space with the $\mu_{valence}$ along the x-axis and the target intensity relative to the neutral along the y-axis (the coloured outline codes for the type of face within the pair being it the angriest or the happiest, see the legend).

Our set of emotional stimulus pairs determined a total of 64 stimuli, which was the total of the stimuli presented during each experimental session. Such a number resulted by the following factorial combination: 8 characters (4 male, 4 female) × 4 Type of Stimuli (2 mixed-facial expressions pairs differing in term of $\mu_{valence}$ + 2 complete-facial expressions pairs differing in term of Target Absolute Emotional Intensity) × 2 Spatial Congruency (congruent, incongruent). Each different type of stimulus pair appeared only once in each experimental session.

Considering the two sequential tasks included in our experiments (the valence comparison tasks in Experiment 1 and 2, and the emotion identification tasks in Experiment 3), the complete 2 × 2 × 3 × 2 cross-over design included the balancing variable Task Ordering (happy first, angry first in Experiment 1 and 2; emotional first, neutral first in Experiment 3), the Spatial Congruency of the pair with the left-to-right mental format (spatially congruent, spatially incongruent), the $\mu_{valence}$ (-50, 0, 50), and the Response Side (left-hand, right-hand). The ordering of the tasks was balanced across participants in order to avoid possible effects of the ordering of the series. Furthermore, the $\mu_{valence} = 0$ condition included two additional levels of Target Absolute Emotional Intensity relative to the neutral that in our design are tested by means of post-hoc *t*-tests only in Experiment 1 and 2 in which the categorization was qualified by the task.

2.7. Procedure

The same procedure was applied in all 3 experiments. The procedure included the following sequence of events: (a) Edinburgh handedness inventory; (b) oral instructions about the structure of the experiment as subdivided into 4 phases (training 1 + session 1, training 2 + session 2), and anticipating the difference between stimuli in the training and in the experimental session (i.e., drawing vs. photographs); (c) a first training session introduced by written on-screen instructions; (d) a first experimental session introduced by written on-screen instructions (same as those of the training); (e) a second training session introduced by written on-screen instructions differing from the first instructions for the only type of emotional face to which the participant was asked to choose for; (f) a second experimental session introduced by written on-screen instructions (same as those of the second training); (g) post-experimental questioning.

The training blocks was designed having in mind two goals: (a) familiarization with the procedure (requiring to judge opposite valence emotions within pairs including schematized happy, angry as well as neutral, facial expressions for the sake of comparison or identification depending on the Experiment); (b) elimination of participants with an inadequate level of accuracy. Only participants with more than 75% correct responses during the training entered the experimental session.

For all participants, the complete experiment included: (1) 36 training trials, lasting about 3.7 min., in Experiment 1 and 3 and 3.5 min. in Experiment 2; and (2) 128 experimental trials lasting about 13 min. in Experiment 1 and 3 and 12.5 min. in Experiment 2 (time for reading the instructions included).

Written instructions informed participants that they would have been asked to select among a pair of horizontally aligned facial expressions of emotions which of the two appear to be the angriest/happiest (in Experiment 1 and 2), or the emotional/neutral (in Experiment 3). Participants were instructed to press on the response box with the index finger the key with the spatial position

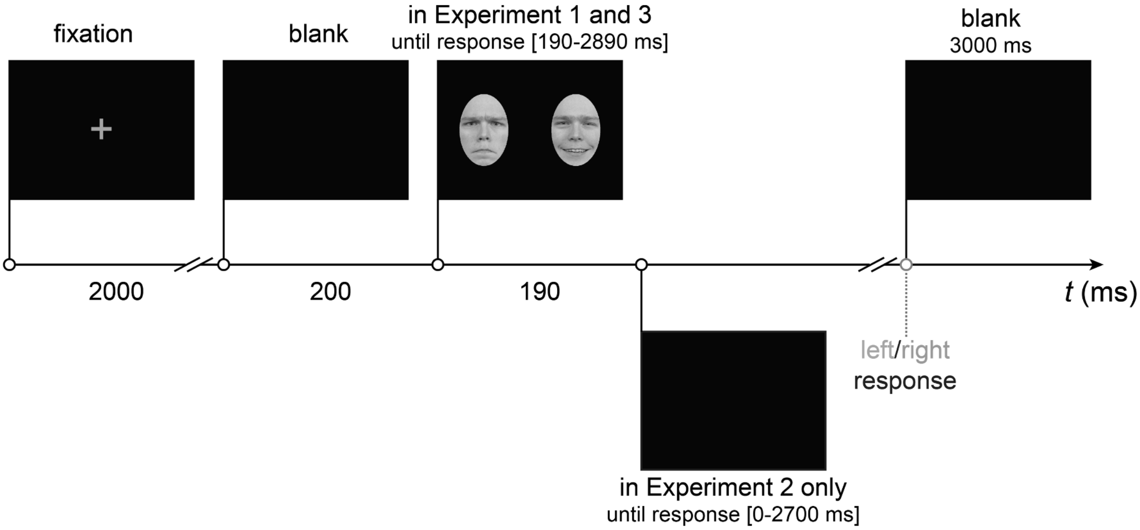

Fig. 4. Trial temporal structure. This specific example illustrates the subset including a mixed-facial expressions stimulus pair with positive $\mu_{valence}$ in spatially congruent position, i.e., a [0, +100] tuple-2. Depending on the task (in Experiment 1 and 2, "choose the angriest/happiest" in the pair, in Experiment 3, "choose the neutral/emotional" in the pair), the target face was either the one on the left or the one on the right (coinciding with the response keys left/right). Depending on the Experiment, the stimulus was either self-terminated by the participant response (in Experiment 1 and 3, lasting from a minimum to a maximum duration of 190 to 2890 ms, respectively), or terminated after 190 ms by a blank screen (in Experiment 2, lasting from a minimum to a maximum duration of 0 to 2700 ms, respectively).

corresponding with the spatial position of the target (left key press for target on the left vs. right key press for target on the right). Written instructions required participants to use the green cross mark to support steady fixation before and during stimulus presentation, to keep in mind that also neutral facial expression might be a target, and to be fast and accurate, considering that stimulus presentation was either terminated by the response, in Experiment 1 and 3, or self-terminated after a short lag period, in Experiment 2. The experimenter also required the participant to keep a steady and comfortable positioning of their hands upon the response box, with the right index finger placed upon the extreme right key and the left index finger placed upon the extreme left key of the response box.

As shown in Fig. 4, participants thus performed the same comparative judgements of emotions, either through a direct comparison task (in Experiment 1 and 2), or through an indirect identification of emotion task. At the beginning of each trial a 26 pixel-wide green fixation cross was displayed at the centre of the screen for about 2000 ms. This was substituted by a brief refreshing blank screen of about 200 ms. The emotional stimulus pair was then displayed until the participant pressed one of two response keys with his/her left/right hand (stimulus duration range from a minimum of 190 ms to a maximum of 2700 ms above which the response was skipped) in Experiment 1 and 3, while lasted on the screen for about 190 ms (at 75 Hz refresh rate, given the non-integer frame duration of 13.3 ms, this duration corresponded to a stimulus duration in the [176.6 ms − 203.3 ms] range, SD = 35.361) in Experiment 2. In Experiment 2 a blank screen substituted the stimulus until the key press (maximum duration = 2700 ms), after which a low tone lasting 400 ms signalled the response recording and a blank screen lasting about 3000 ms followed. The next trial was thus presented.

At the very end of the experiment, all participants were screened for compliance through post-experimental questioning asking them: (1) whether in any time, during the two experimental blocks, they got the feeling to have acted applying different/similar motor strategies; and (2)—in the case they answer "different"—to describe the reasons at the basis of such a difference. Post-experimental questioning demonstrated that all participants were unaware of the hypothesis of the study. All of them indeed reported that they were applying a similar action mode during the execution of the task in the two blocks.

2.8. Data analysis

In Experiments 1, 2 and 3, individual values of the Δspeeds used to measure synthetically how, in our comparative judgements, the side of motor response (right- vs. left-hand) was affected in positive (if the response speed of the right-hand motor response was larger than the left-hand motor response)/negative (if the response speed of the left-hand motor response was larger than the right-hand motor response) directions by the $\mu_{valence}$ of emotion depending on the Spatial Congruency of the pair with the left-to-right mental format of valence, were calculated on individual values of response speed, computed as the inverse of response time (i.e., 1000/RT; with RT in ms). As discussed by Whelan (2008, but see also Ratcliff, 1993), the rationale for using such a transform of response latencies -rather than raw data- resides on: (1) the homologous nature of the inverse transformation with the notion of speed and response accuracy, and (2) the normalization of the skewed distribution of response latencies leading into an increased statistical power and a reduced likelihood of outlier removal. Each individual's speed value was the reciprocals of RT of a valid correct response, i.e., RTs associated to correct responses above and below the [200 ms, 2500 ms] response time limits. As regards Experiment 3, given that responses to complete-facial expressions pairs could not be categorized as correct/incorrect provided the specific indirect nature of the task, we decided to limit the analysis to half of our trials: specifically, to those featuring the 4 types of mixed-facial expressions pairs resulting from the combination of 2 Spatial Congruency × 2 $\mu_{valence}$. Our temporal criterion thus lead to the exclusion of 4 trials out of the of total correct responses in Experiment 1 (4998 trials corresponding to 97.6% of all trials), 2 out of the of total correct responses in Experiment 2 (4518 trials corresponding to 90.5% of all trials), and 1 out of the of total correct responses in Experiment 3 (3342 trials corresponding to 90.1% of all mixed-facial expressions pairs trials). Finally, we excluded from the analysis of all scores falling outside ± 3 standard deviations from the predicted value of the best generalized linear mixed effect regression model including all experimental factors and interactions: 77 trials corresponding to 1.54% of the total of correct responses in Experiment 1, 73 trials corresponding to 1.64% of the total of correct responses in Experiment 2, and 51 trials corresponding to 1.52% of the total of correct responses in Experiment 3. This barely lenient cut-off criterion for outlier exclusion was selected to produce more uniform estimates of speeds effects across unbalanced conditions relative to more conservative cut-offs also considering that the loss involved in our technique might lead to an unbalance along the levels of our designs (i.e., see Miller, 1991; Ratcliff, 1993).

The combination of exclusion criteria we used allowed us to extract for each participant of Experiments 1 and 2, 8 individual scores of Δspeeds resulting from the difference between right and left response speeds to our 4 Type of Stimuli (2 complete-facial expressions pairs plus 2 mixed-facial expressions pairs) × 2 Spatial Congruency level (spatially congruent, spatially incongruent) of our experimental design, averaged across valid trials. In Experiments 3, 4 individual scores of Δspeeds were analysed keeping the difference between average right and left response speeds resulting from responses to the 4 mixed-facial expression pairs averaged across valid trials. On average the number of valid trials per condition over the 8 repetitions included in our experiments was equal to: 7.68 ± 0.64 SD range = [4, 8] in Experiment 1 (corresponding to an average accuracy of about 0.96 ± 0.08 SD and an average normalized deviation of the % correct from the 75% chance level in our 2AFC of about 1.37 ± 0.52 SD); 7.12 ± 1.30 SD range = [3, 8] in Experiment 2 (corresponding to an average accuracy of about 0.89 ± 0.16 SD and an average normalized deviation of the 75% chance level in our 2AFC of about 0.88 ± 1.07 SD); and 7.35 ± 1.07 SD range = [2, 8] in Experiment 3 (corresponding to an average accuracy of about 0.92 ± 0.13 SD and an average normalized deviation of the 75% chance level in our 2AFC of about 1.10 ± 0.87 SD).

To provide an additional converging measure of accuracy in our two tasks, beyond individual speeds and Δspeeds we also analyzed the normalized deviation of the % correct from the chance level in our sequential 2AFC task, out of 8 repetitions of the 16 experimental conditions.

Distributions of individual values of performance indices (response speed, Δspeeds, normalized per cent correct), were analyzed using linear mixed-effect (*lme*) models, with participants and the balancing factor (the Task Ordering) as random intercepts, with a structure selected according to a step-wise procedure contrasting *lmes* of increasing complexity depending on the number of fixed effects, modelled by the factors of our experimental design: μ_{valence}, Target Absolute Emotional Intensity, Spatial Congruency, Response Side. (Bates, 2010; Bates, Mächler, Bokler, & Walk, 2014; Fantoni, Rigutti, Piccoli, Sommacal, & Carnaghi, 2016b). The Handedness (small vs. large categorized according to median split) was used as a covariate in our *lme* model so to control for any possible dependence of our effects from the embodiment of action-perception linkage (Casasanto, 2009; Casasanto, 2011). This follow from the idea that a positive relationship between degree of handedness and degree of cerebral lateralization could be a determinant of the processing of facial expressions of emotions, with the effect of spatial congruency being known to be maximally reliable on fully right-hander participants that are known to be well lateralized (Bourne, 2008; Bryden, 1965). Models were fitted using Restricted Maximum Likelihood. We followed Bates (2010) and used this statistical procedure to obtain two-tailed *p*-values by means of likelihood ratio test based on $\chi 2$ statistics when contrasting *lme* with different complexities (for a discussion of advantages of a *lme* procedure over the more traditional mixed models analysis of variance see Kliegl, Wie, Dambacher, Yan, & Zhou., 2011). AIC-index and BIC-index were used as a supporting comparative measure of the goodness of fit. Furthermore, we used type 3-like two tailed ***p-values*** for significance estimates of *lme*'s fixed effects and parameters adjusting for the *F*-tests the denominator degrees-of freedom with the Satterthwaite approximation based on SAS proc mixed theory. Among the indices that have been proposed as reliable measures of the predictive power and of the goodness of fit for *lme* models we selected the concordance correlation coefficient r_c, which provides a measure of the degree of agreement between observed and predicted values in the $[-1, 1]$ range (Rigutti, Fantoni, & Gerbino, 2015; Vonesh & Chinchilli, 1996). Post-hoc tests were performed on *lme* estimated coefficients with paired two sample *t*-tests with unequal variance. As a measure of significant effect size we provided Cohen's *d*. Raw data for all experiments can be found as [dataset] supplementary data.

3. Results and discussion

3.1. Preliminary analyses

3.1.1. Speed-accuracy relationship

We executed two preliminary *lme* analyses on the relationship between individual accuracy values (normalized per cent correct) and response speed averaged within all cells of the overall experimental design and controlling for the 3 main experimental factors in Experiment 1, 2, and 3: the μ_{valence}, the Spatial Congruency, and the Response Side. The *lme* analysis in Experiment 1 revealed a reliable speed-accuracy positive correlation ($F_{1,\ 146.1} = 31.49$, $p < 0.001$) resembling the requirements of our experimental task (to be both fast and accurate). Accuracy increased of about 0.078 ± 0.010 per cent every unit increment of speed ($t = 7.45$, $df = 259.74$, $p < 0.001$, $d = 0.925$). No other main effects or interaction were revealed ($\chi^2_{14} = 31.55$, $p = 0.005$), with the 4 *df* model with the speed as the only predictor reaching the lowest AIC-index (1463), relative to the 18 *df* model including all experimental factors (1467), and no reliable reduction of the concordance correlation coefficient (18 *df* model, $r_c = 0.32$, 95%CI [0.27, 0.36] vs. 4 *df* model, $r_c = 0.27$, 95%CI [0.22, 0.30]). A similar result was obtained for the analysis of the speed-accuracy relationship obtained in Experiment 2 ($F_{1,\ 137.85} = 37.85$, $p < 0.001$) and 3 ($F_{1,\ 310.73} = 18.73$, $p < 0.001$). Again accuracy increased as speed increased in both experiments, at a rate of about 0.19 ± 0.033 per cent ($t = 5.58$, $df = 379.9$, $p < 0.001$, $d = 0.572$) in Experiment 2, and of about 0.226 ± 0.024 per cent ($t = 9.54$, $df = 336.09$, $p < 0.001$, $d = 1.04$) in Experiment 3. No other reliable main effects or interaction raised in both Experiment 2 and 3 from the contrast of models including the speed as the only predictor (Experiment 2: AIC = 560, $r_c = 0.41$, 95% CI [0.36, 0.45]; Experiment 3: AIC = -7.38, $r_c = 0.59$, 95% CI [0.27, 0.91]) vs. models including as predictors the speeds with all experimental factors and all their combinations (Experiment 2: AIC = 655, $r_c = 0.31$, 95% CI [0.29, 0.34]), $\chi^2_{14} = 122.05$, $p = 0.001$; Experiment 3: AIC = -137.59, $r_c = 0.55$, 95% CI [0.23, 0.88]), $\chi^2_{14} = 158.21$, $p = 0.001$). The lack of reliable interaction between accuracy, speeds and other experimental factors supports our decision to focus the main analyses of our Experiments on indices of comparative judgement performance based on speed alone (i.e., individual response speeds and Δspeeds).

3.1.2. Handedness

Two farther preliminary analyses were conducted in order to test for the possible effects of handedness on judgement's speeds in Experiment 1, 2 and 3 when controlling for Response Side, Spatial Congruency and μ_{valence}. In Experiment 1 and 3 the *lme* analyses revealed a marginally significant $\mu_{\text{valence}} \times$ Handedness interaction (Experiment 1: $F_{1,\ 4863.1} = 4.36$, $p = 0.037$; Experiment 3: $F_{1,\ 2646.4} = 6.52$, $p = 0.011$). The speed of response increased more steeply as a function of μ_{valence} for those observers collecting a large (Experiment 1: 0.0035 ± 0.00018; Experiment 3: 0.0026 ± 0.00015) rather than a low (Experiment 1: 0.0030 ± 0.00019; Experiment 3: 0.0026 ± 0.00016) score on the Edinburgh handedness inventory (Experiment 1: $t = 1.97$, $df = 4875$, $p < 0.04$, $d = 0.056$; Experiment 3: $t = 2.53$, $df = 2658$, $p < 0.02$, $d = 0.1$). No other interactions or main effects due to handedness were observed. In Experiment 2, the only significant effect associated with handedness regards its interaction with the Response Side ($F_{1,\ 4462.7} = 17.45$, $p < 0.001$): right-handers were faster when the target emotion was displayed to the right (1.47951 ± 0.094), rather than to the left (1.438 ± 0.094, $t = 2.64$, $df = 1825$, $p = 0.008$, $d = 0.124$). The opposite occurred with left-

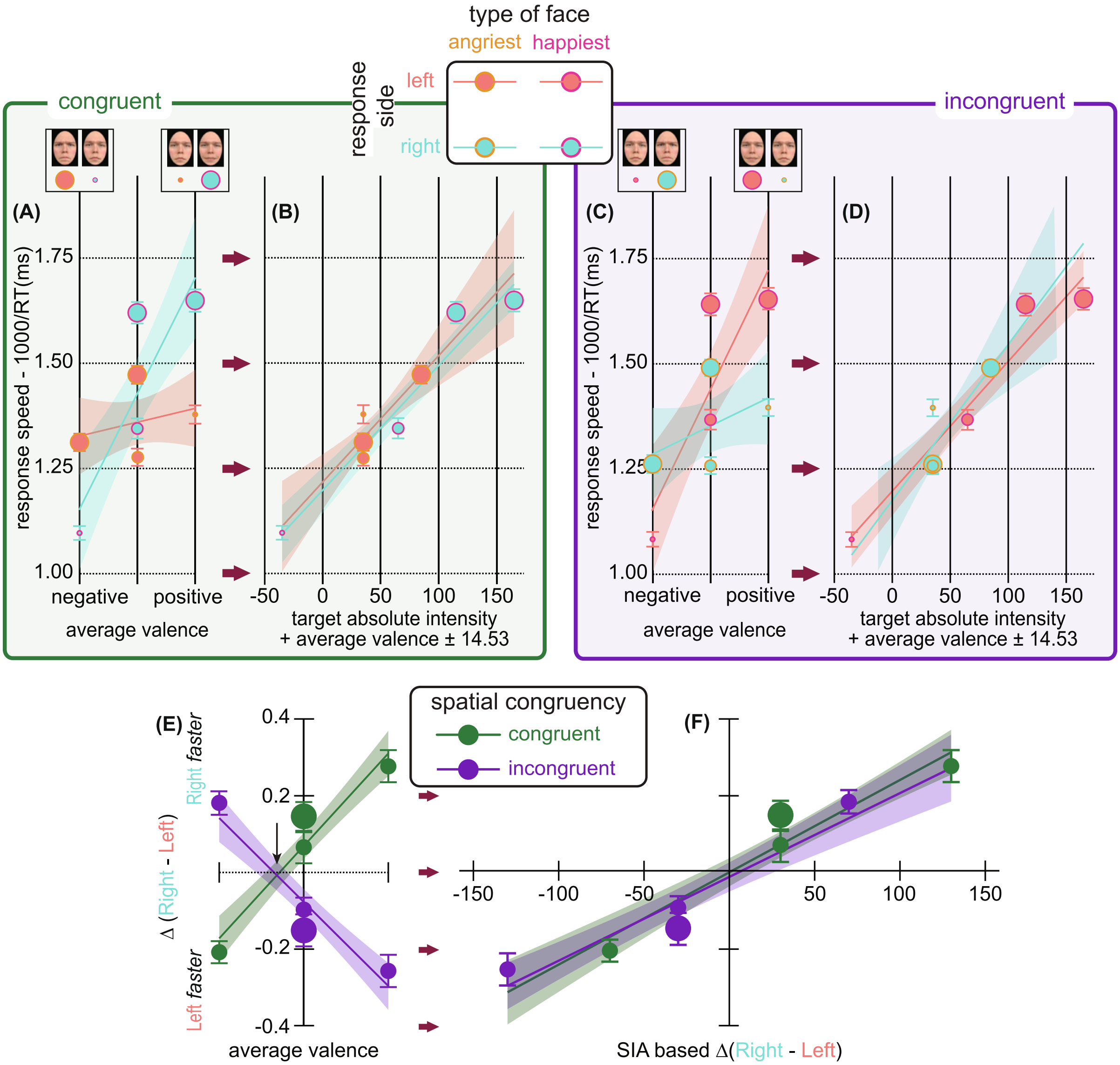

Fig. 5. Comparative judgements performance in Experiment 1. (A-D), illustration of the mean individual response speeds in Spatially Congruent (A and B, green frame) and Spatially Incongruent (C and D, violet frame) conditions, either as a function of $\mu_{valence}$ (A and C) or as a function of the best recoding of experimental conditions intensities obtained applying an equal weights SIA model (Type III, details in Section 2.1) with $k = 14.53$ (B and D). Error bars represent $\pm$ 1 s.e.m. and the size of the circles the absolute emotion intensity (small = neutral; medium = 50 per cent angry or 50 per cent happy; large = 100 per cent angry or 100 per cent happy). The Response Side and the type of target face are coded by the colours filling and bounding the circles, respectively (legend). Red/blue lines in panels A-D are the *lme* model regression lines for Left/Right Response Side conditions, with the shaded bands corresponding to $\pm$ 1 standard error of the regression. Panels E-F show average Δspeeds resulting from subtracting individual response speeds of left-hand responses from those of right-hand responses in the ordinate either as a function of average valence (E) or as a function of the best SIA model prediction (F) in the abscissa, with error bars representing $\pm$ 1 s.e.m. The size of the circles represents the absolute emotional distance of the pair along the valence continuum (large = $[-100, +100]$ tuple-2, small = $[0, \pm 100]$ or $[-50, +50]$). The Spatial Congruency condition is coded by the colour of the circles (legend). Green/violet lines in panels E, F are the *lme* model regression lines for congruent/incongruent conditions, with the shaded bands corresponding to $\pm$ 1 standard error of the regression. Panels B, D and F, help visualizing how the SIA model reliably accounts for both individual speeds and Δspeeds: it nulls the three-way interaction observed on individual response speeds (Panel B and D), and the two-way interaction observed on Δspeeds (Panel F).

handers being slower when the target emotion was displayed to the right (1.620 ± 0.070), rather than to the left (1.675 ± 0.070, $t = 3.83$, $df = 2577$, $p < 0.001$, $d = 0.151$). Given that handedness did not modified the way in which Response Side, Spatial Congruency, and $\mu_{valence}$ interacted, we thus decided to not focus the main analyses of our Experiments on handedness.

3.2. Experiment 1: Comparative judgements with a direct task in presence of foveation

Fig. 5 illustrates average response speeds (Fig. 5A, B, C, D), and average Δspeeds (Fig. 5E, F) of comparative judgements of emotions self-terminated by observers' responses as in Experiment 1. Data are shown for targets' expressions presented in spatially congruent (Fig. 5A, B and green circles in Fig. 5E, F), and spatially incongruent positions (Fig. 5C, D and violet circles in Fig. 5E, F), appearing in the rightmost (blue filled circles) or the leftmost (red filled circles) position depending on whether the target was the angriest (orange outline) or the happiest face (pink outline) within the pair. Individual average speeds and speed deviations are plotted either as a function of $\mu_{valence}$ (Fig. 5A, C for response speeds and Fig. 5E for Δspeeds), or as a function of values extracted following SIA predictions (details Section 2.1), with an emotion anisotropy in favour of the happiest face (corresponding to the positive categorization task) of about 14.53% (Fig. 5B, D for response speeds and Fig. 5F for Δspeeds). Such a value was empirically extracted following the rationale discussed in Section 1.2: it corresponded to the $\mu_{valence}$ in which the best fitting linear mixed-effect regressors of Δspeed, for the congruent and incongruent condition, intersected.

Independent of Spatial Congruency (Fig. 5A vs. C), the distributions of average response speeds for happiness/anger detection as a function of $\mu_{valence}$ were in strong agreement with ESC as modelled by SIA, but not with a SLE. A clear *cross-over effect* consistent with ESC was indeed observed on comparative judgements' speed in both the spatial congruent and incongruent condition, with speed of judgements belonging to the same display being reliably faster when associated to an emotional target rather than a neutral target regardless of the type of task and the side of response. Fig. 5A, C helps clarifying this: among a pair of circles with same $\mu_{valence}$, the larger one is always above the smaller one regardless of the outline (type of face corresponding with the type of task) and the filling-in colour (Response Side).

3.2.1. Individual speeds

We validate our observations on Fig. 1A-D by the linear mixed-effect (*lme*) analyses of Experiment 1 on individual response speeds, with participants and Task Ordering as random effects, and Spatial Congruency (Congruent - happiest ⇒ right - vs. Incongruent - happiest ⇒ left), Response Side (Left and Right) and Average Valence ($\mu_{valence}$ = -50, 0, +50) as fixed effects. The cross-over pattern was statistically supported by a reliable Response Side × Spatial Congruency × $\mu_{valence}$ interaction ($F_{1,\ 4870.0} = 341.36$, $p < 0.001$): as consistent with ESC, for negative $\mu_{valence}$ pairs the response speed was relatively faster for the angriest/emotional target (1.287 ± 0.035) than for the happiest/neutral target (1.091 ± 0.035, $t = 13.04$, $df = 1139$, $p < 0.001$, $d = 0.773$), and the reverse was true for positive pairs ($M_{happiest/emotional} = 1.648 \pm 0.049$ vs. $M_{angriest/neutral} = 1.383 \pm 0.049$; $t = 16.04$, $df = 1208$, $p < 0.001$, $d = 0.923$). This regularity occurred both when the target was in a spatially congruent position or spatially incongruent position thus producing, respectively: (1) a pattern consistent with the standard SLE pattern, with faster left-hand responses for negative $\mu_{valence}$ pairs with the happiest face in the rightmost position ($M_{left/angriest} = 1.306 \pm 0.037$; $M_{right/happiest}$ 1.099 ± 0.037; $t = 10.25$, $df = 559.2$, $p < 0.001$, $d = 0.867$) vs. faster right-hand responses for positive $\mu_{valence}$ pairs ($M_{left/angriest} = 1.37423 \pm 0.052$; $M_{right/happiest} = 1.646 \pm 0.052$; $t = 11.38$, $df = 580.2$, $p < 0.001$, $d = 0.945$); or (2) a pattern of response speed that is reversed relative to the one predicted by SLE; namely a fully reversed SLE pattern, with faster right-hand responses for negative $\mu_{valence}$ pairs with the happiest face in the leftmost position ($M_{left/angriest} = 1.079 \pm 0.036$ vs. $M_{right/happiest} = 1.26176 \pm 0.036$; $t = 8.47$, $df = 539.4$, $p < 0.001$, $d = 0.729$), vs. faster left-hand responses for positive $\mu_{valence}$ pairs ($M_{left/angriest} = 1.6507 \pm 0.050$ vs. $M_{right/happiest} = 1.394 \pm 0.050$; $t = 11.37$, $df = 587.1$, $p < 0.001$, $d = 0.939$).

The Response Side × Spatial Congruency × $\mu_{valence}$ interaction was further qualified by a main effect of $\mu_{valence}$ ($F_{1,\ 4870.1} = 682.25$, $p < 0.001$) and by a significant Response Side × Spatial Congruency interaction ($F_{1,\ 4870.0} = 73.25$, $p < 0.001$). The main effect of $\mu_{valence}$ was consistent with a size effect in the domain of emotion, with the speed of comparative judgements increasing steadily as $\mu_{valence}$ grew larger ($\beta = 0.0032 \pm 0.0001$, $t = 25.12$, $df = 4876$, $p < 0.001$), from negative to null emotions (estimated speed increment due to $\mu_{valence}$ increase = 0.245 ± 0.011, $t = 21.94$, $df = 4875$, $p < 0.001$, $d = 0.628$), as well as from null to positive emotions (estimated speed increment due to $\mu_{valence}$ increase = 0.327 ± 0.013, $t = 25.51$, $df = 4875$, $p < 0.001$, $d = 0.731$). The Response Side × Spatial Congruency interaction was consistent with a response speed unbalance across the two types of task with a reliably faster choice for positive (estimated average speed for incongruent ⇒ left and congruent ⇒ right conditions = 1.435 ± 0.043) over negative (estimated average speed for congruent ⇒ left and incongruent ⇒ right conditions = 1.357 ± 0.043) emotions across Spatial Congruency conditions ($t = 8.10$, $df = 4875$, $p < 0.001$, $d = 0.232$). This unbalance produced a funnelling of the cross-over pattern predicted by ESC, with the best fitting *lme* regressors intersecting in points with negative $\mu_{valence}$ in both the congruent (−14.55), and incongruent (−17.74) conditions. Such a negativity of the points of intersection between best fitting *lme* regressors is diagnostic of a general emotion anisotropy favouring positive rather than negative valence judgements of about 14.55 and 17.74 points in the congruent and incongruent conditions, respectively.

A further analysis revealed that response latencies associated to complete-facial expressions pairs statistically belonged to the ESC patterns in both spatial congruency conditions. The *lme* analysis on complete-facial expressions pairs (with $\mu_{valence} = 0$), indeed revealed a Spatial Congruency × Response Side × Target Absolute Emotional Intensity interaction ($F_{1,\ 2441.1} = 7.77$, $p = 0.005$) which was further qualified by a main effect of Target Absolute Emotional Intensity ($F_{1,\ 2441.0} = 443.44$, $p < 0.001$). These effects were consistent with a distance effect in the domain of emotion, similar to the one generally observed on symbolic magnitudes (i.e., numerals). The speed of judgements increased as the difference between the pair grew larger both for the "choose the angriest" task ($M_{Target\ Absolute\ Emotional\ Intensity=100} = 1.481 \pm 0.014$ vs. $M_{Target\ Absolute\ Emotional\ Intensity=50} = 1.267 \pm 0.014$, $t = 10.455$, $df = 1242$, $p < 0.001$, $d = 0.593$), and for the "choose the happiest" task ($M_{Target\ Absolute\ Emotional\ Intensity=100} = 1.630 \pm 0.018$ vs. $M_{Target\ Absolute\ Emotional\ Intensity=50} = 1.356 \pm 0.017$, $t = 11.007$, $df = 1242$, $p < 0.001$, $d = 0.625$).

3.2.2. Right-to-left speed deviations

The *lme* analysis on the pattern of individual Δspeeds (Fig. 5E) showed a reliable Spatial Congruency × $\mu_{valence}$ interaction ($F_{1,\ 316} = 145.409$, $p < 0.001$), and a main effect of Spatial Congruency ($F_{1,\ 316} = 30.977$, $p < 0.001$). This result is consistent with a standard vs. reversed SLE pattern for spatially congruent (positive *lme* estimated slope = 0.0048 ± 0.0005, $df = 316$, $t = 8.94$, $p < 0.001$, $d = 1.006$) vs. spatially incongruent (negative *lme* estimated slope = −0.0044 ± 0.0005, $df = 316$, $t = -8.15$, $p < 0.001$, $d = -0.917$) displays. In spatially congruent displays left side response were faster with negative $\mu_{valence}$ vs. slower for positive $\mu_{valence}$ pairs ($M_{\mu valence=-50} = -0.206 \pm 0.029$ vs. $M_{\mu valence=\ 50} = 0.\ 275 \pm 0.042$, $t = 10.075$, $df = 39$, $p < 0.001$, $d = 3.227$), and vice-versa for spatially incongruent displays ($M_{\mu valence=\ -50} = 0.181 \pm 0.030$ vs. $M_{\mu valence=\ 50} = -0.255 \pm 0.042$, $t = 9.107$, $df = 39$, $p < 0.001$, $d = 2.916$). Such a reverse pattern is consistent with a funnelling of the cross-over pattern predicted on the basis of ESC and can be accounted for by SIA as a by-product of a general emotion anisotropy favouring happiness over anger. This bias is diagnosed by a shift towards negative $\mu_{valence}$ of the point of intersection between the two-best fitting *lme* regressors describing the model with $\mu_{valence}$ and Spatial Congruency as fixed and participants as the random effect ($r_c = 0.53$ 95% CI [0.46, 0.59]). With such a model the estimated emotion anisotropy equals 14.53. This anisotropy was further supported by the analysis on complete-facial expressions pairs, revealing a significant overall positive Δspeed (*right* faster) associated to spatially congruent displays with the happiest expression on the *right* (0.106 ± 0.028, t vs. 0 = 3.842, $df = 158$, $p < 0.001$, $d = 0.611$), as opposed to a significant overall negative Δspeed (*left* faster) associated to spatially incongruent displays with the happiest expression on the *left* (−0.123 ± 0.028, t vs. 0 = −4.453, $df = 158$, $p < 0.001$, $d = -0.709$).

3.2.3. SIA based remapping

We quantitatively tested the goodness of ESC predictions as modelled by our stimulus driven SIA model by remapping the entire set of values associated to our experimental factors applying the most parsimonious linear combination of intensity components in SIA (details in

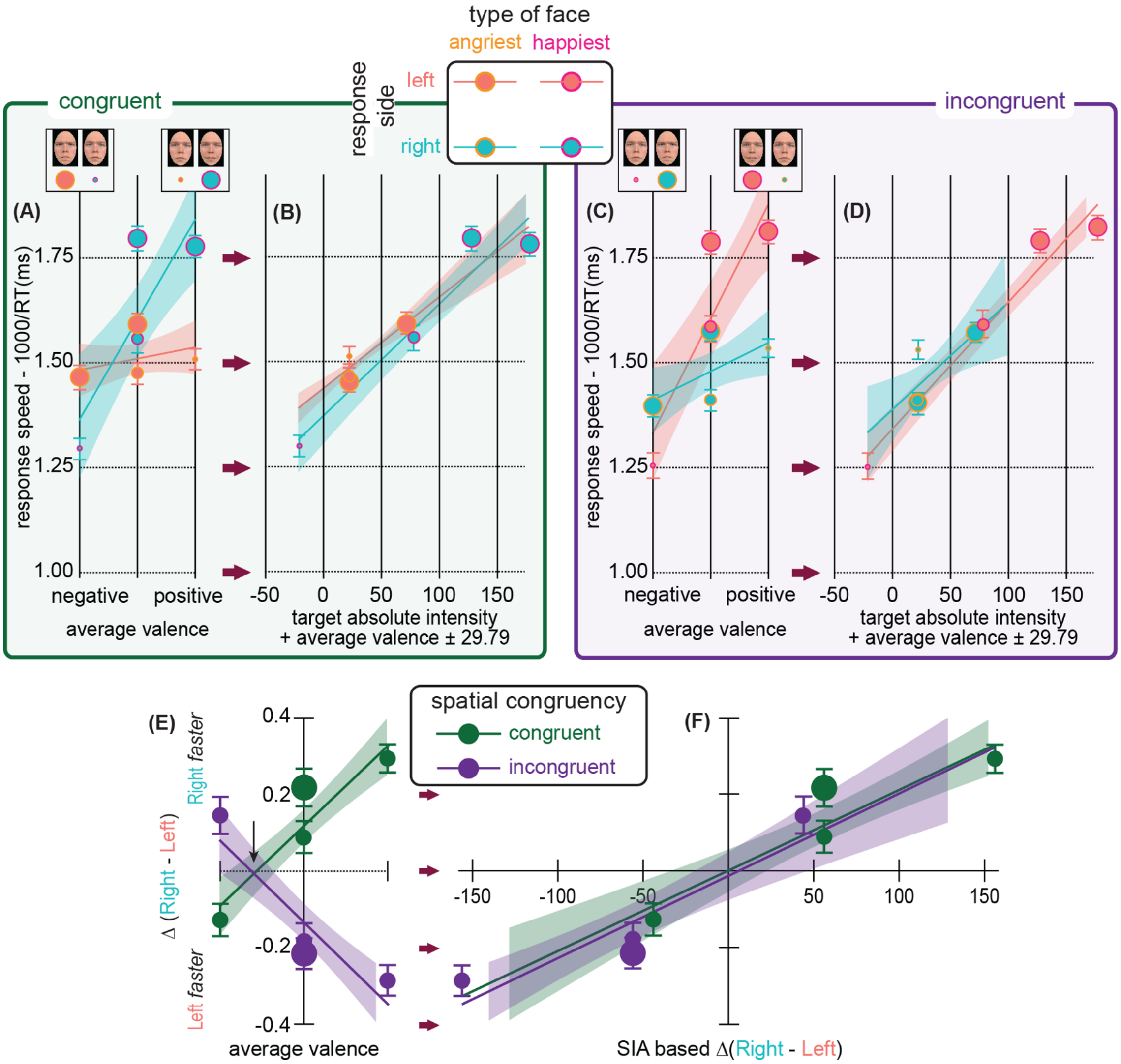

Fig. 6. Comparative judgements performance in Experiment 2. See caption of Fig. 5 for further explanations. As in Experiment 1, Panels B, D and F show that the best recoding of experimental conditions intensities obtained applying an equal weights SIA model (Type III, details in Section 2.1), with k = 29.79 reliably accounts for both individual speeds and Δspeeds: even in the absence of foveation, SIA nulls the three-way interaction observed on individual response speeds (Panels B and D), and the two-way interaction observed on Δspeeds (Panel F).

Section 2.1), i.e., the one implementing the equal weighting between ESC, SE and EA components depicted in Fig. 2. This meant recoding each single target image value within a pair in terms of the sum between its Absolute Emotional Intensity, the Average valence of the pair and the empirically determined value standing for the Global Emotion Anisotropy (14.53) signed according to its relative valence polarity (+ if it is the happiest vs. – if it is the angriest within the pair). The pattern of average individual response speeds and average individual speeds deviations shown in Fig. 5A, C and E are remapped in Fig. 5B, D and F, respectively. This remapping, with no free parameters, fully accounts for the effects we found both when considering individual speeds and individual speeds deviations. This is confirmed by the results of a *lme* analysis testing the effects of Spatial Congruency and Response Side, once the effect of stimulus intensity predicted by SIA on individual response speed is controlled, by including it as a third covariate in the same analysis performed on the dataset shown in Fig. 5A and C, so to control for its effect. The SIA individual speed estimates resulted to be the only significant factor ($F_{1,\ 4870}$ = 506.78, p < 0.001), with the Spatial Congruency × Response Side interaction now becoming no longer statistically significant ($F_{1,\ 4870}$ = 1.86, p = 0.17). Individual speeds increased proportionally as the SIA speed estimates increased at a rate of about 0.003 ± 0.0004 speed units every unit increment of SIA estimates (t = 7.943, df = 4870, p < 0.001, d = 0.228), regardless of the Side of Response and Spatial Congruency (χ^2 = 6.709, df = 6, p = 0.349). A totally constrained model including the equal weight SIA as the only predictor of speed (5 df) accounts for a larger amount of variance of a more complex model (11 df) including the full factorial combination of all experimental conditions in our design (54% vs. 50% respectively, with r_c = 0.69 95% CI [0.68, 0.71] vs. r_c = 0.66 95% CI [0.65, 0.67]). It resulted to be the best fitting model of the two ($AIC_{df=5}$ = 2077 vs. $AIC_{df=11}$ = 2492; $BIC_{df=5}$ = 2109.5 vs. $BIC_{df=11}$ = 2563.6).

Results were strikingly similar when testing for the effect of $\mu_{valence}$ and Spatial Congruency on the pattern of Δspeeds and controlling for SIA based speed deviations as a predictor (Fig. 5F). Again, the SIA was the only significant factor accounting for individual Δspeed ($F_{1,\ 316}$ = 145.409, p < 0.001): average deviations increased steadily at a rate of about 0.0024 ± 0.00027 every unit of increase of the SIA predictor (t = 8.93, df = 316, p < 0.001, d = 1.005). No other effects were significant (χ^2 = 0.6, df = 2, p = 0.718). As for the individual speed, the model including SIA resulted to be the best fitting one: relative to a 6 df model including the full factorial combination of all experimental variables (i.e., Spatial Congruency × $\mu_{valence}$) a SIA based model with 4 *df* accounted for a similar amount of variance of the pattern of Δspeeds (36% in both cases) though collecting the best indices for the goodness of fit ($AIC_{df=4} = 1.1$ vs. $AIC_{df=6} = 4.4$; $BIC_{df=4} = 16.2$ vs. $BIC_{df=6} = 27.0$).

In general, on the basis of the pattern of both individual speeds and Δspeeds, there is no evidence that other factors beyond stimulus-driven emotion intensities may have affected comparative judgements performance in our task.

3.3. Experiment 2: Comparative judgements with a direct task in absence of foveation

Would results be similar (as those of Experiment 1) when comparative judgements are not supported by foveation? In order to answer such a question, we performed Experiment 2 with facial expressions of emotions presented tachistoscopically, rather than until participants' response (Experiment 1). Results of Experiment 1 might indeed be due to a lack of control for the lateralized presentation of emotional pairs. In Experiment 1, even though the target emotion was presented with a sufficient amount of eccentricity relative to fixation for a lateralized encoding of emotion, visual spatial attention could have been evoked by the task in the region of the visual hemifield displaying the target emotion thus letting the target emotion always appear in central vision: this could have inhibited the effect of emotion lateralization which is necessary for the occurrence of a stable SLE in our task and may have favoured a mere direct association between stimulus intensities and response speeds. The strength of such a direct association should instead be reduced in the covert attention condition by displaying each emotional pair for a time-lapse short enough to hinder foveation, thus reducing the likelihood that any one of the two single images of the emotional pair would have time to fall within the spotlight of attention in central vision.

Fig. 6 illustrates average response speeds (Fig. 6A, B, C, D) and average Δspeeds (Fig. 6E, F) obtained in Experiment 2 in which the comparative judgement was performed after tachistoscopically presented emotions following the same rationale and variable encoding used in Fig. 5. The distribution of data indicates the robustness of ESC (against SLE).

3.3.1. Individual speeds

The key result on Individual speeds is the similar Response Side × Spatial Congruency × $\mu_{valence}$ interaction found in Experiments 1 and 2 ($F_{1,\ 4392.1} = 200.89$, $p < 0.001$). As in Experiment 1, and consistently with ESC (but not SLE), the response speed for pairs with $\mu_{valence}$ = -50 was relatively faster for the angriest/emotional ($M_{angriest/emotional} = 1.430 \pm 0.055$) than for the happiest/neutral face within the pair ($M_{happiest/neutral} = 1.290 \pm 0.055$, $t = 7.028$, $df = 896.5$, $p < 0.001$, $d = 0.469$), while the reverse occurred for pairs with $\mu_{valence} = 50$ ($M_{happiest/emotional} = 1.798 \pm 0.060$ vs. $M_{angriest/neutral} = 1.512 \pm 0.060$; $t = 16.08$, $df = 1149$, $p < 0.001$, $d = 0.949$). As in Experiment 1 this effect was elicited by: (1) a standard SLE pattern for spatially congruent emotional pairs with faster left-hand responses for negative $\mu_{valence}$ pairs with the happiest/neutral face in the rightmost position ($M_{left/angriest} = 1.452 \pm 0.056$; $M_{right/happiest} = 1.309 \pm 0.056$; $t = 5.29$, $df = 443.7$, $p < 0.001$, $d = 0.502$), and vice-versa for positive emotional pairs ($M_{left/angriest} = 1.498 \pm 0.064$; $M_{right/happiest}$ 1.784 ± 0.064; $t = 11.34$, $df = 546.2$, $p < 0.001$, $d = 0.97$); and (2) a fully reversed SLE pattern for spatially incongruent emotional pairs (for $\mu_{valence} = -50$: $M_{left/angriest} = 1.248 \pm 0.056$ slower than $M_{right/happiest} = 1.397 \pm 0.056$; $t = 5.33$, $df = 416.5$, $p < 0.001$, $d = 0.522$; for $\mu_{valence} = 50$: $M_{left/angriest} = 1.811 \pm 0.059$ faster than $M_{right/happiest} = 1.524 \pm 0.059$; $t = 11.70$, $df = 562.9$, $p < 0.001$, $d = 0.986$).

Also, the size effect and the response speed unbalance across the two types of task/faces were similar to those observed in Experiment 1, as supported by the main effect of $\mu_{valence}$ ($F_{1,\ 4392.1} = 400.75$, $p < 0.001$) and the significant Response Side × Spatial Congruency interaction ($F_{1,\ 4392.0} = 176.66$, $p < 0.001$), respectively. Again: (1) individual speeds increased steadily as $\mu_{valence}$ grew larger ($\beta = 0.0028 \pm 0.0001$, $t = 19.22$, $df = 4398$, $p < 0.001$), from negative to null emotions (speed increment due to $\mu_{valence}$ increase $= 0.243 \pm 0.019$, $t = 13.038$, $df = 3247$, $p < 0.001$, $d = 0.458$), and from null to positive emotions (speed increment due to $\mu_{valence}$ increase $= 0.061 \pm 0.018$, $t = 3.449$, $df = 3500$, $p < 0.001$, $d = 0.117$); and (2) choices were reliably faster for positive (estimated average speed for incongruent ⇒ left and congruent ⇒ right conditions $= 1.639 \pm 0.059$) over negative (estimated average speed for congruent ⇒ left and incongruent ⇒ right conditions $= 1.495 \pm 0.059$) emotions across Spatial Congruency conditions ($t = 13.83$, $df = 4398$, $p < 0.001$, $d = 0.417$).

As far as complete-facial expressions pairs are concerned (i.e., $\mu_{valence} = 0$), a similar main effect of Target Absolute Emotional Intensity ($F_{1,\ 22741} = 215.88$, $p < 0.001$), and a similar Spatial Congruency × Response Side × Target Absolute Emotional Intensity interaction ($F_{1,\ 2274.0} = 8.55$, $p = 0.00348$) emerged in Experiment 2 and 1 consistent with a distance effect in the domain of emotion. Again, speeds were larger as the difference between the pair increased both when the target face was the angriest ($M_{Target\ Absolute\ Emotional\ Intensity=100} = 1.581 \pm 0.018$ vs. $M_{Target\ Absolute\ Emotional\ Intensity=50} = 1.438 \pm 0.018$, $t = 5.564$, $df = 1149$, $p < 0.001$, $d = 0.327$) and when the target face was the happiest ($M_{Target\ absolute\ emotional\ intensity=100} = 1.794 \pm 0.021$ vs. $M_{Target\ absolute\ emotional\ intensity=50} = 1.575 \pm 0.023$, $t = 7.122$, $df = 1160$, $p < 0.001$, $d = 0.418$) between the two.

The data also revealed an overall effect of the stimulus duration with shorter duration (in Experiment 2 vs. 1) that prioritized speed over accuracy. This is confirmed by the overall lower choice accuracy with an average per-cent accuracy of 88% ± 0.66 vs. 96% ± 0.32 in Experiments 2 vs. 1 ($t = 10.3$, $df = 898.43$, $p < 0.001$, $d = 0.687$), respectively, vs. the higher speed with an average speed of 1.57 ± 0.18 vs. 1.39 ± 0.14 ($t = -19.8$, $df = 8708.2$, $p < 0.001$, $d = 0.424$) in Experiments 2 vs. 1, respectively. We obtained stronger evidence for the general conclusions relating the two experiments by comparing the patterns of individual speeds in Experiment 2 directly to those of Experiment 1, including in the *lme* the Experiment as an additional fixed factor. The analysis revealed that the Experiment, beyond producing a main effect supported by the analysis reported in the preceding paragraph ($F_{1,\ 76.9} = 6.70$, $p = 0.01$), it did significantly interacted with Response Side and Spatial Congruency ($F_{1,\ 9240.1} = 17.3$, $p < 0.001$), with an *lme* estimated gain, due to the happiest face observed in Experiment 2, almost twice the one observed in Experiment 1 (Gain observed in Experiment 1 $= 0.07743 \pm 0.00972$; amount of additional gain relative to Experiment 1 observed in Experiment 2 $= 0.06576 \pm 0.014$; $t = 4.653$, $df = 9252$, $p < 0.001$, $d = 0.097$). In particular, the larger response speed unbalance in favour of the happiest face observed in Experiment 2 produced a larger funnelling of the cross-over pattern (predicted on the basis of ESC) than the one observed in Experiment 1. In Experiment 2 the best fitting *lme* regressors associated to the Left and Right Response Side in congruent and incongruent spatial position indeed intersects in points with larger negativity being diagnostic of a general emotion anisotropy favouring positive rather than negative valence emotion of about 28.93% and 38.88% in the congruent and incongruent conditions, respectively. No other reliable interactions were found for individual speeds due to the inclusion of the Experiment as an additional factor.

3.3.2. Right-to-left speed deviations

As in Experiment 1, we analyzed Δspeeds shown in Fig. 6E for the 8 conditions of the experimental design. The result of the *lme* analysis revealed the following set of reliable effects common to both Experiments: Spatial Congruency ($F_{1,\ 270} = 68.43$, $p < 0.001$), with an overall positive Δspeed in spatially congruent condition (*lme* estimate for right faster than left = 0.12 ± 0.025, $t = 4.675$, $df = 310$, $p < 0.001$, $d = 0.531$), opposed to an overall negative Δspeed in spatially incongruent condition (*lme* estimate for right slower than left = -0.14 ± 0.025, t = -5.466, $df = 310$, $p < 0.001$, d = -0.621); Spatial Congruency × $\mu_{valence}$ ($F_{1,\ 270} = 96.574$, $p < 0.001$), with a standard (positive *lme* estimated slope = -0.0042 ± 0.0006, $t = 6.90$, $df = 270$, $p < 0.001$, $d = 0.84$), vs. an equally reliable though reversed SLE (negative *lme* estimated slope = -0.0043 ± 0.0006, $df = 270$, t = -6.98, $p < 0.001$, $d = 0.85$) for spatially congruent vs. spatially incongruent pairs.

Again, this pattern was consistent with SIA predictions (not with SLE) including a rather large emotion anisotropy diagnostic for a happiness advantage speeding up the selection of happy faces over angry faces of about the 29.79% ($r^2 = 0.37$, $r_c = 0.53$, 95% CI [0.47, 0.60]).

As in Experiment 1, we corroborated the emotion anisotropy through focusing on complete-facial expressions pairs, and analysing how Δspeeds are affected by Spatial Congruency ($F_{1,\ 154} = 62.88$, $p < 0.001$). Such an analysis revealed a significant overall positive Δspeed (right faster) associated to spatially congruent displays with the happiest expression on the right (0.15 ± 0.031, t vs. 0 = 4.834, $df = 154$, $p < 0.001$, $d = 0.779$), as opposed to a significant overall negative Δspeed (left faster) associated with spatially incongruent displays with the happiest expression on the left (-0.200 ± 0.031, t vs. 0 = -6.38, $df = 158$, $p < 0.001$, d = -1.015).

3.3.3. SIA based remapping

We tested the goodness of SIA predictions using the same procedure applied in Experiment 1 to remap our stimulus conditions into intensities now including the larger value of global emotion anisotropy obtained from the data of Experiment 2 (29.79 instead of 14.53). Fig. 6B, D and F shows how the same average individual response speeds and average Δspeeds shown in Fig. 6A, C and E as a function of $\mu_{valence}$, are distributed after SIA-based remapping. Again, the fully constrained combination of intensity values associated to our experimental conditions predicted by the equal weight SIA model fully accounts for the entire patterns of data obtained in Experiment 2. The SIA predictor was the only significant factor reliably affecting both individual speeds ($F_{1,\ 4397} = 261.92$, $p < 0.001$), and Δspeed ($F_{1,\ 270} = 96.33$, $p < 0.001$). When it is included in the *lme* model as a covariate of individual speeds the effects of both Congruency and Spatial Congruency × Response Side turned out to be non-significant ($\chi^2 = 10.687$, $df = 6$, $p = 0.100$), with a fully constrained *lme* model (5 *df*) including the SIA predictor as the only covariate of speeds accounting for a larger amount of variance of a fully unconstrained model (11 *df*) including the full factorial combination of all our experimental conditions (60% vs. 58% respectively, with $r_c = 0.75$ 95% CI [0.73, 0.76] vs. $r_c = 0.73$ 95% CI [0.72, 0.74]), and optimizing the goodness of fit ($AIC_{df=5} = 2569.5$ vs. $AIC_{df=11} = 2805.5$; $BIC_{df=5} = 2596.1$ vs. $BIC_{df=11} = 2869.5$). Again, when SIA predictor was included in the *lme* model as a covariate of Δspeeds the effect of Spatial Congruency vanished ($\chi^2 = 0.032$, $df = 2$, $p = 0.998$). The test variance was largely accounted for by SIA ($\beta = 0.0021 \pm 0.0003$, $t = 6.90$, $df = 270$, $p < 0.001$), with an *lme* model including it as the only covariate (4 *df*) both accounting for a similar amount of variance (38% vs. 37% respectively, with $r_c = 0.54$ 95% CI [0.47, 0.60] vs. $r_c = 0.53$ 95% CI [0.47, 0.60]), and optimizing the goodness of fit (AIC = 81.32, BIC = 96.29), relative to a fully unconstrained model including the full factorial combination of all our experimental conditions (AIC = 85.31, BIC = 107.77).

3.4. Experiment 3: Comparative judgements with an indirect task in presence of foveation

Would results be similar (as those of Experiment 1) when comparative judgements are performed in a condition in which the valence intensity is task irrelevant? In order to answer such a question, we performed the Experiment 3, with the same facial expressions of emotions used in Experiment 1 and viewed under the exact same free viewing condition as self-terminated by the participant's response, but with an indirect emotion identification task rather than a direct valence comparison task (Experiment 1).

The presence of a pattern of result consistent with ESC rather than with SLE of Experiment 1 did not provide information about the specific nature of the process governing the encoding of motor responses during our comparative judgements. In particular, it did not exclude the possibility that our ESC pattern was grounded on a controlled and task-dependent process based on the semantic encoding of valence. Anyhow, our SIA model is based on a purely stimulus-driven assumption, which makes its predictions fully task-independent being motor reactivity driven by an automatic and direct association between absolute emotion intensity and speeds. Namely, comparative judgements of emotions should be faster for the "choose the emotional" rather than for the "choose the neutral" instruction, irrespective of the compatibility between the response side and the average valence in both spatial congruency conditions. On the other hand, according to the results of Holmes and Lourenco (2011) on the categorization of single isolated facial expression of emotions, an indirect (rather than direct) task, might elicit a pattern of motor reactivity consistent with SLE.

Fig. 7 illustrates the average response speeds (Fig. 7A, B, C, D) and average Δspeeds (Fig. 7E, F) obtained in Experiment 3 in which the comparative judgement was performed in indirect task conditions, following the same rationale and variable encoding used for Figs. 5 and 6. Again, the distribution of data indicates the robustness of ESC (against SLE) and its stimulus-dependence (not goal-dependence) as being automatically elicited from an irresistible perceptual elaboration of emotional intensities.

3.4.1. Individual speeds

Results of Experiment 3 closely mirrored results of Experiment 1 and 2, demonstrating a stimulus-driven and task independent ESC. This was revealed by a similar Response Side × Spatial Congruency × $\mu_{valence}$ interaction ($F_{1,\ 2653.2} = 22.83$, $p = 0.002$), with faster responses for the "choose emotional" (M = 1.501 ± 0.052) rather than for the "choose the neutral" instruction (M = 1.407 ± 0.052, $t = 6.194$, $df = 1394$, $p < 0.001$, $d = 0.33$) irrespective of the Response Side and the Spatial Congruency. This general response speed advantage of emotional over neutral faces was further qualified by a funnelling of the cross-over pattern predicted by ESC alone. When $\mu_{valence} = 50$, but not when $\mu_{valence} = -50$, the right-hand response was faster than the left-hand response in the spatially congruent conditions ($M_{right/emotional} = 1.471 \pm 0.052$ faster than $M_{left/neutral} = 1.413 \pm 0.052$; $t = 2.70$, $df = 667.17$, $p = 0.007$, $d = 0.21$), and vice-versa in the spatially incongruent conditions ($M_{left/emotional} = 1.530 \pm 0.055$ faster than $M_{right/neutral} = 1.403 \pm 0.055$; $t = 6.17$, $df = 680.04$, $p < 0.001$, $d = 0.47$), which was again consistent with a standard SLE pattern for spatially congruent emotional pairs, and a reversed SLE pattern for spatially incongruent emotional pairs: both patterns expected on the basis of ESC (but not SLE).

As for Experiment 1 and 2 the three-way interaction was further qualified by a main effect of $\mu_{valence}$ ($F_{1,\ 2653.4} = 696.29$, $p < 0.001$), and a significant Response Side × Spatial Congruency interaction ($F_{1,\ 2653.2} = 15.37$, $p < 0.001$). The former one, was diagnostic of a similar size effect in the domain of emotion of the one observed in Experiments 1 and 2, with individual speeds increasing steadily as $\mu_{valence}$ grew larger ($\beta = 0.0028 \pm 0.0001$, $t = 26.08$, $df = 2659$, $p < 0.001$), while the latter one, was diagnostic of an emotion anisotropy consistent with a response speed unbalance across the two types of expressions to be detected within our emotional pairs (the angriest/happiest). As in Experiment 1 and 2, choices were reliably faster for the happiest (estimated average speed for incongruent ⇒ left and congruent ⇒ right conditions = 1.336 ± 0.011), over the angriest (estimated average

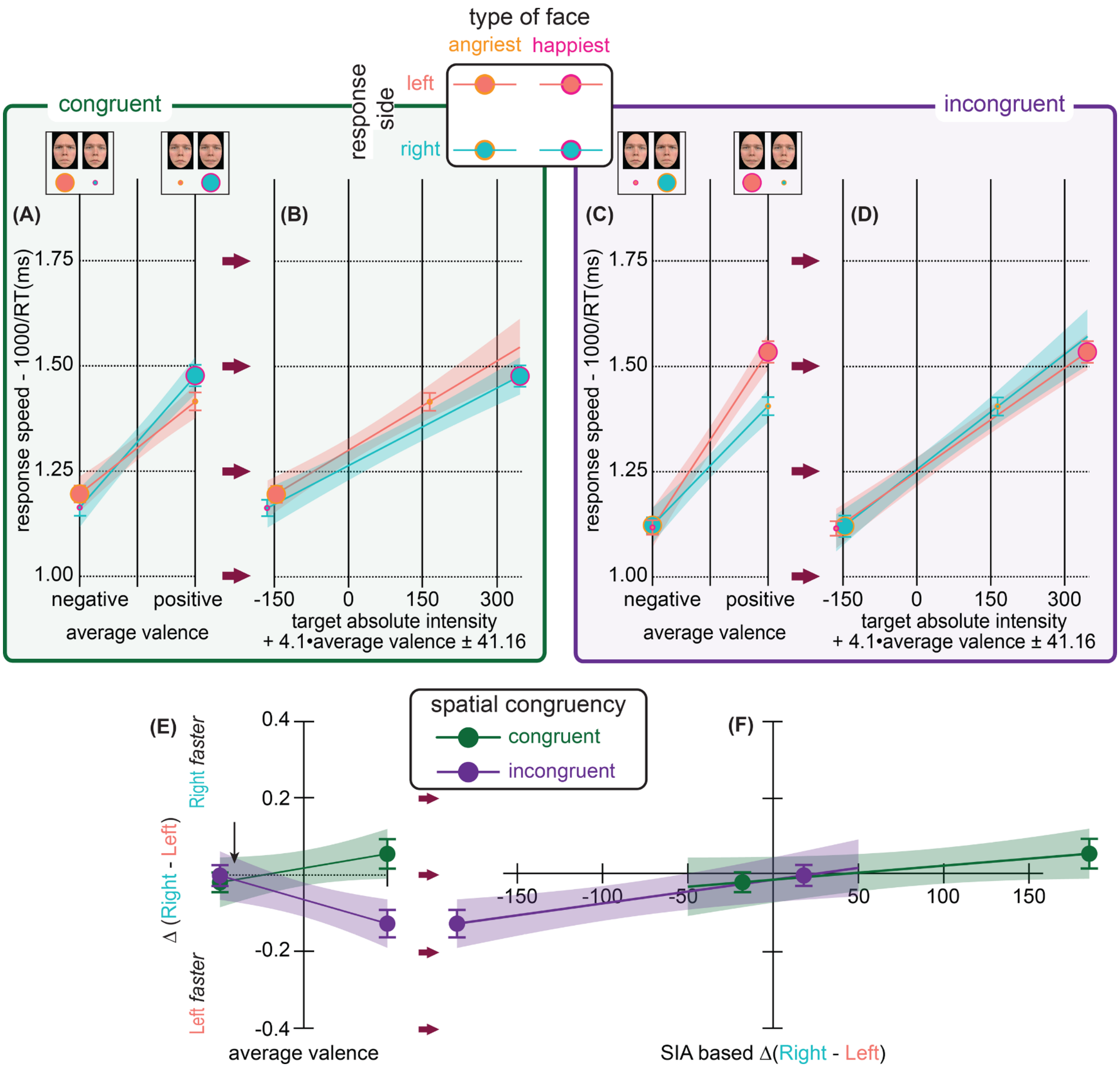

Fig. 7. Comparative judgements performance in Experiment 3. See caption of Fig. 5 or 6 for further explanations. Panels B, D and F show that the best recoding of experimental conditions intensities obtained applying an unequal weights SIA model (Type III, details in Section 2.1), with $k = 41.16$ and $\alpha = 4.1$ reliably accounts for both individual speeds and Δspeeds: even with the indirect emotion identification tasks of Experiment 3, SIA nulls the three-way interaction observed on individual response speeds (Panels B and D), and the two-way interaction observed on Δspeeds (Panel F).

speed for congruent ⇒ left and incongruent ⇒ right conditions = 1.292 ± 0.011) facial expressions across Spatial Congruency conditions ($t = 2.70$, $df = 2704$, $p < 0.007$, $d = 0.1$), producing a funnelling effect in the domain of emotion. The funnelling effect was somehow stronger in the incongruent rather than in the congruent condition, as testified by the significant Spatial Congruency × $\mu_{valence}$ ($F_{1,\ 2653.1} = 12.03$, $p < 0.001$) interaction, due to globally faster response speeds for congruent ($M_{congruent} = 1.185 \pm 0.037$) over incongruent ($M_{incongruent} = 1.135 \pm 0.037$, $t = 3.65$, $df = 1218.5$, $p < 0.001$, $d = 0.21$) conditions only when $\mu_{valence}$ was negative. Such a difference in the speed-$\mu_{valence}$ relationship caused the best fitting *lme* regressors associated to the left and right response side in congruent and incongruent spatial position to intersect in points with rather different negativity: a large (55.26) and intermediate (23.87) negativity, respectively.

The data also revealed that performing the comparative judgements under the implicit task demands of Experiment 3 produces an overall loss in response speed and accuracy. This was confirmed by the overall lower choice accuracy with an average per-cent accuracy of 91.92% ± 0.13 vs. 94.88% ± 0.09 ($t = 3.49$, $df = 638.23$, $p < 0.001$, $d = 0.28$), in Experiments 3 vs. 1 respectively, and the overall lower choice speed with an average speed of 1.31 ± 0.70 vs. 1.36 ± 0.49 ($t = 3.74$, $df = 5079.1$, $p < 0.001$, $d = 0.1$), in Experiments 3 vs. 1 respectively. We obtained stronger evidence for the specific effect of task demands comparing the patterns of individual speeds in Experiment 3 directly to those of Experiment 1. As for the comparative analysis performed in our Experiment 2, we included in the *lme* model the Experiment as an additional fixed factor but excluded from the analysis the complete-facial expressions trials of Experiment 1. The *lme* analysis revealed that task demand somehow modulates the size and the cross-over effect. The size effect was smaller in the indirect task condition of Experiment 3 rather than 1 as confirmed by the significant Experiment × $\mu_{valence}$ interaction ($F_{1,\ 5035.5} = 6.83$, $p = 0.009$). The rate of increase of judgement speed over $\mu_{valence}$ decreased of about -0.00043 ± 0.00016 ($t = -2.575$, $df = 5048$, $p = 0.010$, $d = 0.07$) in Experiment 3 vs. Experiment 1. A similar reduction of the cross-over effect due to the indirect task condition of Experiment 3 was confirmed by the significant Experiment × Response Side × Spatial Congruency × $\mu_{valence}$ ($F_{1,\ 5035.2} = 127.78$, $p < 0.001$), as due to the global loss of response speed advantage of emotional over neutral faces observed in Experiment 3 vs. 1 both when $\mu_{valence} = 50$ ($\Delta M_{emotional/Experiment\ 3}/M_{emotional/Experiment\ 1} = -0.17109 \pm 0.02230$,

$t = -7.671$, $df = 2602.11$, $p < 0.001$, $d = 0.30$), and when $\mu_{valence} = -50$ ($\Delta M_{emotional/Experiment\ 3}/M_{emotional/Experiment\ 1}$ = -0.18544 ± 0.02030, $t = -9.136$, $df = 2357.90$, $p < 0.001$, $d = 0.38$). No other reliable interactions were found for individual speeds due to the inclusion of the Experiment as an additional factor.

3.4.2. Right-to-left speed deviations

The *lme* analysis on the pattern of individual Δspeeds (Fig. 7E) showed the same set of significant effects observed in Experiment 1 and 2: Spatial Congruency ($F_{1,\ 180} = 6.493$, $p = 0.01$), with the Δspeed globally balanced over response sides in spatially congruent condition (*lme* estimate for right faster than left = 0.017 ± 0.023, $t = 0.763$, $df = 182$, $p = 0.4467$), opposed to a globally unbalanced Δspeed in spatially incongruent condition in favour of left-side responses (*lme* estimate for right slower than left = −0.064 ± 0.023, $t = -2.763$, $df = 182$, $p = 0.006$, $d = -0.41$); Spatial Congruency × $\mu_{valence}$ ($F_{1,\ 180} = 9.581$, $p = 0.002$), with a tendentially standard (positive *lme* estimated slope = 0.0007 ± 0.0004, $df = 180$, $t = 1.63$, $p = 0.1052$, $d = 0.24$), vs. reliable though reversed SLE-pattern (negative *lme* estimated slope = −0.0013 ± 0.0005, $df = 180$, $t = -2.75$, $p < 0.01$, $d = -0.41$), for spatially congruent vs. spatially incongruent pairs. This pattern was consistent with Type III SIA prediction (not with SLE) including a rather large emotion anisotropy diagnostic for a happiness advantage speeding up the selection of the happiest over the angriest face within the pair of about the 41.16% ($r_c = 0.16$ 95% CI [0.08, 0.23]).

3.4.3. SIA based remapping

We quantified the likelihood of predicting our pattern of response speeds by means of the combination of emotion intensity components included into SIA following the same rationale of Experiment 1 and 2. In a first analysis we used the same equal weight type III SIA combination fully accounting for the pattern of comparative judgement speeds of Experiment 1 and 2, in order to remap our stimulus conditions into intensities now including the larger value of global emotion anisotropy obtained from the data of Experiment 3 (41.16 instead of 14.53). Such, a fully constrained combination of intensity values associated to our experimental conditions did not fully accounts for the entire set of individual speeds obtained in Experiment 3, with the equal weight SIA predictor alone (5*df*) leading into a suboptimal fit of the pattern of data relative to a fully unconstrained model (11 *df*) including the full factorial combination of all our experimental conditions ($\chi^2 = 302.9$, $df = 6$, $p < 0.001$, $AIC_{df=5} = 1283.1$ vs. $AIC_{df=11} = 992.2$; $BIC_{df=5} = 1312.6$ vs. $BIC_{df=11} = 1057.2$; $r^2_{df=5} = 0.54$, $r^2_{df=11} = 0.58$ respectively, with $r_{c\ df=5} = 0.69$ 95% CI [0.68, 0.71] vs. $r_{c\ df=11} = 0.74$ 95% CI [0.72, 0.75]). This lack of fit was confirmed by the results of the *lme* analysis testing for the effects of Spatial Congruency and Response Side, once the effect of stimulus intensity predicted by SIA on individual response speed was controlled, with the Spatial Congruency × Response Side interaction surviving significance ($F_{1,\ 2642.3} = 233.97$, $p < 0.001$), and interacting with the SIA predictor ($F_{1,\ 2642.3} = 236.34$, $p < 0.001$). Such a result was a consequence of the specific prediction rising from the assumption of equal ESC and SE weights intrinsic of the most parsimonious linear combination of intensity components tested in this first analysis. In particular, the almost flat relationship between speeds and $\mu_{valence}$ for left-hand responses in spatially congruent and right-hand responses in spatially incongruent conditions predicted by an equal weight SIA was violated by the rather strong speed advantage for the choice of neutral faces coupled with happy faces over the choice of angry faces coupled with neutral faces ($\Delta = 0.23 \pm 0.015$ ms, $t = 15.32$, $df = 2657$, $p < 0.001$, $d = 0.59$).

In order to account for such a rather strong violation we tested an unequal weight SIA, now including as an additional free parameter the best fitting multiplying factor α of $\mu_{valence}$ operationalizing a larger weighting of the SE over the ESC component. The α value was the minimum positive required value for the unequal weight Type III SIA based combination in order to optimize the goodness of fit of individual speeds. In particular, an *lme* model (5 *df*) now including a unequal weight SIA predictor with $\alpha = 4.1$ as the only covariate of speeds accounted for the exact same amount of variance of an 11 *df* unconstrained model including the full factorial combination of all our experimental conditions (58%, with $r_c = 0.73$ 95% CI [0.72, 0.75]), and produced a fit with comparable goodness (AIC = 1003.8; BIC = 1033.4). Fig. 7B, D and F shows how the same average individual response speeds and average Δspeeds of Fig. 7A, C and E, are distributed after such an unequal weight SIA-based remapping. Notably, this SIA predictor was now the only significant factor reliably affecting both individual speeds ($F_{1,\ 2653.4} = 603.80$, $p < 0.001$), and Δspeed ($F_{1,\ 4870} = 506.78$, $p < 0.001$). In particular, when it is included in the *lme* model as a covariate of individual speeds the effect of Spatial Congruency × Response Side interaction vanished ($F_{1,\ 2653.2} = 0.99$, $p = 0.32$). Again, when the unequal weight SIA predictor was included in the *lme* model as a covariate of Δspeeds the effect of Spatial Congruency turned out to be not significant ($\chi^2 = 0.642$, $df = 2$, $p = 0.726$).

4. Conclusions

We reported three experiments on the link between simultaneously presented emotions shown side-by-side and the lateralization of motor response, demonstrating that comparative judgements of emotions are fully driven by stimulus properties used for the encoding of emotion intensity from facial expressions, regardless of a controlled or automatic valence-specific lateral bias. The speeds of choice indeed increased as the absolute emotion intensity of the chosen face grew larger together with the average emotion intensity of the pair in both foveal (Experiment 1 and 3), and non-foveal emotion presentation conditions (Experiment 2), and when valence was either task relevant (in the valence comparison task of Experiment 1 and 2) or task irrelevant (in the emotion identification task of Experiment 3). This is consistent with a rather automatic semantic congruency effect (Banks et al., 1975) in the domain of emotion, regardless of a SNARC-like association between a left-to-right mental representation of valence and response side: a novel Emotional Semantic Congruency effect, ESC. We formalized ESC with a stimulus driven model of the comparative judgements of emotions: the direct Speed-Intensity Association, SIA model. The direct association between diverse sources of emotion intensities elicited by facial expressions and response speeds accounts for both the standard SNARC-like and the reversed SNARC-like patterns we found in conditions in which the spatial arrangement of the pair is spatially congruent and incongruent, respectively, with the left-to-right mental format of valence. Notably, the pattern of observers' responses are markedly different from those predicted neither on the basis of a strong nor of a weak effect of the association between the left-to-right mental representation of valence, thus undermining previous interpretation of results in the context of comparative judgements based on the lateralization of emotions (e.g., SNARC-like instructional flexibility, Lee et al., 2016; Patro & Shaki, 2016; Shaki & Fischer, 2008; Shaki et al., 2012). Indeed, we did not observe any reliable compatibility effect between the speed of left-to-right hand responses and the global valence elicited by a pair of facial expressions, beyond a global emotion anisotropy speeding up performance associated with the happiest rather than the angriest face to be judged. According to ESC but not SNARC-like instructional flexibility, we instead found a full cross-over effect between right-to-left response speed deviations calculated amongst emotional pairs in congruent vs. incongruent condition. This finding satisfies one major operative purpose of our study: to test whether SNARC-like instructional flexibility can be reinterpreted in the light of a task independent ESC bias, thus controlling for the possible effect of the spatial congruency of an highly overlearned magnitudes (i.e., facial expressions of emotions depicting affects opposed on the only domain of valence like anger vs. happiness). The empirical data from all our three experiments are equally consistent with the SIA estimates: a proof that such a stimulus driven theoretical framework provides a thoughtful and effective predictor for speed performances in comparative judgement of emotions.

How can we reconcile our results with previous results on comparative judgements on non-symbolic magnitudes assuming an association between the mental spatial representation of intensities and the response code?

The robustness of our results across Experiments and in particular the finding of a similar ESC pattern in Experiment 1, in which we used explicit comparative instructions with the valence that was task relevant, and Experiment 3, in which we used implicit comparative instructions with the valence that was task irrelevant, are consistent with the standard cross-over pattern characterizing the semantic congruency effect (Banks et al, 1976). This cross-over pattern has been shown to be robust to the domain of the judged intensity, to past-experience and instructions, differently from the one expected on the basis of the SNARC-like effect which have been demonstrated to be culturally (Shaki & Fischer, 2008; Shaki et al., 2009; Zebian, 2005), domain (Prpic et al, 2018; Shaki & Fischer, 2008; Shaki et al., 2009), as well as action (Pitt & Casasanto, 2017), and instruction dependent (Bächtold et al., 1998; Macnamara et al., 2018; Prpic et al. 2016; 2018). A cross-over pattern similar to the one characterizing our ESC in the direct and the indirect task conditions of Experiment 1 and 3 respectively, has indeed been found to occur also in both overlearned symbolic magnitudes, like positive numerals (Banks et al., 1976), as well as on unfamiliar spatial attributes like balloons and yo-yo (Banks et al., 1975), pictures, words of animals (Banks & Flora, 1977), age, (Ellis, 1972), probabilities of events (Marks, 1972), racial identity as defined by skin colour (Friend, 1973), and also in comparison judgements of auditory stimuli (Banks & Root, 1979), thermal stimuli (Zhou, et al., 2017), as well as in several visual dimensions like brightness (Audley & Wallis, 1964; Patro & Haman, 2012), height, depth, size, and width (Clark et al., 1973), and in different instruction conditions (blocked and randomized, Shaki et al., 2006; usual and category-contingent, Leth-Steensen, Petrusic, & Shaki, 2014; just learned, Petrusic, Shaki, & Leth-Steensen, 2008). Furthermore, the typical cross-over pattern we observed in ESC has been found to be independent of cognitive processes involved in the encoding stage of the stimulus like the Stroop effect (Shaki & Algom, 2002), as well as on the acquisition of counting/semantic principles as occurring in animals and preschool children (Cantlon & Brannon, 2005; Jones, Cantlon, Merritt, & Brannon, 2010; Patro & Haman, 2012). These results together with our results suggest that the locus of ESC is likely to be located at a rather low level stage of decision (Shaki & Algom, 2002), thus being a manifestation of bottom-up affective stimulus processing. The occurrence of a task independent ESC in Experiment 1 and 3 is thus consistent with the great amount of evidence showing a prioritization in early sensory processing of affective emotional over neutral stimuli with emotional stimuli evoking greater activation in relevant early visual cortical regions (Lane et al., 1999; Morris et al., 1998; Sabatinelli et al., 2005; Vuilleumier et al., 2003), and being more likely to capture visual spatial attention (Fox, 2002; Hansen & Hansen, 1994; Öhman et al., 2001a; Öhman et al., 2001b). According to this evidence, judgement speeds in our Experiments might have been modulated by stimulus-driven exogenous attention with emotional faces being automatically and rapidly encoded. It is likely, that such an automatic encoding produced a twofold effect: speeding up responses, when the target face is emotional vs. slowing down responses when the target face is neutral, as a by-product of a capturing of observer's motor behaviour because of motivational significance (Reeck & Egner, 2015; Carretié, 2014; Ferrari et al., 2008). It is possible that a similar attentional process regulated the comparative judgement speeds obtained by previous studies on non-symbolic numerosities that interpreted their mixed SLE pattern in favour of SLE (e.g., Patro & Shaki, 2016). However, a recoding of judgement speeds using the spatial congruency of the pair relative to the right-to-left mental format rather than the type of task ("Choose Fewer" vs. "Choose More"), could reveal a pattern of data compatible with the cross-over pattern characterizing our ESC (e.g., consider for instance the pattern of RTs published in the Table 1 by Patro & Shaki, 2016). This would undermine previous interpretation of results in the context of comparative judgements based on SLE.

In general the results of Experiment 2 together with those of Experiment 1 allow us to answer to two further questions: (1) Is the effect of the direct association between stimulus intensities and response speed in comparative judgements of facial expressions of emotions found in Experiment 1 independent of the spatial reorienting of attention (supporting the robustness of the SIA model excluding the requirement of a lateralized presentation of stimuli for the occurrence of an SLE pattern)?; (2) Is comparative judgements of facial expressions of emotions, on average, modified by displaying an emotional pair tachistoscopically rather than until the observer's response?

Overall results support a positive answer to both questions. The data trends obtained in Experiment 2 were strikingly similar to those of Experiment 1 (Question 1), despite the fact that in Experiment 2 emotions were presented briefly, producing a prioritization of response speeds over accuracy (Question 2). These findings support the idea that motor planning is directly linked to stimulus intensities even in the absence of explicit attentional shift, and that the process governing choice in comparative judgements of emotions, is likely to be isotropic on task demand (as supported by the absence of SLE) and fully constrained by the intensities conveyed by the emotional pair (as supported by the consistent reversal of SLE pattern in spatially incongruent conditions). The overall planning of motor response (i.e., onset) is, in contrast, anisotropic and likely consisting of a reduced effectiveness of emotional pairs tachistoscopically presented vs. self-terminated by the participant's response, as supported by the overall performance loss of Experiment 2 producing a reduction of accuracy in favour of response speed.

There is a great amount of evidence on the existence of a common cerebral representation of both symbolic and non-symbolic magnitudes in the Intraparietal Sulcus (Bueti & Walsh, 2009; Dehaene, Dehaene-Lambertz, & Cohen, 1998; Hubbard, Piazza, Pinel, & Dehaene, 2005; Walsh, 2003; Zorzi, Priftis, & Umiltà, 2002). This evidence further supports the Intraparietal Sulcus is specifically responsive when two stimuli are compared, irrespective of their format (Fias, Lammertyn, Reynvoet, Dupont, & Orban, 2003). Accumulating neuropsychological evidence could shed light on the brain regions in which emotional intensities are remapped into response latencies according to SIA, given that the direct association between emotion intensities and motor responses revealed by our results produces behavioural patterns similar to those induced by an *analog* representation of magnitude. The brain path of Intraparietal Sulcus covered from lateral intraparietal cortex area to the ventral intraparietal cortex -area provides an intermediate *analog* representation of numerosity before the arising of a cardinal representation of number (Dehaene & Changeux, 1993; Verguts & Fias, 2004) sensitive to visual properties like motion directionality (Colby, Duhamel, & Goldberg, 1993; Fanini & Assad, 2009; Schwiedrzik, Bernstein, & Melloni, 2016) might also be responsible for the ESC.

As a perspective point, the overall lack of evidence for an effect of emotion lateralization on the control of left/right responses revealed by our study parallels recent findings on the dynamic of corticospinal excitability during motor preparation in RT left/right tasks, demonstrating a similar recruitment of preparatory inhibitory mechanisms within the two cerebral hemispheres, not a hemispheric asymmetry (Duque, Greenhouse, Labruna, & Ivry, 2017; Greenhouse, Sias, Labruna, & Ivry, 2015; Klein, Duque, Labruna, & Ivry, 2016).

Although we expect our results to generalize to other emotional facial expressions, it is worth noting as a caveat that the current findings are only demonstrated in relation to the happy-to-angry dimension which are optimally opposed along the continuum of valence with angry expressions evoking low likeability and high power/arousal, vs. happy expressions evoking high likeability and high power/arousal

(Davidson, 1984). Future studies might address ESC robustness to different emotional dimensions eliciting opposite approach/withdrawal behavior (e.g., fearful and/or disgusted vs. happy faces).

Acknowledgements

We would like to thank all participants and Soraya Elisabeth Shamloo for help for reading and thoughtful suggestions on a previous version of the paper.

Funding sources

This work was supported by a Finanziamento per Ricerca di Ateneo FRA (FRA 2016, University of Trieste) to CF. GB was supported by an international Fellowship within the FSE 2014-2020 programme of Regione Autonoma Friuli Venezia Giulia.

References

Adolphs, R. (2002). Neural systems for recognizing emotion. *Current Opinion in Neurobiology, 12*(2), 169–177. https://doi.org/10.1016/S0959-4388(02)00301-X.

Adolphs, R., Damasio, H., Tranel, D., & Damasio, A. R. (1996). Cortical systems for the recognition of emotion in facial expressions. *The Journal of Neuroscience, 16*(23), 7678–7687.

Adolphs, R., Jansari, A., & Tranel, D. (2001). Hemispheric perception of emotional valence from facial expressions. *Neuropsychology, 15*(4), 516–524. https://doi.org/10.1037/0894-4105.15.4.516.

Ahs, F., Davis, C. F., Gorka, A. X., & Hariri, A. R. (2014). Feature-based representations of emotional facial expressions in the human amygdala. *Social Cognitive and Affective Neuroscience, 9*(9), 1372–1378. https://doi.org/10.1093/scan/nst112.

Alpers, G. W., & Gerdes, A. (2007). Here is looking at you: emotional faces predominate in binocular rivalry. *Emotion, 7*(3), 495. https://doi.org/10.1037/1528-3542.7.3.495.

Alpers, G., & Pauli, P. (2006). Emotional pictures predominate in binocular rivalry. *Cognition & emotion, 20*(5), 596–607. https://doi.org/10.1080/02699930500282249.

Alpers, G. W., Ruhleder, M., Walz, N., Mühlberger, A., & Pauli, P. (2005). Binocular rivalry between emotional and neutral stimuli: A validation using fear conditioning and EEG. *International Journal of Psychophysiology, 57*(1), 25–32. https://doi.org/10.1016/j.ijpsycho.2005.01.008.

Anderson, A. K. (2005). Affective influences on the attentional dynamics supporting awareness. *Journal of Experimental Psychology: General, 134*(2), 258. https://doi.org/10.1037/0096-3445.134.2.258.

Alves, N. T., Aznar-Casanova, J. A., & Fukusima, S. S. (2009). Patterns of brain asymmetry in the perception of positive and negative facial expressions. *Laterality, 14*(3), 256–272. https://doi.org/10.1080/13576500802362927.

Audley, R. J., & Wallis, C. P. (1964). Response instructions and the speed of relative judgements: I. Some experiments on brightness discrimination. *British Journal of Psychology, 55*(1), 59–73. https://doi.org/10.1111/j.2044-8295.1964.tb00898.x.

Bächtold, D., Baumüller, M., & Brugger, P. (1998). Stimulus-response compatibility in representational space. *Neuropsychologia, 36*(8), 731–735.

Banks, W. P., Clark, H. H., & Lucy, P. (1975). The locus of the semantic congruity effect in comparative judgement. *Journal of Experimental Psychology: Human Perception and Performance, 1*(1), 35–47. https://doi.org/10.1037//0096-1523.1.1.35.

Banks, W. P., & Flora, J. (1977). Semantic and perceptual processes in symbolic comparisons. *Journal of Experimental Psychology: Human Perception and Performance, 3*(2), 278–290. https://doi.org/10.1037/0096-1523.3.2.278.

Banks, W. P., Fujii, M., & Kayra-Stuart, F. (1976). Semantic congruity effects in comparative judgments of magnitudes of digits. *Journal of Experimental Psychology Human Perception & Performance, 2*(3), 435–447. https://doi.org/10.1037/0096-1523.2.3.435.

Banks, W. P., & Root, M. (1979). Semantic congruity effects in judgements of loudness. *Perception & Psychophysics, 26*(2), 133–142. https://doi.org/10.3758/BF03208307.

Bates, D. M. (2010). *Lme4: Mixed-Effects Modeling with R.* New York: Springer.

Bates, D., Mächler, M., Bokler, B., & Walker, S. (2014). Fitting linear mixed-effects models using lme4. Retrieved from http://arxiv.org/abs/1406.5823.

Bayle, D. J., Schoendorff, B., Hénaff, M. A., & Krolak-Salmon, P. (2011). Emotional facial expression detection in the peripheral visual field. *PLoS One, 6*(6), https://doi.org/10.1371/journal.pone.0021584.

Becker, D. V., Anderson, U. S., Mortensen, C. R., Neufeld, S., & Neel, R. (2011). The face in the crowd effect unconfounded: happy faces, not angry faces, are more efficiently detected in the visual search task. *Journal of Experimental Psychology: General, 140*(4), 637–659. https://doi.org/10.1037/a0024060.

Becker, D. V., Neel, R., Srinivasan, N., Neufeld, S., Kumar, D., & Fouse, S. (2012). The vividness of happiness in dynamic facial displays of emotion. *PLoS One, 7*(1), https://doi.org/10.1371/journal.pone.0026551.

Benson, P. J., & Perrett, D. I. (1993). Extracting prototypical facial images from exemplars. *Perception, 22*(3), 257–262. https://doi.org/10.1068/p220257.

Bourne, J. V. (2006). The divided visual field paradigm: methodological considerations. *Laterality: Asymmetries of Body, Brain and Cognition, 11*(4), 373–393. https://doi.org/10.1080/13576500600633982.

Bourne, J. V. (2008). Examining the relationship between degree of handedness and degree of cerebral lateralization for processing facial emotion. *Neuropsychology, 22*(3), 350–356. https://doi.org/10.1037/0894-4105.22.3.350.

Bourne, J. V. (2010). How are emotions lateralised in the brain? Contrasting existing hypotheses using the Chimeric Faces Test. *Cognition and Emotion, 24*(5), 903–911. https://doi.org/10.1080/02699930903007714.

Bryden, M. P. (1965). Tachistoscopic recognition, handedness, and cerebral dominance. *Neuropsychologia, 3*(1), 1–8. https://doi.org/10.1016/0028-3932(65)90015-1.

Buckley, P. B., & Gillman, C. B. (1974). Comparison of digits and dot patterns. *Journal of Experimental Psychology, 103*(6), 1131–1136. https://doi.org/10.1037/h0037361.

Bueti, D., & Walsh, V. (2009). The parietal cortex and the representation of time, space, number and other magnitudes. *Philosophical Transactions of the Royal Society B: Biological Sciences, 364*(1525), 1831–1840. https://doi.org/10.1098/rstb.2009.0028.

Canli, T. (1999). Hemispheric asymmetry in the experience of emotion: A perspective from functional imaging. *The Neuroscientist, 5*(4), 201–207. https://doi.org/10.1177/107385849900500409.

Cantlon, J. F., & Brannon, E. M. (2005). Semantic congruity affects numerical judgments similarly in monkeys and humans. *Proceedings of the National Academy of Sciences of the United States of America, 102*(45), 16507–16511. https://doi.org/10.1073/pnas.0506463102.

Carretié, L. (2014). Exogenous (automatic) attention to emotional stimuli: a review. *Cognitive, Affective, & Behavioral Neuroscience, 14*(4), 1228–1258. https://doi.org/10.3758/s13415-014-0270-2.

Casasanto, D. (2009). Embodiment of abstract concepts: good and bad in right- and left-handers. *Journal of Experimental Psychology: General, 138*(3), 351–367. https://doi.org/10.1037/a0015854.

Casasanto, D. (2011). Different bodies, different minds: the body specificity of language and thought. *Current Directions in Psychological Science, 20*(6), 378–383. https://doi.org/10.1177/0963721411422058.

Casasanto, D., & Chrysikou, E. G. (2011). When left is "right": motor fluency shapes abstract concepts. *Psychological Science, 22*(4), 419–422. https://doi.org/10.1177/0956797611401755.

Cech, C. G. (1995). Is congruity due to encoding? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*(5), 1275–1288. https://doi.org/10.1037/0278-7393.21.5.1275.

Cech, C. G., Shoben, E. J., & Love, M. (1990). Multiple congruity effects in judgments of magnitude. *Journal of Experimental Psychology: Learning, Memory, & Cognition, 16*(6), 1142–1152. https://doi.org/10.1037/0278-7393.16.6.1142.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *The Journal of the acoustical society of America, 25*(5), 975–979. https://doi.org/10.1121/1.1907229.

Clark, H. H., Carpenter, P. A., & Just, M. A. (1973). On the meeting of semantics and perception. In W. G. Chase (Ed.). *Visual information processing.* New York: Academic Press.

Colby, C. L., Duhamel, J. R., & Goldberg, M. E. (1993). Ventral intraparietal area of the macaque: anatomic location and visual response properties. *Journal of Neurophysiology, 69*(3), 902–914. https://doi.org/10.1152/jn.1993.69.3.902.

Damjanovic, L., & Santiago, J. (2016). Contrasting vertical and horizontal representations of affect in emotional visual search. *Psychonomic Bulletin & Review, 23*(1), 62–73. https://doi.org/10.3758/s13423-015-0884-6.

Davidson, R. J. (1984). 11 Affect, cognition, and hemispheric specialization. In C. E. Izard, J. Kagan, & R. Zajonc (Eds.). *Emotion, Cognition, and Behavior*. New York: Cambridge: University Press.

Davidson, R. J. (1995). Cerebral asymmetry, emotion, and affective style. In R. J. Davidson, & K. Hugdahl (Eds.). *Brain asymmetry*. Massachusetts: MIT Press.

Dehaene, S., Bossini, S., & Giraux, P. (1993). The mental representation of parity and number magnitude. *Journal of Experimental Psychology: General, 122*(3), 371–396. https://doi.org/10.1037/0096-3445.122.3.371.

Dehaene, S., & Changeux, J. P. (1993). Development of elementary numerical abilities: a neuronal model. *Journal of Cognitive Neuroscience, 5*(4), 390–407. https://doi.org/10.1162/jocn.1993.5.4.390.

Dehaene, S., Dehaene-Lambertz, G., & Cohen, L. (1998). Abstract representations of numbers in the animal and human brain. *Trends in Neurosciences, 21*(8), 355–361. https://doi.org/10.1016/S0166-2236(98)01263-6.

Dehaene, S., Dupoux, E., & Mehler, J. (1990). Is numerical comparison digital? Analogical and symbolic effects in two-digit number comparison. *Journal of Experimental Psychology: Human Perception and Performance, 16*(3), 626. https://doi.org/10.1037/0096-1523.16.3.626.

DeKosky, S. T., Heilman, K. M., Bowers, D., & Valenstein, E. (1980). Recognition and discrimination of emotional faces and pictures. *Brain and Language, 9*(2), 206–214. https://doi.org/10.1016/0093-934X(80)90141-8.

Delgado, M. R., Nearing, K. I., LeDoux, J. E., & Phelps, E. A. (2008). Neural circuitry underlying the regulation of conditioned fear and its relation to extinction. *Neuron, 59*(5), 829–838. https://doi.org/10.1016/j.neuron.2008.06.029.

Duncan, E. M., & McFarland, C. E. (1980). Isolating the effects of symbolic distance and semantic congruity in comparative judgments: an additive-factors analysis. *Memory & Cognition, 8*(6), 612–622. https://doi.org/10.3758/BF03213781.

Duque, J., Greenhouse, I., Labruna, L., & Ivry, R. B. (2017). Physiological markers of motor inhibition during human behavior. *Trends in Neuroscience, 40*(4), 219–236. https://doi.org/10.1016/j.tins.2017.02.006.

Ellis, S. H. (1972). Interaction of encoding and retrieval in relative age judgments: an extension of the “crossover” effect. *Journal of Experimental Psychology, 94*(3), 291–294. https://doi.org/10.1037/h0032800.

Everhart, D. E., & Harrison, D. W. (2000). Facial affect perception among anxious and non-anxious men. *Psychobiology, 28*(1), 90–98. https://doi.org/10.3758/BF03330632.

Fanini, A., & Assad, J. A. (2009). Direction selectivity of neurons in the macaque lateral intraparietal area. *Journal of Neurophysiology, 101*(1), 289–305. https://doi.org/10.1152/jn.00400.2007.

Fantoni, C., & Gerbino, W. (2014). Body actions change the appearance of facial expressions. *PLoS One, 9*(9), https://doi.org/10.1371/journal.pone.0108211.

Fantoni, C., Rigutti, S., & Gerbino, W. (2016a). Bodily action penetrates affective perception. *PeerJ, 4*. https://doi.org/10.7717/peerj.1677.

Fantoni, C., Rigutti, S., Piccoli, V., Sommacal, E., & Carnaghi, A. (2016b). Faster but less careful prehension in presence of high, rather than low, social status attendees. *PLoS One, 11*(6), https://doi.org/10.1371/journal.pone.0158095.

Ferrari, V., Codispoti, M., Cardinale, R., & Bradley, M. M. (2008). Directed and motivated attention during processing of natural scenes. *Journal of cognitive neuroscience, 20*(10), 1753–1761. https://doi.org/10.1162/jocn.2008.20121.

Fias, W., Lammertyn, J., Reynvoet, B., Dupont, P., & Orban, G. A. (2003). Parietal representation of symbolic and nonsymbolic magnitude. *Journal of Cognitive Neuroscience, 15*(1), 47–56. https://doi.org/10.1162/089892903321107819.

Fischer, M. H. (2003). Cognitive representation of negative numbers. *Psychological Science, 14*(3), 278–282. https://doi.org/10.1111/1467-9280.03435.

Fox, N. A. (1991). If it's not left, it's right: Electroencephalograph asymmetry and the development of emotion. *American Psychologist, 46*(8), 863. https://doi.org/10.1037/0003-066X.46.8.863.

Fox, E. (2002). Processing emotional facial expressions: The role of anxiety and awareness. *Cognitive, Affective, & Behavioral Neuroscience, 2*(1), 52–63. https://doi.org/10.3758/CABN.2.1.52.

Friend, K. E. (1973). Perceptual encoding in comparative judgments of race. *Memory and Cognition, 1*(1), 80–84. https://doi.org/10.3758/BF03198074.

Fumarola, A., Prpic, V., Da Pos, O., Murgia, M., Umiltà, C., & Agostini, T. (2014). Automatic spatial association for luminance. *Attention, Perception & Psychophysics, 76*(3), 759–765. https://doi.org/10.3758/s13414-013-0614-y.

Fumarola, A., Prpic, V., Fornasier, D., Sartoretto, F., Agostini, T., & Umiltà, C. (2016). The spatial representation of Angles. *Perception, 45*(11), 1320–1330. https://doi.org/10.1177/0301006616661915.

Gerbino, W., & Fantoni, C. (2016). Action valence and affective perception. *Behavioral and Brain Sciences, 39*. https://doi.org/10.1017/S0140525X15002605.

Greenhouse, I., Sias, A., Labruna, L., & Ivry, R. B. (2015). Nonspecific inhibition of the motor system during response preparation. *The Journal of Neuroscience, 35*(30), 10675–10684. https://doi.org/10.1523/JNEUROSCI.1436-15.2015.

Hansen, C. H., & Hansen, R. D. (1994). Automatic emotion: Attention and facial efference. In P. M. Niedenthal, & S. Kitayama (Eds.). *The heart's eye: Emotional influences in perception and attention*. San Diego: Academic Press.

Harmon-Jones, E. (2004). Contributions from research on anger and cognitive dissonance to understanding the motivational functions of asymmetrical frontal brain activity. *Biological Psychology, 67*(1–2), 51–76. https://doi.org/10.1016/j.biopsycho.2004.03.003.

Heilman, K. M., Scholes, R., & Watson, R. T. (1975). Auditory affective agnosia: disturbed comprehension of affective speech. *Journal of Neurology, Neurosurgery, and Psychiatry, 38*(1), 69–72. https://doi.org/10.1136/jnnp.38.1.69.

Holmes, K. J., & Lourenco, S. F. (2011). Common spatial organization of number and emotional expression: a mental magnitude line. *Brain and Cognition, 77*(2), 315–323. https://doi.org/10.1016/j.bandc.2011.07.002.

Holyoak, K. J. (1978). Comparative judgments with numerical reference points. *Cognitive Psychology, 10*(2), 203–243. https://doi.org/10.1016/0010-0285(78)90014-2.

Hubbard, E. M., Piazza, M., Pinel, P., & Dehaene, S. (2005). Interactions between number and space in parietal cortex. *Nature Reviews Neuroscience, 6*(6), 435–448. https://doi.org/10.1038/nrn1684.

Jansari, A., Rodway, P., & Goncalves, S. (2011). Identifying facial emotions: valence specific effects and an exploration of the effects of viewer gender. *Brain and Cognition, 76*(3), 415–423. https://doi.org/10.1016/j.bandc.2011.03.009.

Jansari, A., Tranel, D., & Adolphs, R. (2000). A valence-specific lateral bias for discriminating emotional facial expressions in free field. *Cognition and Emotion, 14*(3), 341–353. https://doi.org/10.1080/026999300378860.

Jones, S. M., Cantlon, J. F., Merritt, D. J., & Brannon, E. M. (2010). Context affects the numerical semantic congruity effect in rhesus monkeys (Macaca mulatta). *Behavioural Processes, 83*(2), 191–196. https://doi.org/10.1016/j.beproc.2009.12.009.

Juth, P., Lundqvist, D., Karlsson, A., & Öhman, A. (2005). Looking for foes and friends: perceptual and emotional factors when finding a face in the crowd. *Emotion, 5*(4), 379–395. https://doi.org/10.1037/1528-3542.5.4.379.

Klein, P. A., Duque, J., Labruna, L., & Ivry, R. B. (2016). Comparison of the two cerebral hemispheres in inhibitory processes operative during movement preparation. *NeuroImage, 125*, 220–232. https://doi.org/10.1016/j.neuroimage.2015.10.007.

Kliegl, R., Wie, P., Dambacher, M., Yan, M., & Zhou, X. (2011). Experimental effects and individual differences in linear mixed models: estimating the relationship between spatial, object, and attraction effects in visual attention. *Frontiers in Psychology, 1*, 238. https://doi.org/10.3389/fpsyg.2010.00238.

Kolb, B., & Taylor, L. (1981). Affective behavior in patients with localized cortical excisions: role of lesion site and side. *Science, 214*(4516), 89–91. https://doi.org/10.1126/science.7280683.

Landis, T., Assal, G., & Perret, C. (1979). Opposite cerebral hemispheric superiorities for visual associative processing of emotional facial expressions and objects. *Nature, 278*(5706), 739–740. https://doi.org/10.1038/278739a0.

Lane, R. D., Chua, P. M., & Dolan, R. J. (1999). Common effects of emotional valence, arousal and attention on neural activation during visual processing of pictures. *Neuropsychologia, 37*(9), 989–997. https://doi.org/10.1016/S0028-3932(99)00017-2.

Langner, O., Dotsch, R., Bijlstra, G., Wigboldus, D. H. J., Hawk, S. T., & van Knippenberg, A. (2010). Presentation and validation of the Radboud Faces Database. *Cognition and Emotion, 24*(8), 1377–1388. https://doi.org/10.1080/02699930903485076.

Lee, D., Chun, J., & Cho, S. (2016). The instructional dependency of SNARC effects reveals flexibility of the space-magnitude association of nonsymbolic and symbolic magnitudes. *Perception, 45*(5), 552–567. https://doi.org/10.1177/0301006616629027.

Leth-Steensen, C., Petrusic, W. M., & Shaki, S. (2014). Enhancing semantic congruity effects with category-contingent comparative judgments. *Frontiers in Psychology, 5*, 1199. https://doi.org/10.3389/fpsyg.2014.01199.

Lim, S. L., Padmala, S., & Pessoa, L. (2009). Segregating the significant from the mundane on a moment-to-moment basis via direct and indirect amygdala contributions. *Proceedings of the National Academy of Sciences, 106*(39), 16841–16846. https://doi.org/10.1073/pnas.0904551106.

Lin, H., Mueller-Bardorff, M., Mothes-Lasch, M., Buff, C., Brinkmann, L., Miltner, W. H., & Straube, T. (2016). Effects of intensity of facial expressions on amygdalar activation independently of valence. *Frontiers in Human Neuroscience, 10*, 646. https://doi.org/10.3389/fnhum.2016.00646.

Macnamara, A., Keage, H. A., & Loetscher, T. (2018). Mapping of non-numerical domains on space: a systematic review and meta-analysis. *Experimental Brain Research, 236*(2), 335–346. https://doi.org/10.1007/s00221-017-5154-6.

Mark, L. S., Nemeth, K., Gardner, D., Dainoff, M. J., Paasche, J., Duffy, M., & Grandt, K. (1997). Postural dynamics and the preferred critical boundary for visually guided reaching. *Journal of Experimental Psychology: Human Perception and Performance, 23*(5), 1365–1379. https://doi.org/10.1037/0096-1523.23.5.1365.

Marks, D. F. (1972). Relative judgement: a phenomenon and a theory. *Perception & Psychophysics, 11*(2), 156–160. https://doi.org/10.3758/BF03210364.

Marsh, A. A., Ambady, N., & Kleck, R. E. (2005). The effects of fear and anger facial expressions on approach-and avoidance-related behaviors. *Emotion, 5*(1), 119. https://doi.org/10.1037/1528-3542.5.1.119.

Marschark, M., & Paivio, A. (1979). Semantic congruity and lexical marking in symbolic comparisons: an expectancy hypothesis. *Memory & Cognition, 7*(3), 175–184. https://doi.org/10.3758/BF03197536.

Marschark, M., & Paivio, A. (1981). Congruity and the perceptual comparison task. *Journal of Experimental Psychology: Human Perception & Performance, 7*(2), 290–308. https://doi.org/10.1037//0096-1523.7.2.290.

McKeever, W. F., & Dixon, M. (1981). Right-hemisphere superiority for discriminating memorized and nonmemorized faces: affective imagery, sex, and perceived emotionality. *Brain and Language, 12*(2), 246–260. https://doi.org/10.1016/0093-934X(81)90017-1.

Medlej, J. (2012). Human Anatomy Fundamentals. Retrieved from https://design.tutsplus.com/series/human-anatomy-fundamentals--cms-724.

Miller, J. (1991). Reaction time analysis with outlier exclusion: bias varies with sample size. *The Quarterly Journal of Experimental Psychology. A, Human Experimental Psychology, 43*(4), 907–912. https://doi.org/10.1080/14640749108400962.

Morris, J. S., Friston, K. J., Büchel, C., Frith, C. D., Young, A. W., Calder, A. J., & Dolan, R. J. (1998). A neuromodulatory role for the human amygdala in processing emotional facial expressions. *Brain: A Journal of Neurology, 121*(1), 47–57. https://doi.org/10.1093/brain/121.1.47.

Morrow, L., Vrtunski, P. B., Kim, Y., & Boller, F. (1981). Arousal responses to emotional stimuli and laterality of lesion. *Neuropsychologia, 19*(1), 65–71. https://doi.org/10.1016/0028-3932(81)90045-2.

Moyer, R. S., & Landauer, T. K. (1967). The time required for judgments of numerical inequality. *Nature, 215*(5109), 1519–1520. https://doi.org/10.1038/2151519a0.

Natale, M., Gur, R. E., & Gur, R. C. (1983). Hemispheric asymmetries in processing emotional expressions. *Neuropsychologia, 21*(5), 555–565. https://doi.org/10.1016/0028-3932(83)90011-8.

Nummenmaa, L., Glerean, E., Hari, R., & Hietanen, J. K. (2014). Bodily maps of emotions. *Proceedings of the National Academy of Sciences of the United States of America, 111*(2), 646–651. https://doi.org/10.1073/pnas.1321664111.

Öhman, A., Flykt, A., & Esteves, F. (2001a). Emotion drives attention: detecting the snake in the grass. *Journal of Experimental Psychology: General, 130*(3), 466. https://doi.org/10.1037/0096-3445.130.3.466.

Öhman, A., Lundqvist, D., & Esteves, F. (2001b). The face in the crowd revisited: a threat advantage with schematic stimuli. *Journal of Personality and Social Psychology, 80*(3), 381.

Oldfield, R. C. (1971). The assessment and analysis of handedness: the Edinburgh Inventory. *Neuropsychologia, 9*(1), 97–113. https://doi.org/10.1016/0028-3932(71)90067-4.

Patro, K., & Haman, M. (2012). The spatial-numerical congruity effect in preschoolers. *Journal of Experimental Child Psychology, 111*(3), 534–542. https://doi.org/10.1016/j.jecp.2011.09.006.

Patro, K., & Shaki, S. (2016). SNARC for numerosities is modulated by comparative instruction (and resembles some non-numerical effects). *Cognitive Processing, 17*(2), 127–137. https://doi.org/10.1007/s10339-015-0745-2.

Petrusic, W. M., Shaki, S., & Leth-Steensen, C. (2008). Remembered instructions with symbolic and perceptual comparisons. *Perception & Psychophysics, 70*(2), 79–189. https://doi.org/10.3758/PP.70.2.179.

Pessoa, L., Kastner, S., & Ungerleider, L. G. (2002). Attentional control of the processing of neutral and emotional stimuli. *Cognitive Brain Research, 15*(1), 31–45. https://doi.org/10.1016/S0926-6410(02)00214-8.

Pitt, B., & Casasanto, D. (2017). Spatializing emotion: no evidence for a domain-general

magnitude system. *Cognitive Science*. https://doi.org/10.1111/cogs.12568.
Prete, G., Laeng, B., Fabri, M., Foschi, N., & Tommasi, L. (2015). Right hemisphere or valence hypothesis, or both? The processing of hybrid faces in the intact and callosotomized brain. *Neuropsychologia, 68*, 94–106. https://doi.org/10.1016/j.neuropsychologia.2015.01.002.
Prpic, V., Fumarola, A., De Tommaso, M., Luccio, R., Murgia, M., & Agostini, T. (2016). Separate mechanisms for magnitude and order processing in the spatial-numerical association of response codes (SNARC) effect: The strange case of musical note values. *Journal of Experimental Psychology: Human Perception and Performance, 42*(8), 1241–1251. https://doi.org/10.1037/xhp0000217.
Prpic, V., Soranzo, A., Santoro, I., Fantoni, C., Galmonte, A., Agostini, T., & Murgia, M. (2018). SNARC-like compatibility effects for physical and phenomenal magnitudes: A study on visual illusions. *Psychological Research, 1–16*. https://doi.org/10.1007/s00426-018-1125-1.
Quaranta, A., Siniscalchi, M., & Vallortigara, G. (2007). Asymmetric tail-wagging responses by dogs to different emotive stimuli. *Current Biology, 17*(6), R199–R201. https://doi.org/10.1016/j.cub.2007.02.008.
Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin, 114*(3), 510–532. https://doi.org/10.1037/0033-2909.114.3.510.
Reeck, C., & Egner, T. (2015). Interactions between Attention and Emotion. In Arthur W. Toga (Vol. Ed.), *Brain Mapping: An Encyclopedic Reference: vol. 3*. Elsevier: Academic Press.
Reuter-Lorenz, P., & Davidson, R. J. (1981). Differential contributions of the two cerebral hemispheres to the perception of happy and sad faces. *Neuropsychologia, 19*(4), 609–613. https://doi.org/10.1016/0028-3932(81)90030-0.
Reuter-Lorenz, P. A., Givis, R. P., & Moscovitch, M. (1983). Hemispheric specialization and the perception of emotion: evidence from right-handers and from inverted and non-inverted left-handers. *Neuropsychologia, 21*(6), 687–692. https://doi.org/10.1016/0028-3932(83)90068-4.
Rigutti, S., Fantoni, C., & Gerbino, W. (2015). Web party effect: a cocktail party effect in the web environment. *PeerJ, 3*. https://doi.org/10.7717/peerj.828.
Robinson, R. G., & Price, T. R. (1982). Post-stroke depressive disorders: a follow-up study of 103 patients. *Stroke, 13*(5), 635–641. https://doi.org/10.1161/01.STR.13.5.635.
Robinson, R. G., & Szetela, B. (1981). Mood change following left hemispheric brain injury. *Annals of Neurology, 9*(5), 447–453. https://doi.org/10.1002/ana.410090506.
Root, J. C., Wong, P. S., & Kinsbourne, M. (2006). Left hemisphere specialization for response to positive emotional expressions: a divided output methodology. *Emotion, 6*(3), 473–483. https://doi.org/10.1037/1528-3542.6.3.473.
Sabatinelli, D., Bradley, M. M., Fitzsimmons, J. R., & Lang, P. J. (2005). Parallel amygdala and inferotemporal activation reflect emotional intensity and fear relevance. *Neuroimage, 24*(4), 1265–1270. https://doi.org/10.1016/j.neuroimage.2004.12.015.
Schwiedrzik, C. M., Bernstein, B., & Melloni, L. (2016). Motion along the mental number line reveals shared representations for numerosity and space. *eLife, 15*. https://doi.org/10.7554/eLife. 10806.
Shaki, S., & Algom, D. (2002). The locus and nature of semantic congruity in symbolic comparison: evidence from the Stroop effect. *Memory & Cognition, 30*(1), 3–17. https://doi.org/10.3758/BF03195260.
Shaki, S., & Fischer, M. H. (2008). Reading space into numbers – a cross-linguistic comparison of the SNARC effect. *Cognition, 108*(2), 590–599. https://doi.org/10.1016/j.cognition.2008.04.001.
Shaki, S., Fischer, M. H., & Petrusic, W. M. (2009). Reading habits for both words and numbers contribute to the SNARC effect. *Psychonomic Bulletin & Review, 16*(2), 328–331. https://doi.org/10.3758/PBR.16.2.328.
Shaki, S., Leth-Steensen, C., & Petrusic, W. M. (2006). Effects of instruction presentation mode in comparative judgments. *Memory & Cognition, 34*(1), 196–206. https://doi.org/10.3758/BF03193398.
Shaki, S., Petrusic, W. M., & Leth-Steensen, C. (2012). SNARC effects with numerical and non-numerical symbolic comparative judgments: instructional and cultural dependencies. *Journal of Experimental Psychology: Human Perception & Performance, 38*(2), 515–530. https://doi.org/10.1037/a0026729.
Silberman, E. K., & Weingartner, H. (1986). Hemispheric lateralization of functions related to emotion. *Brain and Cognition, 5*(3), 322–353. https://doi.org/10.1016/0278-2626(86)90035-7.
Smith, J. R., Lee, G. P., Fountas, K., King, D. W., & Jenkins, P. D. (2006). Intracranial stimulation study of lateralization of affect. *Epilepsy & Behavior, 8*(3), 534–541. https://doi.org/10.1016/j.yebeh.2005.12.014.
Srivastava, P., & Srinivasan, N. (2010). Time course of visual attention with emotional faces. *Attention, Perception & Psychophysics, 72*(2), 369–377. https://doi.org/10.3758/APP.72.2.369.
Tucker, D. M., Watson, R. T., & Heilman, K. M. (1977). Discrimination and evocation of affectively intoned speech in patients with right parietal disease. *Neurology, 27*(10), 947–950. https://doi.org/10.1212/WNL.27.10.947.
Vallortigara, G., Chiandetti, C., & Sovrano, V. A. (2011). Brain asymmetry (animal). *Wiley Interdisciplinary Reviews: Cognitive Science, 2*(2), 146–157. https://doi.org/10.1002/wcs.100.
Verguts, T., & Fias, W. (2004). Representation of number in animals and humans: a neural model. *Journal of Cognitive Neuroscience, 16*(9), 1493–1504. https://doi.org/10.1162/0898929042568497.
Vonesh, E. F., Chinchilli, V. M., & Pu, K. (1996). Goodness-of-fit in generalized nonlinear mixed-effects models. *Biometrics, 52*(2), 572–587. https://doi.org/10.2307/2532896.
Vuilleumier, P., Armony, J. L., Driver, J., & Dolan, R. J. (2003). Distinct spatial frequency sensitivities for processing faces and emotional expressions. *Nature neuroscience, 6*(6), 624. https://doi.org/10.1038/nn1057.
Wallis, C. P., & Audley, R. J. (1964). Response instructions and the speed of relative judgements. II. *Pitch discrimination. British Journal of Psychology, 55*, 121–132. https://doi.org/10.1111/j.2044-8295.1964.tb02712.x.
Walsh, V. (2003). A theory of magnitude: common cortical metrics of time, space and quantity. *Trends in Cognitive Sciences, 7*(11), 483–488. https://doi.org/10.1016/j.tics.2003.09.002.
Wedding, D., & Stalans, L. (1985). Hemispheric differences in the perception of positive and negative faces. *The International Journal of Neuroscience, 27*(3–4), 277–281. https://doi.org/10.3109/00207458509149773.
Whelan, R. (2008). Effective Analysis of Reaction Time Data. *The Psychological Record, 58*(3), 475–482. https://doi.org/10.1007/BF03395630.
Willems, R. M., Van der Haegen, L., Fisher, S. E., & Francks, C. (2014). On the other hand: including left-handers in cognitive neuroscience and neurogenetics. *Nature Reviews Neuroscience, 15*(3), 193–201. https://doi.org/10.1038/nrn3679.
Zebian, S. (2005). Linkages between number concepts, spatial thinking, and directionality of writing: The SNARC effect and the reverse SNARC effect in English and Arabic monoliterates, biliterates, and illiterate Arabic speakers. *Journal of Cognition and Culture, 5*(1), 165–190. https://doi.org/10.1163/1568537054068660.
Zhou, Y., Ho, H. N., & Watanabe, J. (2017). Perceptual-semantic congruency facilitates semantic discrimination of thermal qualities. *Frontiers in Psychology, 8*, 2113. https://doi.org/10.3389/fpsyg.2017.02113.
Zorzi, M., Priftis, K., & Umiltà, C. (2002). Brain damage: neglect disrupts the mental number line. *Nature, 417*(6885), 138–139. https://doi.org/10.1038/417138a.