UNIVERSITÀ DEGLI STUDI DI TRIESTE

XXXII CICLO DEL DOTTORATO DI RICERCA IN

NEUROSCIENZE E SCIENZE COGNITIVE

PO FRIULI VENEZIA GIULIA - FONDO SOCIALE EUROPEO 2014/2020

EMOTIONAL SEMANTIC CONGRUENCY BASED ON STIMULUS DRIVEN COMPARATIVE JUDGEMENTS. FACES IN UPRIGHT/INVERTED ORIENTATION AND NUMBERS

Settore scientifico-disciplinare: **M-PSI/01**

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CONTENTS

Abstract

The left-to-right spatial mental representation of emotional valence has been extensively studied in the past decades. Studies based on speeded classification of centrally presented emotions showed a valence-specific lateral bias, characterized by faster left-sided responses for negative emotions (angry face) and faster right-sided responses for positive emotions (happy face). However, it is not clear whether the valence-specific lateral bias occurs in a valence comparison task (CT) between pairs of simultaneously displayed facial expressions (horizontally aligned), with the instruction to choose the most negative/positive. Differently from studies involving single emotion, in the CT there is a lateralization of both the stimuli (one face is presented at the left- and one at the right-side of the screen) and the responses (using left- and right-hands).

In the present study, I investigated the possible occurrence of the valence-specific lateral bias in a valence CT pairing facial expressions, belonging to the anger-to-neutral-to-happiness emotional continuum, into two types of stimulus pairs: (1) half-range emotional pairs (i.e, a neutral face paired with a 100% emotional angry/happy face); and (2) cross-range emotional pairs (i.e., a 50% or 100% emotional face paired with another emotional face of the same emotional intensity, but with the opposite emotional valence).

In the Study 1, I demonstrated that in a valence CT (with stimulus self-terminated by the participant response), the lateralized motor reactivity is independent from any valence-specific lateral bias. The motor reactivity resulted to be proportional to the target absolute emotional intensity relative to the cutoff (i.e., the neutral face), irrespective of the response side and the congruency with the spatial arrangement of the pair with the left-to-right spatial mental representation of emotional valence. The occurrence of this bias, namely Emotional Semantic Congruency effect (ESC), is fully consistent with a stimulus-driven theoretical framework and a capture of visual spatial attention due to emotional stimuli. The attentional capture phenomenon is predicted by a direct Speed-Intensity Association (SIA) with a remapping of three source of intensities, all intrinsic in the stimulus pairs,

into response speeds. The three sources of intensities are: the target absolute emotional intensity relative to the cutoff, the average valence of the stimulus pair, and an additive/subtractive constant which formalizes an emotion anisotropy, that produces a general improvement of the performance for relatively positive vs. negative emotion intensities. ESC resulted to be independent on lateralization of emotions and it occurs both under tachistoscopic presentation of stimuli and in indirect task condition in which the valence intensity is task irrelevant.

In the Study 2, I demonstrated that ESC is independent from motivational significance of the stimuli, and it is generalizable from the specific domain of emotion (non-symbolic with high motivational significance) to the domain of numbers (symbolic with low motivational significance).

In the Study 3, I demonstrated that ESC is independent from the type of stimulus processing (i.e., part-based or holistic) involved in the processing of face. ESC resulted to be independent form inversion of facial expressions (beyond a global slowing down of responses due to the face inversion effect). Furthermore, I investigated the nature of the emotion anisotropy which is cutoff dependent, and it occurs only in the case in which the cutoff need to be extrapolated from image pairs.

In conclusion, the present work revealed a general mechanism regulating CT, based on a capture of visual spatial attention by the extremal values of a series. This capture is independent from both the representational domain (emotional vs. numerical) and the type of stimulus processing involved (holistic vs. part-based).

1 Introduction

The spatial mental representation of numerical and non-numerical stimuli has been extensively studied in the past decades. A pioneering study based on speeded odd-even judgment of centrally presented digit showed an intensity-specific lateral bias. This bias was characterized by faster left-sided responses for relative small digits and faster right-sided responses for relative large digits, namely a Spatial-Numerical Association of Response Code, SNARC, effect (Dehaene, Bossini, & Giraux, 1993). The SNARC effect resulted to be robust across the type of task, being it either a direct task in which the number magnitude is task relevant (e.g., magnitude comparison task, (Dehaene, Dupoux, & Mehler, 1990), or an indirect task in which the number magnitude is task irrelevant (e.g., odd-even judgment task, (Dehaene et al., 1993).

The SNARC effect resulted to be robust across domains. Indeed, it was found also in non-numerical domains, such as: angle magnitude (Fumarola et al., 2016), loudness (Hartmann & Mast, 2017), luminance (Fumarola et al., 2014), physical size (Ren, Nicholls, Ma, & Chen, 2011), or visually presented note values (Prpic et al., 2016). All these studies found faster left-sided responses for relatively small intensities and faster right-sided responses for relatively large intensities. In the case of non-symbolic domains, the intensity-specific lateral bias is called SNARC-like effect. The SNARC-like effect was also investigated in studies based on speeded classification of centrally presented emotions showing a valence-specific lateral bias (Casasanto, 2011; Holmes & Lourenco, 2011; Lourenco & Aulet, 2019; Pitt & Casasanto, 2017). In these studies, the motor reactivity was characterized by faster left-sided responses for negative emotions (e.g., an angry face) and faster right-sided responses for positive emotions (e.g., a happy face).

When displaying a centrally presented intensity (e.g., Dehaene et al., 1993), the stimulus is non-lateralized, while the responses are lateralized. The difference, in terms of motor reactivity for the same stimulus is observed with the comparison between the motor reactivity (i.e., the response speed) of the left-hand and the right-hand (for review, see Fischer & Shaki, 2014). It is still matter of debate, whether the SNARC effect (or the more general SNARC-like effect) occurs in the case of a comparison task between pairs of simultaneously and horizontally aligned digits (non-numerical intensities), with the instruction to choose the smallest or the largest digit in the pair (Fischer, 2003; Patro & Shaki, 2016; Shaki, Fischer, & Petrusic, 2009). Differently from studies involving single intensity, in the comparison task there is both a lateralization of the stimuli (i.e., one face is presented at the left-side and one at the right-side of the screen) and a lateralization of the responses (i.e., using the left- and right-hands). A clear SNARC effect occurred in the case of numerical magnitude, but a mixed SNARC-like effect pattern occurred with non-numerical magnitudes (e.g., Lee, Chun, & Cho, 2016). The mixed SNARC-like effect was in the standard direction when participants were asked to select the smallest intensity of a pair, and it was null (though weakly reversed) when participants were asked to select the largest member of a pair.

Experimental studies suggested that whether the motor reactivity during a direct comparison task is shaped by purely stimulus-driven factors due to the perceptual encoding of intensity, an alternative bias might occur: the semantic congruency bias (e.g., Banks, Clark, & Lucy, 1975). According to the semantic congruency bias, motor reactivity is proportional to the absolute intensity of the target emotion relative to the cutoff of the series (e.g., the digit 5 in the 1-to-9 digit 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 intensity.

In the present thesis, I report three Studies including seven Experiments (Study 1 includes three Experiments, Study 2 includes two Experiments, and Study 3 includes two Experiments) and investigating whether the motor reactivity in a direct comparison task either depends on the left-to-right spatial mental representation of emotional valence, typically observed with a centrally presented emotions, or depends on stimulus-driven factors due to the perceptual encoding of intensity. In the direct valence comparison task, participants had to choose the angriest (i.e., the most negative) or the happiest (i.e., the most positive) facial expression in the stimulus pair. Facial expressions of emotions belonged to the anger-to-neutral-to-happiness emotional continuum. Such an emotional continuum was characterized by a fully emotional angry face and a fully emotional happy face as extremal intensities and by a neutral face as a central intensity (i.e., the cutoff face). Facial expressions were paired into two types of stimuli that I studied throughout the thesis:

- half-range emotional pairs in which a neutral face was paired with a fully emotional angry/happy face. This resulted in two facial expressions pairs differing in terms of their average valence, being it negative (i.e., angry/negative-neutral faces) or positive (i.e., happy/positive-neutral faces);
- cross-range emotional pairs in which an emotional face was paired with another emotional face of the same emotional intensity, but with the opposite emotional valence. This resulted in the creation of two facial expressions pairs with either two fully emotional angry/happy face (i.e., both faces with 100% emotional intensities) or half-emotional angry/happy face (i.e., both faces with 50% emotional intensities).

All the Experiments and data collected in the three Studies reported in the current thesis, have been conducted in the Active Vision Laboratory of the Department of Life Sciences of the University of Trieste, under the supervision of Professor Carlo Fantoni, with the advice of Professor Tiziano Agostini, Ph.D. Mauro Murgio, Professor Valter Prpic, and Professor Dražen Domijan. All three Studies presented are currently published (the three Experiments of Study 1 and the two Experiments of Study 2) or under revision process (the two Experiments of Study 3) on peer-review journals, and they were all supported by an International Fellowship within the European Social Fund (2014-2020 programme of Regione Autonoma Friuli-Venezia Giulia). Study 1 is published on *Cognition* in 2019 (Fantoni, Baldassi, Rigutti, Prpic, Murgia, & Agostini, 2019, Emotional Semantic Congruency based on stimulus driven comparative judgements, doi: 10.1016/j.cognition.2019.04.014), Study 2 is currently in press on *Psychological Research* (Baldassi, Murgia, Prpic, Rigutti, Domijan, Agostini, & Fantoni, in press, Large as being on top of the world and small as hitting the roof: A common magnitude representation for the comparison of emotions and numbers, doi: 10.1007/s00426-020-01306-3), and Study 3 is currently under review on *Scientific Reports* (Baldassi, Murgia, Prpic, Rigutti, Domijan, Agostini, & Fantoni, under review, Attentional capture in emotion comparison is orientation independent).

In Experiment 1 of Study 1, I first demonstrated that in a direct valence comparison task (i.e., the stimulus was self-terminated by the participant response), the lateralized motor reactivity is independent from any valence-specific lateral bias. The response speeds resulted proportional to the target absolute emotional intensity relative to the cutoff of the emotional continuum (i.e., the neutral face), irrespective of the side of response and the congruency with the spatial arrangement of the pair with the left-to-right spatial mental representation of emotional valence. The occurrence of this bias, namely Emotional Semantic Congruency effect (ESC), is fully consistent with a stimulus-driven theoretical framework and a capture of visual spatial attention due to emotional stimuli (Carretié, 2014; Ferrari, Codispoti, Cardinale, & Bradley, 2008). The attentional capture phenomenon is predicted by a direct Speed-Intensity Association with a remapping of three sources of intensities, all intrinsic in the stimulus pairs, into response speeds. The three sources of intensities are: the target absolute emotional intensity relative to the cutoff of the continuum, the average valence of the stimulus pair, and an additive/subtractive constant which formalizes an *emotion anisotropy*, that produces a general improvement of the performance for relatively positive vs. negative emotion intensities.

In the remaining six Experiments of my thesis, I further investigated the occurrence of ESC in different experimental conditions, that allowed me to address to the following five *research questions*.

(1) *Would ESC hold when the direct valence comparison task is not supported by foveation?*

I attempted to address the following research question in Experiment 2 of Study 1. If ESC holds when the direct valence comparison task is not supported by foveation, it should occur also under tachistoscopic stimulus presentation. In the present Experiment, I used the same direct valence comparison task, but different visual spatial attention requirements, with the tachistoscopic presentation of emotional pairs (i.e., 190 ms), in order to hinder stimulus foveation (Bourne, 2006). This was relevant for investigating whether hemispheric specialization of visual perception of facial expressions of emotions might relate with performance in the direct valence comparison task.

(2) *Is ESC really stimulus-driven as dependent on bottom-up exogenous attention (and not goal-directed as dependent on top-down endogenous attention)?*

I attempted to address the following research question in Experiment 3 of Study 1. If ESC is stimulus-driven as dependent on bottom-up exogenous attention, it should occur in indirect task conditions in which the valence intensity is task irrelevant. In the present Experiment, in a self-terminating stimulus duration (as in the first experiment), I used an emotion identification task, with participants requiring choosing the emotional/neutral face in the emotional pair.

(3) *Is ESC independent from motivational significance of the stimuli and should occur in the symbolic domain, as in the case of Arabic numbers?*

I attempted to address the following research question in Experiments 1 and 2 of Study 2. If ESC is independent from motivational significance of the stimuli and it occurs in the symbolic domain, it should be generalizable from the specific domain of emotion (non-symbolic, high motivational significance) to the domain of numbers (symbolic, absence of motivational significance). In the present Experiment, I to demonstrated that ESC is independent from motivational significance of the stimuli, and it is generalizable from the specific domain of emotion (non-symbolic with high motivational significance) to the domain of numbers (symbolic with low motivational significance). In two experiments participants performed the same direct comparison task on stimulus pairs that were fully comparable in terms of their analog representation of intensity: symbolic magnitudes in the first experiment, vs. facial expressions of emotions in the second experiment.

(4) *Is ESC independent from perceptual components due to the type of stimulus processing (part-based vs. holistic)?*

I attempted to address the following research question in Experiment 1 of Study 3. If ESC is independent from perceptual components due to the type of stimulus processing, it should be not modified by the inversion of facial expressions (beyond a global slowing down of responses due to the face inversion effect). In the present Experiment, I demonstrated that ESC is independent from the type of stimulus processing generally involved in the processing of face. It is well known that human faces are processed differently from other objects. While objects are processed on the basis of their individual parts (e.g., Biederman, 1987), namely a part-based processing, human faces are processed depending on their orientation. Human faces in upright orientation are processed holistically, since faces have properties that cannot be derived from the constituent parts (e.g., Wagemans et al., 2012). Conversely, inverted faces are processed as part-based, and consequently they are processed as non-face objects (Piepers & Robbins, 2012; Valentine, 1988). In the present Experiment I used a direct valence comparison task displaying only half-range emotional pairs in both upright and inverted orientation.

(5) *Is the emotion anisotropy dependent on how emotional magnitudes are represented and in particular by the type of cutoff of the emotional series (explicit vs. implicit within the pair)?*

I attempted to address the following research question in Experiment 2 of Study 3. If the emotion anisotropy depends on the type of cutoff, it should be more evident in the implicit condition when the cutoff need to be extrapolated from image pairs. In a direct comparison task, the attentional strategy used by participants in a comparison task would be based on an implicit/explicit reference frame (e.g., Holyoak & Mah, 1982), namely, the cutoff face of the emotional continuum. In the present Experiment, I used a direct valence comparison task displaying only cross-range expressions pairs in both upright and inverted orientation (in the first experiment), and I compared both the emotion anisotropy between the two Experiments of Study 3 and across the orientation of emotional pairs.

The present thesis aimed to investigate a general mechanism regulating the direct comparison task, which is based on the way visual spatial attention is captured. The extremal values of the intensity continuum, which are maximum in terms of absolute intensity relative of the cutoff, capture visual spatial attention for a larger extend compare to intermediate values of the same intensity continuum. This attentional capture phenomenon is expected to be independent from any intensity-specific lateral bias.

2 Study 1

2.1 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, 2011; Casasanto & Chrysikou, 2011; Dehaene et al., 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 standpoint, 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 (G. Alpers & Pauli, 2006; G. W. Alpers & Gerdes, 2007; G. W. Alpers, Ruhleder, Walz, Mühlberger, & 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 (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).

Considering 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 require (indirect task) the processing of valence (Holmes & Lourenco, 2011; Lee et al., 2016; Shaki, Petrusic, & Leth-Steensen, 2012). In its standard form a comparative judgement would indeed consist in the simultaneous 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 et al., 2009, 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 I addressed this question testing whether simultaneously presented highly overlearned non-symbolic magnitudes automatically (directly – Experiment 1 & 2/indirectly – Experiment 3), and depending on a lateralised processing of valence (under tachistoscopic – Experiment 2- /natural free-viewing conditions – Experiment 1 & 3), elicits 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, 1985; 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 cross-range expressions (with one face being half or fully happy and the other anger) or half-range emotional (with one face being neutral and the other fully happy/or anger) 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" 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 responses (Canli, 2016; Jansari, Tranel, & Adolphs, 2000; Reuter-Lorenz & 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 et al., 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 et al., 1975; Banks, Fujii, & Kayra-Stuart, 1976; Banks & Flora, 1977; 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 subsection 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.

2.1.1 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, Givis, & Moscovitch, 1983; Reuter-Lorenz & Davidson, 1981; 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, & Jenkins, 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; Reuter-Lorenz et al., 1983; Reuter-Lorenz & Davidson, 1981), 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 have used spatial congruency as a predictor variable: the type of direct comparison task is used in its place instead (Fischer, 2003; Jansari et 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).

2.1.2 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

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[1] I considered two different types of half-range emotional 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 I used in in Experiment 1 and 2: "choose the angriest", or the "happiest" between the two. According to spatial congruency, if considering 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 considering 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 I 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.

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.

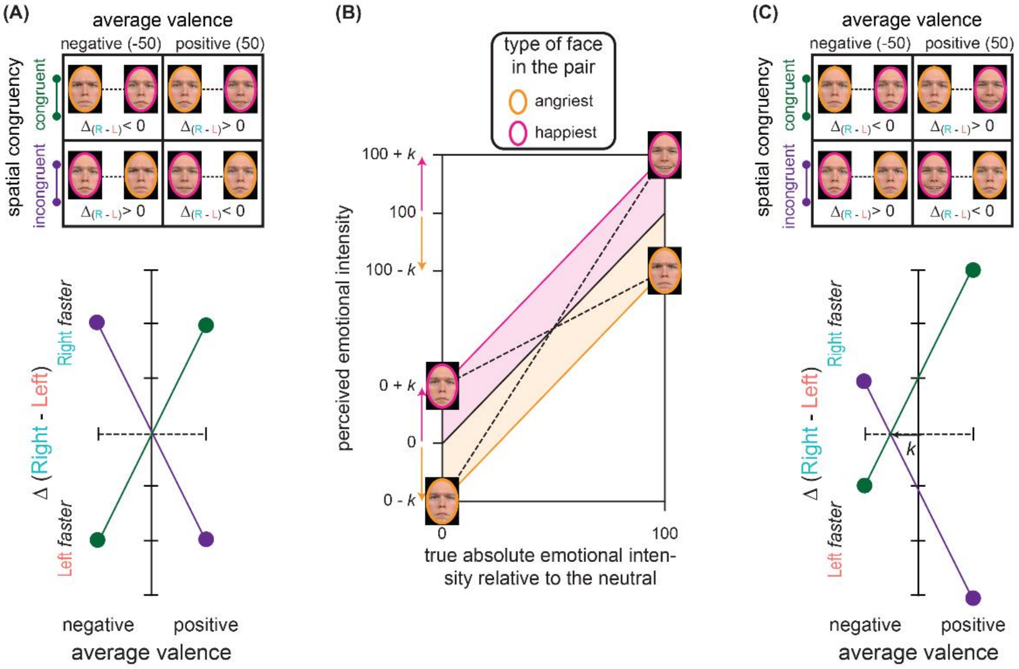

Figure 2.1. ESC-pattern resulting from a stimulus driven framework for comparative judgements of emotions (half-range emotional pairs considered). A and C: Predicted ESC in the average valence × Δspeed Cartesian space resulting from the 2 Spatial Congruency (in rows and coded by colour) × 2 Average Valence (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 half-range emotional 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 Δspeed = |-100| - |0| = + 100 (purple dot in the top-left Cartesian quadrant). The opposite occurs in half-range emotional pairs with large average magnitudes ([+100, 0] tuple-2) and Average 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 average 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 average 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 half-range emotional pairs with positive and negative average 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 emotion 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 2*k* and intersecting in a point with null ordinate and Average 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 average valence and smaller for negative average valence.

Inspiring from pioneering studies on comparative judgements (Audley & Wallis, 1964; Banks et al., 1976, 1976; Clark, Carpenter, & Just, 1973), I 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, I modelled the expected ESC through a stimulus-driven (not goal-directed) theoretical framework of the comparative judgements of emotions.

Consider the two half-range emotional pairs used in the current experiments and shown in Figure 2.1: neutral-fully happy and neutral-fully angry with positive and negative average valence, respectively, in congruent (Figure 2.1A, contingency table, top row), and incongruent (Figure 2.1A, 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

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[2] Throughout the chapter the overall intensity of a pair is operationalized by its average 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 (Figure 1B, x-axis). For instance, a neutral-fully happy pair (Figure 1A or 1C, 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 Average Valence being equal to 50, i.e., (0+100)/2; a neutral-fully angry pair maps into a [0, -100] tuple-2, with negative Average Valence = -50 (Figure 1A or 1C, left, bottom quadrant of contingency table).

[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 half-range emotional pairs belonging to the same average valence domain (average valence = -50 and average valence = +50). Importantly, one major implication of ESC is a reversed SLE pattern for pairs of emotional magnitudes displayed in spatially incongruent position (Figure 2.1A and 2.1C, purple lines and dots), but not for pair of emotions displayed in spatially congruent position (Figure 2.1A and 2.1C, green lines and dots). However, given that this pattern of predictions produces a positive relationship between absolute emotion intensity and expected judgements' speed (Figure 2.1B, 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. I 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 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, 2001; Öhman, Lundqvist, & Esteves, 2001).

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 and Audley (1964) dealing with the funnel effect in comparative judgements of pitch, and of brightness. In Figure 2.1B I 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 (Figure 2.1B continuous pink line) vs. negative for the facial expression that appear angriest (Figure 2.1B 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, 2016; Juth, Lundqvist, Karlsson, & Ohman, 2005; Srivastava & Srinivasan, 2010). In particular, relative to the balanced ESC resulting from an isotropic representation of emotion intensity (Figure 2.1B, black continuous line), such a remapping produces a reduction of the perceived difference between absolute emotional intensities of half-range emotional pairs with negative average valence (Figure 2.1C, left quadrants), relative to those with positive average valence (Figure 2.1C, right quadrants). Under the assumption of a direct SIA the $\Delta\text{speed}_{\text{congruent, negative}} = -100 + 2k$ is expected to be largely smaller than the $\Delta\text{speed}_{\text{congruent, positive}} = 100 + 2k$ and vice-versa the $\Delta\text{speed}_{\text{incongruent, positive}} = -100 - 2k$ is expected to be smaller than the $\Delta\text{speed}_{\text{incongruent, negative}} = 100 - 2k$.

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 average 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.

2.2 Material and methods

In order to fulfil the purpose of our study I 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 lateralised 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 I 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 half-range emotional pairs (i.e., neutral-fully happy or angry pairs) with average valence = +50 or -50 and target intensity = 0 or ± 100; (2) or cross-range emotional pairs (i.e., happy - angry pairs) with average 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 Ishow how the SIA described in section 1.2 (Figure 2.1) 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 (Figure 2.2), likewise:

(1) the target absolute emotional intensity (Figure 2.2A and 2.2D), formalizing ESC-alone and producing a *full cross-over effect* in the domain of emotions;

(2) the average valence formalizing a Size Effect (SE) in the domain of emotion leading overall response speeds to increase as average valence gets larger (Figure 2.2B and 2.2E);

(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 (Figure 2.2C and 2.2F), producing a *funnel effect* in the domain of emotion.

2.2.1.1 Half-range emotional 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 Average Valence when pooling response speeds as a function of Spatial Congruency (not the Type of Task). Figure 2.2 clarifies how, according to SIA, the cross-over pattern expected on the basis of ESC defining an Average Valence × Spatial Congruency interaction on Δspeed (Figure 2.1A and 2.1C), is further qualified by a three-way Average 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, Iwill statistically reveal which type (Type I, II or III) most likely account for our pattern of response speeds, as follows:

- Type I) ESC alone (Figure 2.2A and 2.2D): will be revealed by a three-way Average 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 average valence for the conditions left-congruent (Figure 2.2A, red circles with orange outline), and right-incongruent (Figure 2.2D, 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 average valence (as in Figure 2.2B, 2.2C, 2.2E, and 2.2F), the SE and possibly an EA will also affect the performance;
- Type II) ESC + SE (Figure 2.2B and 2.2E): will be revealed by a main effect of Average Valence (a *size effect*) combined with a three-way Average Valence × Spatial Congruency × Response Side interaction (*full cross-over effect*).
- Type III) ESC + SE + EA (Figure 2.2C and 2.2F): will be revealed by a main effect of Average Valence combined with a two-way Spatial Congruency × Response Side interaction plus a three-way Average Valence × Spatial Congruency × Response Side interaction. In particular, the point

of intersection between the lines describing the relationship between speeds and average valence for left- and right-hand responses in spatially congruent and incongruent conditions will be informative: if characterized by a negative average 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 Figure 2.2C): a *funnel effect* in the domain of emotion.

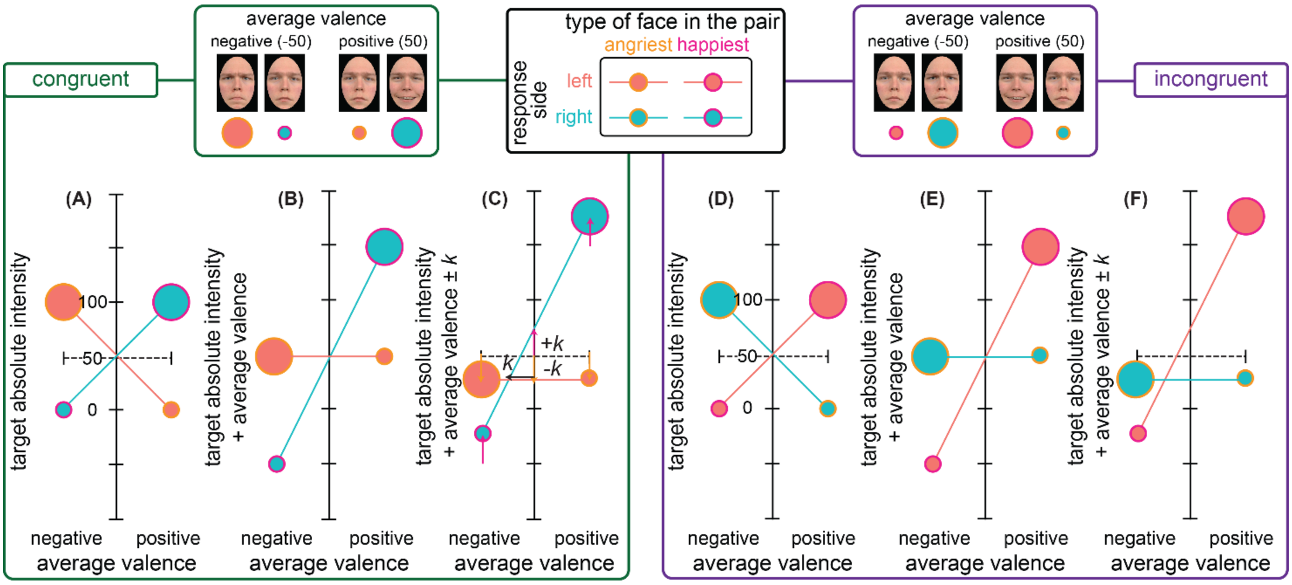

Figure 2.2. The direct Speed-Intensity Association model, SIA. Illustrations of the three possible types of three-way interaction rising from the assumption that there is a direct association between response speeds and different sources of intensities intrinsic of stimulus pair used in our experiments 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 Figure 2.1. In all panels the three possible combinations of intensities are plotted as a function of the average 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 Response Side (red = left; blue = right). If speed directly corresponds to any one of the three combinations of intensities a Response Side × Spatial Congruency × Average Valence interaction should raise qualified by well distinct statistical properties.

Notice that, the Type I and II SIA based combination (Figure 2.2A, 2.2B, 2.2D, and 2.2E) leads to a pattern of Δspeeds consistent with the unbiased relationship between real and perceived emotion intensities shown in Figure 1A. Only the Type III SIA (Figure 2C and 2.2F) based combination leads to a pattern of Δspeeds consistent with the biased relationship between real and perceived emotion intensities shown in Figure 2.1C (*funnel effect*). Furthermore, Figure 2.2 (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 average valence pair should be similar to the response speed associated to the angry face belonging to the negative average valence pair. This would produce an almost flat relationship between speeds and average 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 average valence (operationalizing a larger weight of SE over ESC), would proportionally increases the steepness of the relationship between speeds and average 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 average valence pair should be larger than the response speed associated to the angry face belonging to the negative average 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 average valence of a half-range emotional 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 half-range emotional pairs; and vice-versa for positive half-range emotional 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 Average Valence on the Δspeed that is accompanied by an Average Valence × Response Side interaction and a main effect of Spatial Congruency on individual response speeds.

2.2.1.2 Cross-range emotional pairs

Cross-range emotional 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 cross-range emotional 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 biases on the performance. 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.

2.2.1.3 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; M. Marschark & Paivio, 1981; Marc Marschark & Paivio, 1979), or at latest stages of decision processing, as requiring a sustained stimulus elaboration (e.g., Banks & Flora, 1977; Čech, 1995; Čech, 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).

2.2.1.4 Task demands: Experiment 1 vs. 3

Observers performing the comparative judgements of emotions in Experiments 1 and 3 underwent the same free-viewing 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., 1990, 1993), 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 from 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 average 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 I 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.

2.2.2 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 minutes. 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, 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; 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 have reached a level of accuracy averaged across the 16 different pairs resulting from our experimental design (see Figure 2.3 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.

2.2.3 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 (3.2GHz) 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 utilised to compose our emotional pairs in the training and in the experimental sessions.

For the training sessions I utilized black and white drawings of facial expressions created according to an online tutorial on human anatomy (Medley, 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) I utilized coloured photographs of human facial expressions taken from the same facial set used by Fantoni et al. (2016), 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 I utilised faces displaying two basic emotions (fully happy and fully angry), and one neutral facial expression. I followed the exact same morphing technique used by Fantoni et al. (2016) 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. Figure 2.3A shows an exemplar of the five facial expressions of emotions utilized in our experiments in order to compose our emotional pairs (either cross- or half-range emotional pairs).

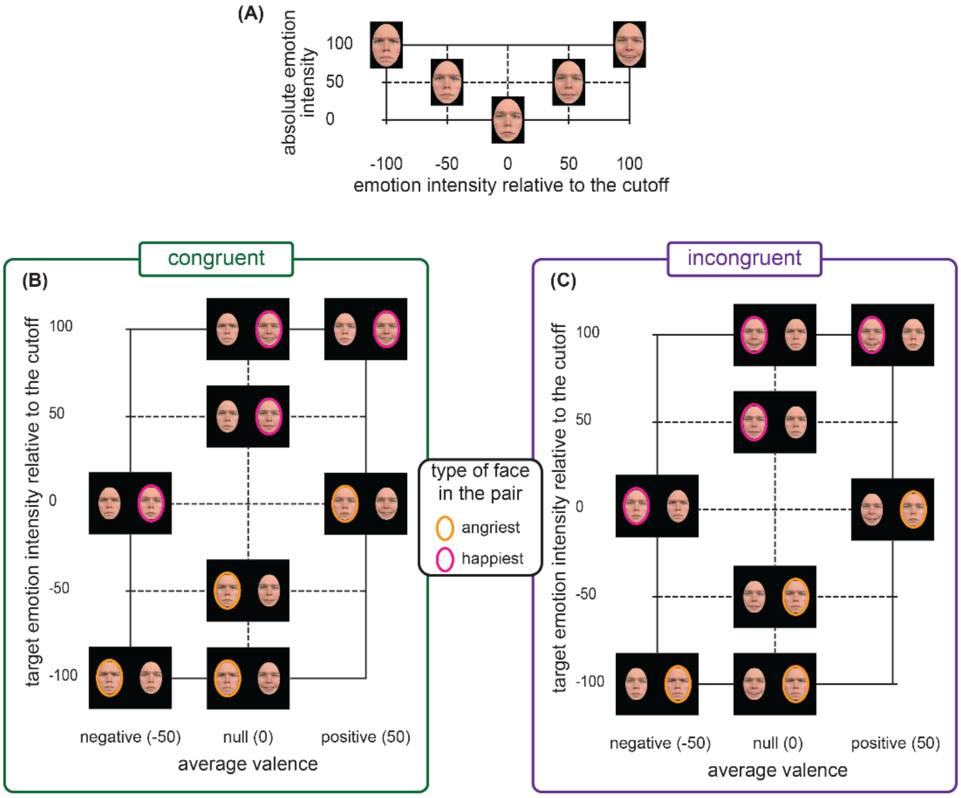

Figure 2.3. Facial stimuli and emotional pairs used in Study 1. (A) Exemplar of facial stimuli (identity not used in our experiments who gave permission for the usage of his image) used for the generation of the 8 types of emotional pairs used in our experiment (B and C congruent and incongruent Spatial 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 pairs resulting by combining the facial stimuli in A in the average 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 average valence = +50 and average valence = -50, respectively, and vice-versa for the “choose the neutral” instruction). Throughout the paper, stimuli with average valence = 0 are named cross-range emotional pairs, while stimuli with average valence = ±50 are named half-range emotional pairs, with cross-range emotional pairs including values of target absolute emotion intensity of 50 or 100, while half-range emotional pairs including values of target absolute emotion intensity of 0 or 100.

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 centred 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 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 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 Figure 2.3C and 2.3B, each set of 5 facial stimuli belonging to the same character were paired in order to obtain 4 types of half-range emotional pairs resulting from the combination of 2 Spatial Congruency (spatially congruent, spatially incongruent) × 2 Average Valence (negative and positive), and 4 types of cross-range emotional 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.

Figure 2.3 shows how all emotional pairs (n = 8) in both the spatially congruent (Figure 3B, the angriest-negative facial expression on the left side and the happiest-positive facial expression on the right side) and spatially incongruent condition (Figure 2.3C, 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 average 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 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 half-range emotional pairs differing in term of Average Valence + 2 cross-range emotional pairs differing in term of Target Absolute Emotional Intensity) × 2 Spatial Congruency (congruent, incongruent). Each different type of emotional 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 Average 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 Average 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.

2.2.4 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 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 response box.

As shown in Figure 2.4, 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 25.71 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 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 75Hz 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.

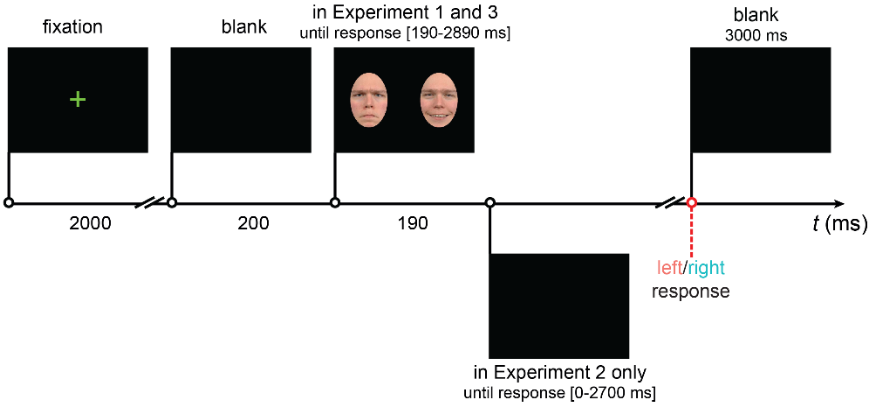

Figure 2.4. Trial temporal structure. This specific example illustrates the subset including a half-range emotional pair with positive average valence in spatially congruent position, i.e., a [0, +100] tuple-2. Depending on the task (in Experiment 1 and 2, "choose the angriest/happiest" in the pair, 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).

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.

2.2.5 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 average 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 cross-range emotional pairs could not be categorized as correct/incorrect provided the specific indirect nature of the task, I decided to limit the analysis to half of our trials: specifically, to those featuring the 4 types of half-range emotional pairs resulting from the combination of 2 Spatial Congruency × 2 Average 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 half-range emotional pairs trials). Finally, I excluded from the analysis of all three experiments 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., Miller, 1991; Ratcliff, 1993).

The combination of exclusion criteria I 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 cross-range emotional pairs plus 2 half-range emotional 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 half-range emotional 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 I also analysed 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 analysed 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 *lme*s of increasing complexity depending on the number of fixed effects, modelled by the factors of our experimental design: Average Valence, Target Absolute Emotional Intensity, Spatial Congruency, Response Side (Bates, 2010; Bates, Mächler, Bolker, & Walker, 2015; Fantoni, Rigutti, Piccoli, Sommacal, & Carnaghi, 2016). 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. Following 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 (Kliegl, Wei, Dambacher, Yan, & Zhou, 2010). AIC-index and BIC-index were used as a supporting comparative measure of the goodness of fit. Furthermore, I 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 I 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, & Pu, 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, I provided Cohen's *d*.

2.3 Results and discussion

2.3.1 Preliminary analyses

2.3.1.1 Speed-accuracy relationship

I 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 Average 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).

2.3.1.2 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, Average Valence. In Experiment 1 and 3 the *lme* analyses revealed a marginally significant Average Valence × 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 Average 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-handers being slower when the target emotion was displayed on the right (1.620 ± 0.070), rather than on 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 Average Valence interacted, I thus decided to not focus the main analyses of our Experiments on handedness.

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

Figure 2.5 illustrates average response speeds (Figure 2.5A, 2.5B, 2.5C, and 2.5D), and average Δspeeds (Figure 2.5E and 2.5F) of comparative judgements of emotions self-terminated by observers' responses as in Experiment 1. Data are shown for targets' expressions presented in spatially congruent (Figure 2.5A and 2.5B and green circles in Figure 2.5E and 2.5F), and spatially incongruent positions (Figure 2.5C and 2.5D and violet circles in Figure 2.5E and 2.5F), 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 Average Valence (Figure 2.5A and 2.5C for response speeds and Figure 2.5E for Δspeeds), or as a function of values extracted following SIA predictions, with an emotion anisotropy in favour of the happiest face (corresponding to the positive categorization task) of about 14.53% (Figure 2.5B and 2.5D for response speeds and Figure 2.5F for ∆speeds). Such a value was empirically extracted following the rationale discussed in section 2.1.2: it corresponded to the Average Valence in which the best fitting linear mixed-effect regressors of ∆speed, for the congruent and incongruent condition, intersected.

Independent of Spatial Congruency (Figure 2.5A vs. 2.5C), the distributions of average response speeds for happiness/anger detection as a function of Average Valence were in strong agreement with ESC as modelled by SIA, but neither with a SLE nor with 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. Figure 2.5A and 2.5C helps clarifying this: among a pair of circles with same Average 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).

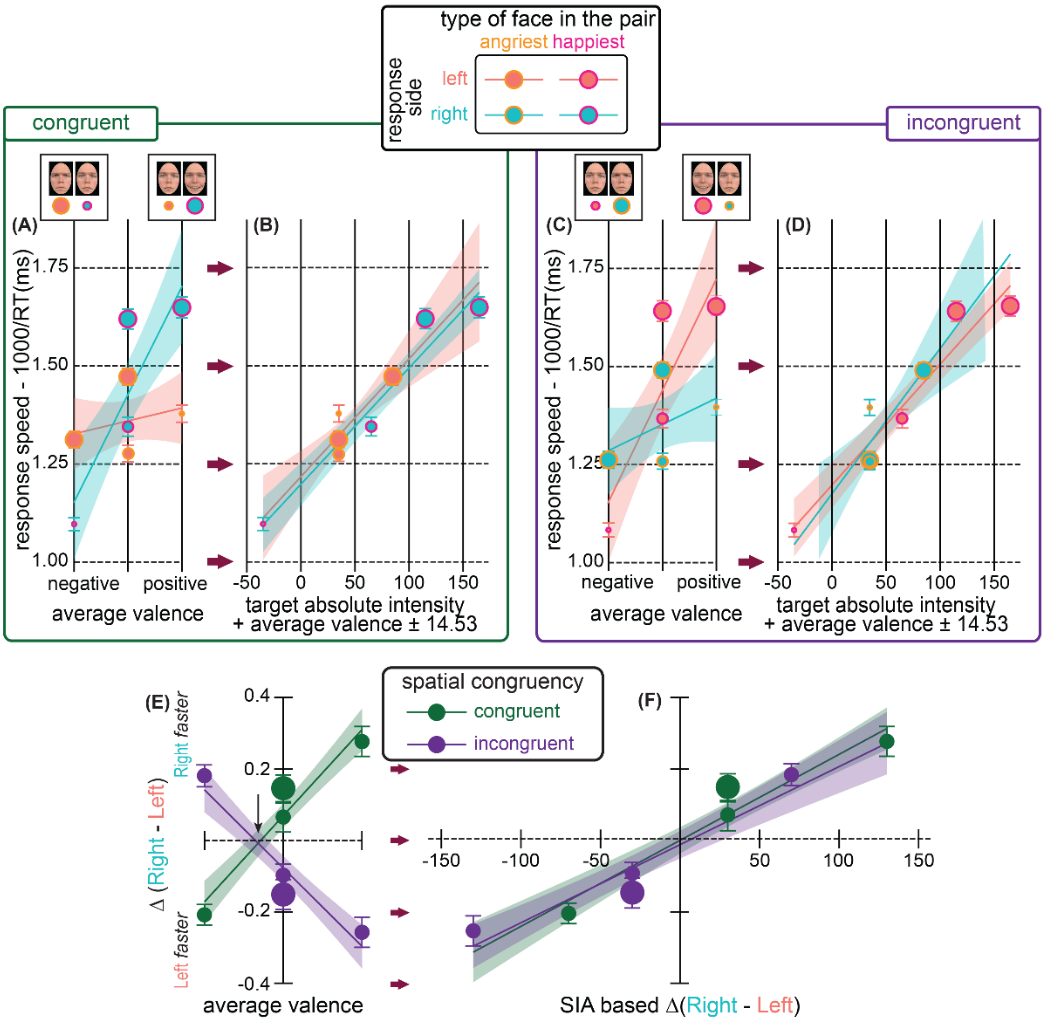

Figure 2.5. Comparative judgements performance in Study 1, Experiment 1. (A-D), illustration of the mean individual response speeds in Spatially Congruent (A and B, green frame) and Spatially Incongruent (C and D, violet frame) conditions, either as a function of Average Valence (A and C) or as a function of the best recoding of experimental conditions intensities obtained applying an equal weights SIA model (Type III, details in subsection 2.1.1) with $k = 14.53$ (B and D). Error bars represent ± 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 ± 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 ± 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, ±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 ± 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).

2.3.2.1 Individual speeds

I validate my observations on Figure 2.1A-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 (-50, 0, +50) as fixed effects. The cross-over pattern was statistically supported by a reliable Response Side × Spatial Congruency × Average Valence interaction ($F_{1,\ 4870.0} = 341.36$, $p < 0.001$): as consistent with ESC, for negative Average 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 ($M_{\text{happiest/emotional}} = 1.648 \pm 0.049$ vs. $M_{\text{angriest/neutral}} = 1.383 \pm 0.049$; $t = 16.04$, $df = 1208$, $p < 0.001$, $d = 0.923$). 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 Average Valence pairs with the happiest face in the rightmost position ($M_{\text{left/angriest}} = 1.306 \pm 0.037$; $M_{\text{right/happiest}}$ 1.099 ± 0.037; $t = 10.25$, $df = 559.2$, $p < 0.001$, $d = 0.867$) vs. faster right-hand responses for positive Average Valence pairs ($M_{\text{left/angriest}} = 1.37423 \pm 0.052$; $M_{\text{right/happiest}} = 1.646 \pm 0.052$; $t = 11.38$, $df = 580.2$, $p < 0.001$, $d = 0.945$); 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 Average Valence pairs with the happiest face in the leftmost position ($M_{\text{left/angriest}} = 1.079 \pm 0.036$ vs. $M_{\text{right/happiest}} = 1.26176 \pm 0.036$; $t = 8.47$, $df = 539.4$, $p < 0.001$, $d = 0.729$), vs. faster left-hand responses for positive Average Valence pairs ($M_{\text{left/angriest}} = 1.6507 \pm 0.050$ vs. $M_{\text{right/happiest}} = 1.394 \pm 0.050$; $t = 11.37$, $df = 587.1$, $p < 0.001$, $d = 0.939$).

The Response Side × Spatial Congruency × Average Valence interaction was further qualified by a main effect of Average 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 Average

Valence was consistent with a size effect in the domain of emotion, with the speed of comparative judgements increasing steadily as Average 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 Average 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 Average 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 Average Valence in both the congruent (-14.55), and incongruent (-17.74) conditions. Such a negativity of the point 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 cross-range emotional pairs statistically belonged to the ESC patterns in both spatial congruency conditions. The *lme* analysis on cross-range emotional pairs (with Average 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 ($M_{\text{Target Absolute Emotional Intensity} = 100} = 1.481 \pm 0.014$ vs. $M_{\text{Target Absolute Emotional Intensity} = 50} = 1.267 \pm 0.014$, $t = 10.455$, df

= 1242, $p < 0.001$, $d = 0.593$), and for the "choose the happiest" task ($M_{\text{Target Absolute Emotional Intensity = 100}} = 1.630 \pm 0.018$ vs. $M_{\text{Target Absolute Emotional Intensity = 50}} = 1.356 \pm 0.017$, $t = 11.007$, $df = 1242$, $p < 0.001$, $d = 0.625$).

2.3.2.2 Right-to-left speed deviations

The *lme* analysis on the pattern of individual Δspeeds (Figure 2.5E) showed a reliable Spatial Congruency × Average 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 Average Valence vs. slower for positive Average Valence pairs ($M_{\text{Average Valence = -50}} = -0.206 \pm 0.029$ vs. $M_{\text{Average Valence = 50}} = 0.\ 275 \pm 0.042$, $t = 10.075$, $df = 39$, $p < 0.001$, $d = 3.227$), and vice-versa for spatially incongruent displays ($M_{\text{Average Valence = -50}} = 0.181 \pm 0.030$ vs. $M_{\text{Average Valence = 50}} = -0.255 \pm 0.042$, $t = 9.107$, $df = 39$, $p < 0.001$, $d = 2.916$). 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 Average Valence of the point of intersection between the two-best fitting *lme* regressors describing the model with Average 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 cross-range emotional 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, $df = 158$, $p < 0.001$, $d = -0.709$).

2.3.2.3 SIA based remapping

I 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 subsection 2.1.1), i.e., the one implementing the equal weighting between ESC, SE and EA components depicted in Figure 2.2. 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 Figure 2.5A, 2.5C and 2.5E are remapped in Figure 2.5B, 2.5D and 2.5F, respectively. This remapping, with no free parameters, fully accounts for the effects I 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 Figure 2.5A and 2.5C, 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 ($\chi^2 = 6.709$, $df = 6$, $p = 0.349$). 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 Average Valence and Spatial Congruency on the pattern of Δspeeds and controlling for SIA based speed deviations as a predictor (Figure 2.5F). 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 × Average 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.

2.3.3 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, I 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.

Figure 2.6 illustrates average response speeds (Figure 2.6A, 2.6B, 2.6C, and 2.6D) and average Δspeeds (Figure 2.6E and 2.6F) obtained in Experiment 2 in which the comparative judgement was performed after tachistoscopically presented emotions following the same rationale and variable encoding used in Figure 2.6. The distribution of data indicates the robustness of ESC (against SLE).

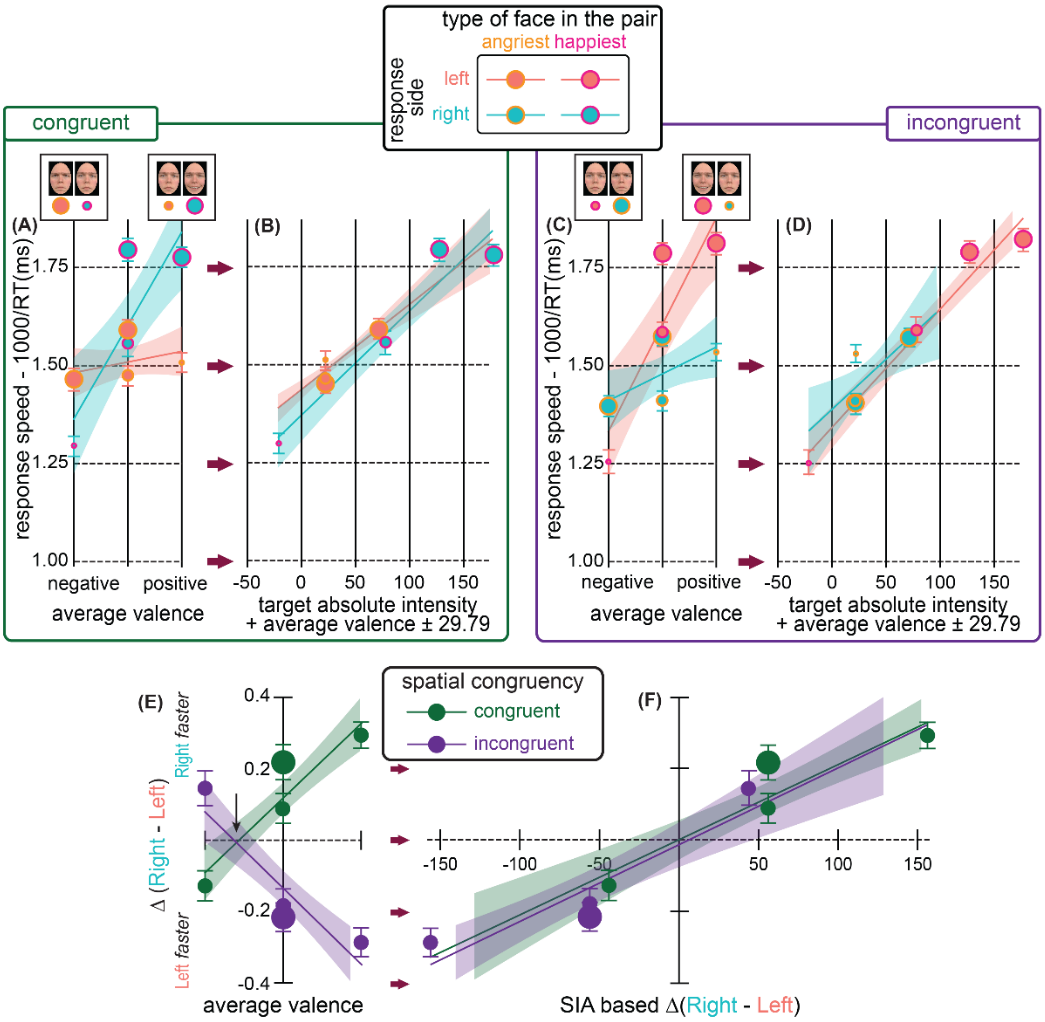

Figure 2.6. Comparative judgements performance in Study 1, Experiment 2. See caption of Figure 2.5 for further explanations. As in Experiment 1, Panels B, D and F show that the best recoding of experimental conditions intensities obtained applying an equal weights SIA model (Type III, details in subsection 2.1.1), 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).

2.3.3.1 Individual speeds

The key result on Individual speeds is the similar Response Side × Spatial Congruency × Average 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 Average Valence = -50 was relatively faster for the angriest/emotional ($M_{\text{angriest/emotional}} = 1.430 \pm 0.055$) than for the happiest/neutral face within the pair ($M_{\text{happiest/neutral}} = 1.290 \pm 0.055$, $t = 7.028$, $df = 896.5$, $p < 0.001$, $d = 0.469$), while the reverse occurred for pairs with Average Valence = 50 ($M_{\text{happiest/emotional}} = 1.798 \pm 0.060$ vs. $M_{\text{angriest/neutral}} = 1.512 \pm 0.060$; $t = 16.08$, $df = 1149$, $p < 0.001$, $d = 0.949$). 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 Average 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 Average 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 Average 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 Average 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 Average 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 Average Valence increase = 0.243 ± 0.019, $t = 13.038$, $df = 3247$, $p < 0.001$, $d = 0.458$), and from null to positive emotions (speed increment due to Average Valence increase = 0.061 ± 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 ± 0.059) over negative (estimated average speed for congruent ⇒ left and incongruent ⇒ right conditions = 1.495 ± 0.059) emotions across Spatial Congruency conditions ($t = 13.83$, $df = 4398$, $p < 0.001$, $d = 0.417$).

As far as cross-range emotional pairs are concerned (i.e., Average 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 ($M_{\text{Target Absolute Emotional Intensity} = 100}$ = 1.581 ± 0.018 vs. $M_{\text{Target Absolute Emotional Intensity} = 50}$ = 1.438 ± 0.018, $t = 5.564$, $df = 1149$, $p < 0.001$, $d = 0.327$) and when the target face was the happiest ($M_{\text{Target absolute emotional intensity} = 100}$ = 1.794 ± 0.021 vs. $M_{\text{Target absolute emotional intensity} = 50}$ = 1.575 ± 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. I 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 ± 0.00972; amount of additional gain relative to Experiment 1 observed in Experiment 2 = 0.06576 ± 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 based on 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.

2.3.3.2 Right-to-left speed deviations

As in Experiment 1, I analysed Δspeeds shown in Figure 2.6E 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 × Average 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, I corroborated the emotion anisotropy through focusing on cross-range emotional 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, $df = 158$, $p < 0.001$, $d = -1.015$).

2.3.3.3 SIA based remapping

I 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). Figure 2.6B, 2.6D and 2.6F shows how the same average individual response speeds and average Δspeeds shown in Figure 2.6A, 2.6C and 2.6E as a function of Average 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).

2.3.4 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, I 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 & Laurenco (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.

Figure 2.7 illustrates the average response speeds (Figure 2.7A, 2.7B, 2.7C, and 2.7D) and average Δspeeds (Figure 2.7E and 2.7F) obtained in Experiment 3 in which the comparative judgement was performed in indirect task conditions, following the same rationale and variable encoding used for Figure 2.5 and 2.6. 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.

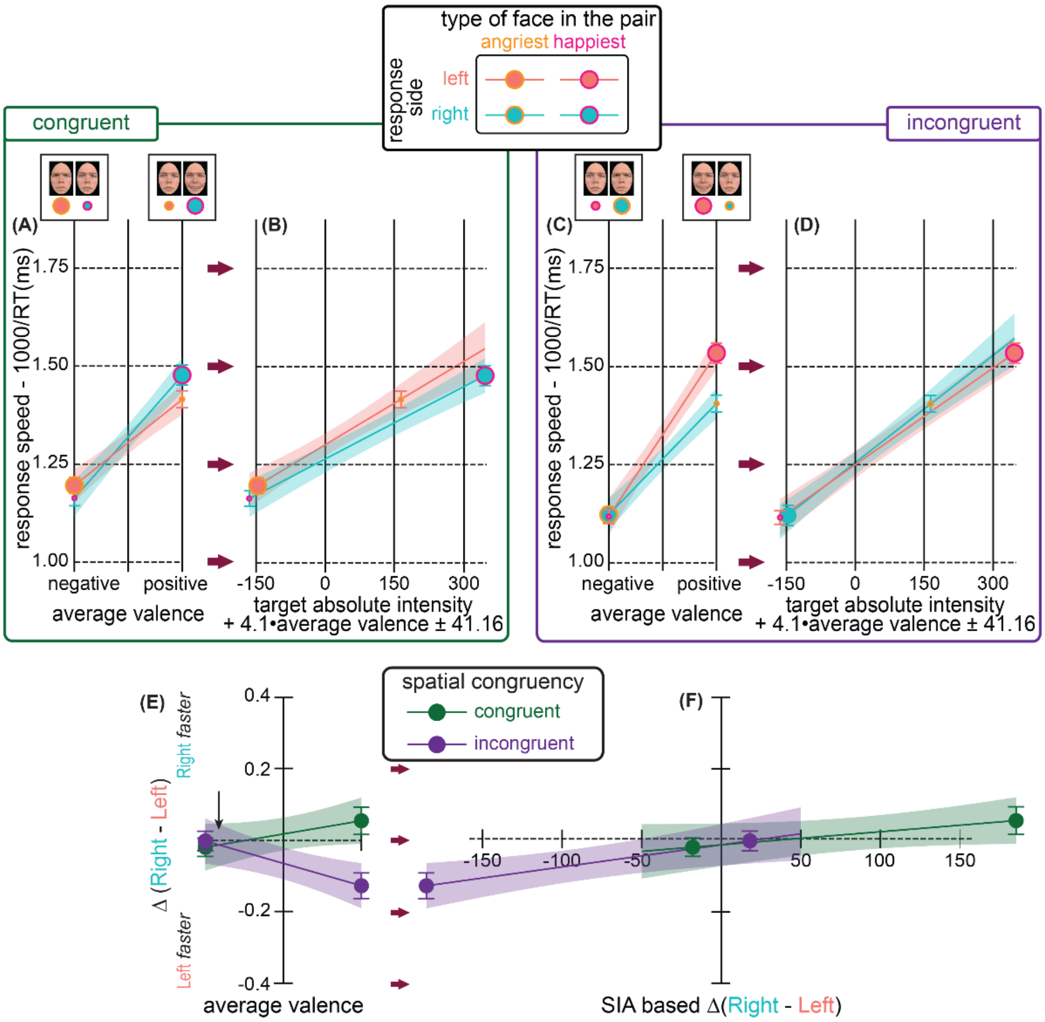

Figure 2.7. Comparative judgements performance in Study 1, Experiment 3. See caption of Figure 2.5 or 2.6 for further explanations. Panels B, D and F show that the best recoding of experimental conditions intensities obtained applying an unequal weights SIA model (Type III, details in subsection 2.1.1), with $k = 29.79$ 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).

2.3.4.1 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 × Average 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 Average Valence = 50, but not when Average 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 Average 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 Average 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 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 × Average 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 Average Valence was negative. Such a difference in the speed- Average 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. I 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, I included in the *lme* model the Experiment as an additional fixed factor but excluded from the analysis the cross-range 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 × Average Valence interaction ($F_{1, 5035.5} = 6.83$, $p = 0.009$). The rate of increase of judgement speed over Average 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 × Average 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 Average Valence = 50 ($\Delta M_{\text{emotional/Experiment 3}}/M_{\text{emotional/Experiment 1}} = -0.17109 \pm 0.02230$, $t = -7.671$, $df = 2602.11$, $p < 0.001$, $d = 0.30$), and when Average Valence = - 50 ($\Delta M_{\text{emotional/Experiment 3}}/M_{\text{emotional/Experiment 1}} = -0.18544 \pm 0.02030$, $t = -9.136$, $df = 2357.90$, $p < 0.001$, $d = 0.38$). No other reliable interactions were found for individual speeds due to the inclusion of the Experiment as an additional factor.

2.3.4.2 Right-to-left speed deviations

The *lme* analysis on the pattern of individual Δspeeds (Figure 2.7E) 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 × Average 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]).

2.3.4.3 SIA based remapping

I 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 I 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 Average 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 I tested an unequal weight SIA, now including as an additional free parameter the best fitting multiplying factor α of Average 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). Figure 2.7B, 2.7D and 2.7F shows how the same average individual response speeds and average Δspeeds of Figure 2.7A, 2.7C and 2.7E, 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 (χ^2 = 0.642, df = 2, p = 0.726).

2.4 General Discussion

I 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 valence 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. I 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 I 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, I 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, I 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 I 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 I used explicit comparative instructions with the valence that was task relevant, and Experiment 3, in which I 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, Baumüller, & Brugger, 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 I 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, Flykt, et al., 2001; Öhman, Lundqvist, et al., 2001). 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 (Carretié, 2014; Ferrari et al., 2008; Reeck & Egner, 2015). 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 and 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 & Shaky, 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 I 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, 1985). Future studies might address ESC robustness to different emotional dimensions eliciting opposite approach/withdrawal behaviour (e.g., fearful and/or disgusted vs. happy faces).

3 Study 2

3.1 Introduction

In a world without comparisons, quantities would be worthless in the absence of the possibility to establish more/less relations: I would be unable to effectively grasp the difference between emotions as well as explicit symbolic quantities like numerals. Humans however are remarkable in their ability to rapidly and efficiently discriminate relevant stimuli on the basis of their magnitude, even when displayed into cluttered environments (Cherry, 1953; Hansen & Hansen, 1988, 1994; Homa, Haver, & Schwartz, 1976; Öhman, Flykt, et al., 2001; Öhman, Lundqvist, et al., 2001; Treisman, 1982). In Study 1, I found that the lateralized motor reactivity with simultaneously presented emotions, shown side-by-side, increased as the emotion intensity of the facial expression increased: this was independent from valence-specific lateral bias (Casasanto, 2009, 2011; Casasanto & Chrysikou, 2011; Holmes, Alcat, & Lourenco, 2019; Holmes & Lourenco, 2011; Pitt & Casasanto, 2017). The effect described in Study 1 results in a capture of visual spatial attention due to affective emotional stimuli, as predicted by a remapping of target absolute (emotional) intensity relative to the cutoff of the series (i.e., a neutral face) into response speeds: namely, a direct Speed (to relative emotion) Intensity Association (i.e., the SIA). Here I show that such a direct SIA generalizes to symbolic quantities, as in the case of simultaneously presented Arabic numbers. This provides a basis for a common magnitude representation for the comparison of emotions and numbers.

In Study 1 I found that the speeds of choice for positive vs. negative emotions defined along the valence continuum (selected accordingly with different instructions like choose the "happiest" or the "angriest" face between two faces) increased as the absolute emotion intensity of a chosen face grew larger together with the average valence of the pair. This increase was found to be independent from the compatibility between the target valence and the side of motor response (left or right), as well as from the spatial congruency of image pairs with the left-to-right mental format of valence (with congruency defined by negative emotions displayed on the leftward vs. positive emotions on the rightward hemifield). I named such a pattern of motor reactivity Emotional Semantic Congruency effect (ESC) for its commonality with the Semantic Congruity (SC) effect, first reported in the pioneering work by Banks et al. (1975). This pattern – which was fully predicted by the SIA – was described as a *crossover* pattern. It was observed in comparative judgements, when the choice speed, plotted against the average magnitude of a pair, crosses-over in a full interaction. In this interaction, the speed belonging to the smallest choice of a pair is above the speed belonging to the largest choice at low intensities, and vice versa at high intensities. In the domain of emotion, a similar pattern was indeed observed in Study 1 on half-range emotional pairs (with one neutral face being at the cutoff of the series and the other emotional), in both spatially congruent and incongruent positions relative to left-to-right spatial mental representation of valence. In spatially congruent pairs, the left angriest emotional face gets *faster* than the right happiest cutoff face, at low average valence. Conversely, the left angriest cutoff face gets *slower* than the right happiest emotional face, at high average valence. In spatially incongruent pairs, the left happiest cutoff face gets *slower* than the right angriest emotional face, at low average valence. Conversely, the left happiest emotional face gets *faster* than the right angriest cutoff face, at high average valence. An analogous pattern was observed in many studies in different domains (Audley & Wallis, 1964; Banks et al., 1975, 1976; Banks & Flora, 1977; Clark et al., 1973; Ellis, 1972; Friend, 1973; Holyoak, 1978; Leth-Steensen et al., 2014; Marks, 1972; Patro & Haman, 2012; Petrusic et al., 2008; Zhou et al., 2017).

Notably, as predicted by the SIA model such a crossover pattern of lateralized motor reactivity is opposed to the SNARC-like compatibility pattern for pairs of emotions displayed in spatially incongruent position. A SNARC-like compatibility pattern would rise from a general compatibility principle between the spatial mental representation of valence and the spatial position (left/right) of the target emotion (Wood, Willmes, Nuerk, & Fischer, 2008). According to such a principle, response speed would be facilitated or hindered depending on whether the target emotion is displayed in a compatible or incompatible position relative to the spatial mental representation of valence, respectively. Spatial incongruence would thus lead to a hindering of response speeds for the most intense emotion within a pair, given its lack of spatial compatibility with the left/right mental spatial representation of valence (i.e., *a happy/positive face in the left hemifield* paired with a relatively angry face, though neutral, in the right hemifield). Importantly, such predicted pattern is reversed compared to the ESC effect found in Study 1 and to the direct SIA model's prediction.

The occurrence of ESC is consistent with a great amount of evidence showing a prioritization in early sensory processing of affective emotional over neutral stimuli (Lane et al., 1999; Morris et al., 1998; Sabatinelli et al., 2005; Vuilleumier et al., 2003), with spatial attention being spontaneously captured by emotions (Fox, 2002; Hansen & Hansen, 1994; Öhman, Flykt, et al., 2001; Öhman, Lundqvist, et al., 2001). According to this evidence, judgement speeds in our previous study might have been modulated by stimulus-driven exogenous attention, as defined by the motivational significance of facial expressions simultaneously displayed in the comparison stimulus (Ferrari et al., 2008; Reeck & Egner, 2015). In this case, emotional expressions are automatically and rapidly encoded, thus, producing an inhibition of the general compatibility principle within a SNARC like pattern, in favour of SIA supporting the ESC. In particular, the latter principle would account for a speeding up, when the target face is emotional, vs. a slowing down of responses when the target face is neutral, as a by-product of attentional capture produced by the emotional/flanker emotion.

Given that our previous work on the direct SIA on comparative judgments (with a pair of emotions) involved only stimuli with high motivational significance, it remains to be established whether the inferred stimulus-driven regulation of lateralized motor reactivity described in Study 1 was due to a common magnitude representation for the comparison of different types of intensities (like emotions and numbers) based on SIA, or to the specific emotional salience of facial expression stimuli capturing attention and eliciting the ESC.

Consequently, I formulated a *research question*: can a similar attentional capture phenomenon occur in the symbolic domain, in the absence of motivational significance of the stimuli, as in the case of Arabic number pairs, which can be directly translated as relative intensities into a magnitude representation? Answering positively to such a question would be twofold in order to: (1) generalize the causal inference resulting from finding of Study 1 from the specific domain of emotion, which is only indirectly related with magnitudes via valence to the symbolic domain of numbers which is explicitly related to magnitude; (2) demonstrate that the SNARC effect does not hold in our simultaneous comparison task, given that a SC pattern for spatially incongruent pair is opposed to the one predicted by SNARC. According to a general SC pattern, in a 1-to-9 series, a digit 9 appearing in the left hemi-field should be selected faster than the cut-off digit 5 appearing in the right hemi-field; according to SNARC, the opposite should occur.

Our *research question* is firmly motivated on theoretical ground. The ESC pattern is fully compatible with the remapping of intensities provided by the direct SIA that in principle can be applied to any type of magnitude (not only emotions). This provides a common magnitude representation for the comparison of emotions and numbers. This is demonstrated by the high predictive power of the SIA model on the pattern of individual choice speeds, as mainly based on the extraction of relative emotion intensity values from emotional pairs. Indeed, the model remaps response speeds into generic magnitudes that are relative intensity values (not necessarily motivationally significant values). These values can be extracted from emotional stimuli, as well as from any other domain in which the intensity of the stimuli is quantifiable as a bipolar unidimensional continuum defined on opposite sides by a neutral midpoint (i.e., the cutoff of a series). In particular, SIA predicted values are given by the weighted linear combination of three additive factors:

(1) the target absolute (emotional) intensity relative to the cutoff of the series (in the case of emotional pair varying along the valence continuum, the facial expression dividing it into two equal portions, like a neutral face or a face morphing an equal proportion of happiness and anger). This factor formalizes a pure ESC effect, leading the pattern of response speeds to fully crossover across the average intensity valence of the display: namely a *crossover effect* (Audley & Wallis,

1964). When such a factor is applied to remap cross-range emotional pairs, with cross-range intensities over the neutral cutoff (e.g., with one face being half or fully happy and the other half or fully angry respectively) it formalizes a *distance effect* (Moyer & Landauer, 1967). Consequently, the speed to choose amongst a pair of intensities increases as the difference between them increases, being such a difference proportional to the target absolute intensity relative to the cutoff;

(2) the average (emotion) intensity of the pair relative to the cutoff. This factor formalizes a *size effect* leading overall response speeds to increase as average (emotion) intensity gets larger from negative to positive;

(3) an additive/subtractive constant. This factor formalizes an (emotion) *intensity anisotropy*, speeding up or slowing down responses of a constant factor depending on the relative polarity of the target (emotion) intensity (if the most positive/negative between the two respectively). Notably, beyond producing a general improvement of the performance for relatively positive vs. negative (emotion) intensities, such an unbalanced distribution of estimated targets' intensities – when combined with the effect of target absolute intensity – produced a well-known variant of the *crossover effect* due to pure ESC: this is known as a *funnel effect* (Audley & Wallis, 1964; Banks & Root, 1979). This variant involves a stronger SC bias for large (above the cutoff), rather than for small (below the cutoff) intensities.

The origin of the attentional capture phenomenon at the basis of ESC might be equally due to the perceptual features of facial expressions used in Study 1, inducing different motivational significance, or to a common *magnitude* representation for the comparison of emotions and numbers encoded according to the direct SIA. In this latter case, given that the same remapping can be assessed with symbolic magnitudes (i.e., discrete Arabic number 1-to-9 series tested in Experiment 1) as well as from any other types of emotional intensities varying along the valence continuum (i.e., the anger-to-happiness per cent in the morph continuum tested in Experiment 2 vs. the anger-to-neutral-to-happiness per cent in the morph continuum tested in Study 1), similar effects should be expected across domains. A general SC pattern should be revealed in this case.

3.1.1 The present study: Conceptual framework and expectations

Here I put forth two complementary experiments in order to answer to our *research question*. Our two Experiments fully replicate the comparative judgement technique used in Study 1, though generalizing the direct comparison task they used to stimulus pairs that were fully comparable in terms of their magnitude representation (at the ordinal level). It is noteworthy that the stimuli I used had a different representational domain as well as a different motivational significance, through being both similarly overlearned: symbolic magnitudes (i.e., Arabic numbers) with rather low motivational significance in Experiment 1 vs. emotional magnitudes with rather high motivational significance in Experiment 2.

Notably, I planned our two experiments in order to be fully comparable in terms of the bipolar unidimensional intensity continua defining our two sets of stimuli, so to keep them comparable in terms of their *magnitude* representation. This constitutes the basis of our general comparative approach, which was aimed at attempting to find general laws valid across domains as diverse as emotions and numbers. In particular, in Experiment 1 I tested lateralized motor reactivity to pairs of Arabic numbers presented side-by-side extracted from the 5 odd digits belonging to the 1-to-9 discrete continuum (see Figure 3.1). In this continuum, the intensity relative to the midpoint of the series (the objective cutoff, i.e., 5), was equal to -4 for the minimum (*min*) digit 1, to +4 for the maximal (*max*) digit 9, and to 0 for the digit 5. As for the *half* negative digit 3 and the half positive digit 7, the intensity relative to the midpoint was -2 and +2, respectively (Figure 3.1A *x*-axis on top). The continuum of stimuli in Experiment 1 was fully comparable to that of stimuli in Experiment 2. Indeed, in Experiment 2, the pairs were extracted from 5 facial expressions of emotions in the anger-to-happiness per cent in the morph continuum. In this continuum, the intensity relative to the midpoint of the series (the objective cutoff, i.e., the neutral face: 50% angry – 50% happy), was equal to -100 for the minimum (*min*) emotion intensity (100% angry – 0% happy), to +100 for the maximal (*max*) emotion intensity (0% angry – 100% happy), and to 0 for the neutral face (50% angry – 50% happy). As for the *half* negative emotion intensity (75% angry – 25% happy) and the *half* positive emotion intensity (25% angry – 75% happy), the intensity relative to the midpoint was -50 and +50, respectively (Figure 3.1A *x*-axis on bottom).

Notably, the emotion intensities were the same as the ones used in Study 1. However, in the previous study, the neutral face was a true neutral face, and the *half* emotion intensity faces were obtained by morphing the fully emotional faces with the true neutral face of the same identity. Conversely, in the present study, the three central stimuli of the continuum (i.e., excluding the fully emotional faces) were obtained from the morph of the fully angry and the fully happy faces of the same identity. The rationale of such a choice was twofold:

(1) I seek to keep our emotional continuum optimized in order to be maximally comparable to the continuum of digits tested in Experiment 1, although different from the one used in Study 1. By purpose, I decided not to include the true neutral face in our series as the cutoff, given that a true neutral face, being void of emotion, might have been perceived as belonging to a different perceptual category than emotional faces (Cheetham, Suter, & Jäncke, 2011; Cheetham, Wu, Pauli, & Jancke, 2015). Such a confound is likely to be reduced by extracting the cutoff face from the extreme emotion intensities of the series (fully happy – fully angry faces), mixing them in equal proportions so to obtain a uniform range of emotional stimuli along the per cent happiness in the morph continuum;

(2) furthermore, using morphed cutoff faces, I seek to generalize the ESC effect also to the case in which the perceptual categorization of the cutoff face, in terms of realism (as resulting by a mixture of a real fully angry and a real fully happy face), should be less favourable than the case originally used in Study 1. Following the MacDorman and Chattopadhyay (2016) theory of realism inconsistency, the reduced consistency in realism involved in our morphed cutoff faces

relative to the true neutral faces – used in Study 1 – should significantly increase their eeriness. This in turn could produce an assimilation of the cutoff faces to the negative emotional feelings produced by the angry faces of the continuum. This assimilation might result into a larger unbalance in the selection of the happiest over the angriest face, within the pair, than the one originally observed in Study 1. Such an unbalance would result in a more evident *funnelling* of the *crossover* pattern expected on the basis of a pure ESC effect.

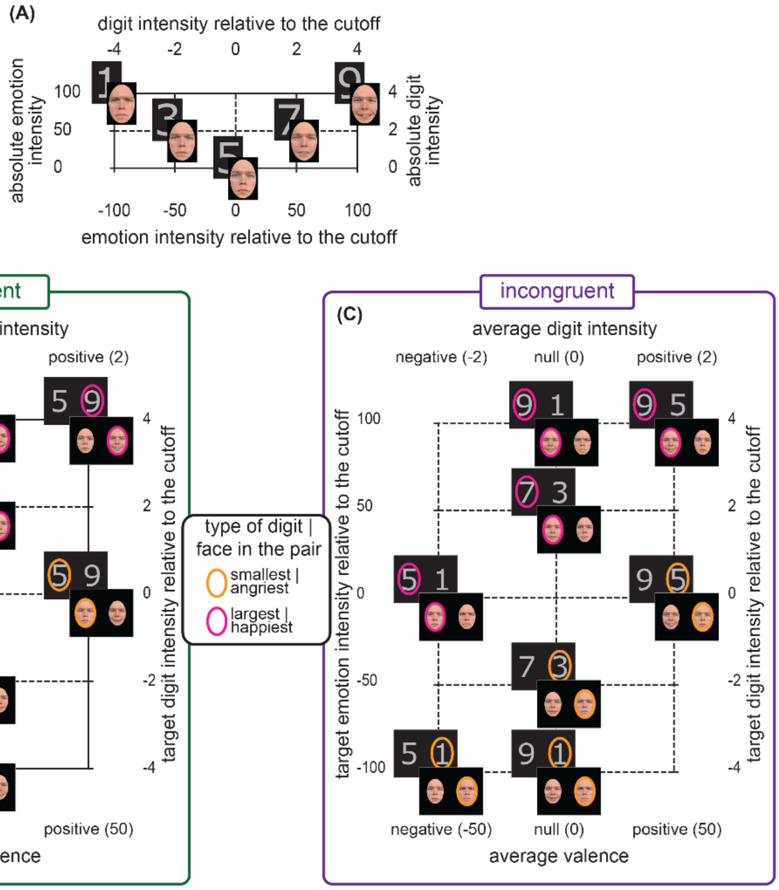

Figure 3.1. Digits/faces stimuli and digits/emotional pairs used in Study 2, Experiment 1 and 2. Digits/faces stimuli (A) and digits/emotional pairs used in Experiment 1 and 2, for the congruent (B) and incongruent (C) spatial position (identity gave permission for the usage of his image but not used in our experiments). In (A), stimuli are depicted in a Cartesian space, with the per cent morph continuum and the numerical values of the digits recoded: (1) according to the emotion or digit intensity relative to the intermediate/cutoff emotion/digit (along the *x*-axis on bottom and on top respectively), so that the angriest as well as the smallest face/digit (i.e., min) and the happiest as well as the largest face/digits (i.e., max) define the negative and positive extreme values of the double *x*-axes (series), respectively; (2) according to the absolute emotion or digit intensity relative to the cutoff (along the left and right *y*-axes, respectively), with the digit 5 = 50% happy-50% angry face = 0, and the digits 9 and 1 as the fully emotional faces. In (B) and (C) the stimulus pairs (digit and emotion) result from the combination of the stimuli in A in the average intensity (valence in the bottom *x*-axis; and digit in the top x-axis) × target intensity relative to the cutoff (emotion in the left *y*-axis; and digit in the right *y*-axis) Cartesian space for the spatially congruent (B, happiest/largest face/digit on the right) and incongruent (C, happiest/largest face/digit to the left) conditions. Notably, our 8 types of digit/face stimuli, depending on the type of

target digit/face (smallest/angriest coded by orange surrounding ellipses or largest/happiest coded by pink surrounding ellipses), determined 16 experimental conditions (8 congruent in panel B and 8 incongruent in panel C).

Globally, I replicated the experimental design of Study 1 balancing the number of presentations across our two fully randomly assigned types of stimulus pairs. These pairs were presented in spatially congruent, as in Figure 3.1B (smallest intensity displayed to the leftmost position), and spatially incongruent positions, as in Figure 3.1C (smallest intensity displayed to the rightmost position), relative to the left-to-right mental format of intensities. In particular, I have two types of pairs: (1) the half-range digits/emotional pairs (i.e., the cutoff digit/emotion paired with the *min* or *max* digit/emotion), with average digit/emotion intensity = ±2/±50, (thus, resulting from the average between 0 and ±4/±100, Figure 3.1B and 3.1C, negative and positive average digit/emotion intensity); (2) the cross-range digits/emotional pairs (i.e., *min* paired with *max* digits/emotions, or *half* negative paired with *half* positive digits/emotions), with average digit/emotion intensity = 0 (thus, resulting from the average between -4/-100 and +4/+100, or -2/-50 and +2/+50, Figure 3.1B and 3.1C, null average digit/emotion intensity).

Participants were tested individually in two successive blocks. In Experiment 1, in the first block, participants were required to choose the smallest (or largest) number of a pair; in the second block they were required to choose largest (or smallest) number (thus, counterbalancing the type of task of the blocks across participants). In Experiment 2, in the first block, participants were required to choose the angriest (or happiest) face of a pair; in the second block they were required to choose happiest (or angriest) face.

Given such a composite design, I here put forth two Alternative Expectations (AE), resulting from theoretically compatible though opposite answers to our *research question*:

3.1.1.1 (AE1) A common magnitude representation: a general SC pattern

If attentional capture, in our comparative judgment task, is regulated by a common magnitude representation based on SIA (beyond motivational significance), then a similar pattern of lateralized motor reactivity to simultaneously displayed facial expressions of emotion as the one observed in Study 1 (i.e., the ESC) is expected to occur in the case of the comparative judgement of Arabic numbers in Experiment 1: a general SC pattern. The same pattern should also be expected for facial expressions in the anger-to-happiness per cent in the morph continuum of Experiment 2. Such a similarity is expected to show up beyond a general difference in the latencies, likely involved in the processing of complex perceptual stimuli like faces vs. those involved in the processing of numerals. Indeed, numerals are known to rapidly and directly access magnitude representation necessary to produce fast comparative judgements (e.g., Banks & Flora, 1977; Banks et al., 1976; Patro & Shaki, 2016; Shaki et al., 2012).

AE1 is motivated by the fact that intensities conveyed by digits can be directly remapped into magnitudes similar to those indirectly representing emotional valence. In any case these values can equally serve the purpose of predicting motor reactivity through a common magnitude code for the comparison of emotions and numbers provided by the SIA weighted linear combination. Namely, in both Experiments the relevant factors combining into SIA-based predicted speeds can be extracted from each tested pair, thus, leading into a similar pattern of prediction, anyhow consistent with the *crossover* effect expected on the basis of the SC. Such an expectation is consistent with the idea that, also in the numerical domain, the joint evaluation proper of any comparison task might be supported by an attentional strategy based on the formation of an intrinsic (stimulus-driven) rather than extrinsic (task dependent) reference frame (Audley & Wallis, 1964; Brannon, 2006; Cantlon, Platt, & Brannon, 2009; Holyoak, 1978; Hsee, 1996; Hsee & Leclerc, 1998; Shafir, Simonson, & Tversky, 1993). The intrinsic reference frame rises from a direct comparison of one option against the other, with the more extreme option of the pair – in terms of intensity relative to the cutoff – constituting an attentional attractor. Notably, such an idea is inspired from pioneering reference point models of comparative judgements (Greenberg, 1963; Holyoak & Mah, 1982; Holyoak & Walker, 1976; Jamieson & Petrusic, 1975; Petrusic, 1992), and their more recent implementations based on Bayesian Analogy with Relational Transformations (Chen, Lu, & Holyoak, 2014; Lu, Chen, & Holyoak, 2012). The major difference is that a single reference point at cutoff – rather than extreme reference point values (defined implicitly or explicitly by the task, i.e., the smallest or largest) – is used as an anchor for comparisons along a given continuum. This is regardless of its representational domain, being symbolic or not, with or without motivational significance. According to findings of Study 1, such a difference provides a task independent model of SC, consistent with the finding that similar ESC patterns were observed both in direct and indirect comparison tasks. In particular, it was observed when the instruction requires the processing of the stimulus dimension that was task relevant (e.g., choose the "happiest" or the "angriest" face) and irrelevant (e.g., choose the "emotional" or the "neutral" face), respectively.

Our stimulus pairs in Experiment 1 and 2 were thus devised so to be fully comparable in term of their relative magnitude representation. Such a rationale allows us to obtain parallel conditions across the Experiments which correspond at an ordinal level, in terms of both target absolute intensity and average digit/emotion intensity (Figure 3.1B and 3.1C). If AE1 holds, a similar pattern of response choice speeds is expected in Experiment 1 and 2: such a general SC pattern should be characterized by a three-way Average Digit/Emotion Intensity × Spatial Congruency × Response Side interaction on individual response speeds due to faster responses for the extreme intensity values within a pair relative to the cutoff of the series (i.e., *max* or *min* intensity). Therefore, in spatially congruent displays, pairs with positive average intensity should be characterized by faster right-hand responses to *max* intensity targets (like the digit 9 or the happy face in Experiment 1 or 2, respectively) relative to left-hand responses to cutoff intensity targets (like the digit 5 or the neutral face in Experiment 1 or 2, respectively), and vice-versa for pairs with negative average intensity. The opposite pattern should be observed for spatially incongruent displays, with positive average intensity pairs now eliciting *slower* (not faster) right-hand responses to cutoff intensity targets (like the digit 5 or the neutral face in Experiment 1 or 2, respectively) relative to max intensity targets (like the digit

9 or the happy face in Experiment 1 or 2, respectively), and vice-versa for pairs with small average intensity. In any case, such a pattern, would be accounted for by the SIA weighted linear combination. According to a general SC, such an interaction could be further qualified by:

AE1.1) a main effect of Average Digit/Emotion Intensity in Experiment 1 and 2, standing for a *size effect*, which should be elicited in opposite directions, considering the way I conventionally encode the relative intensity polarity across two remarkably different representational domains: 1) the domain of numbers in Experiment 1 (with faster response speed produced for stimulus pair with globally small – encoded as the negative pole of our intensity continuum – over large digits, see Moyer & Landauer, 1967); and 2) the domain of emotions in Experiment 2 (with faster response speed produced for stimulus pair with globally more positive – encoded as the positive pole of our intensity continuum – over negative emotions, see Study 1);

AE1.2) a Spatial Congruency × Response Side interaction, standing for an *intensity anisotropy*, produced by a response speed unbalance across the two types of contrasting attributes elicited by the pair, with choices being faster for the happiest/largest over the angriest/smallest element within the pair. Notably, the *intensity anisotropy* should be reflected also on cross-range digits/emotional pairs, with the addition of a main effect of target absolute digits/emotion intensity, consistent with a general (across domains) *distance effect*.

3.1.1.2 (AE2) Different motivational significance: SNARC in Experiment 1 and ESC in Experiment 2

If attentional capture in our direct comparison tasks is regulated by motivational significance (beyond a common magnitude representation), then a different pattern of lateralized motor reactivity than the one observed in Study 1 (i.e., the ESC) is expected to occur in the case of the comparative judgement of Arabic numbers in Experiment 1. A similar attentional capture phenomenon to the one previously observed in Study 1 is expected to occur in Experiment 2 (with facial expressions) but not in Experiment 1 (with digits). Digits are indeed characterized by a lower motivational significance than facial expression of emotions and could be not accounted for by the direct SIA model. In particular, here I put forth the SNARC pattern as a valuable candidate for motor relativities of Experiment 1. Such a solution is motivated by the wide number of studies showing a strict relationship between discrete numerical values and space, with observers being faster in responding to relatively smaller numerals with a left key-press, and to relatively larger numerals with a right key-press (Dehaene et al., 1993; Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006; Proctor & Xiong, 2015; Shaki & Fischer, 2008; Shaki et al., 2009). A SNARC effect has been previously used as explanation in the case of joint evaluations, as those involved in comparative judgement of digits, although its generalizability is still under debate (Fischer, 2003). In the comparative judgement of simultaneously presented stimuli, indeed a mixed SNARC-like pattern is generally observed, with SNARC-like effect appearing in the standard direction when participants were asked to select the smallest member of a pair, vs. null (though weakly reversed) in the opposite case (Lee et al., 2016; Patro & Shaki, 2016; Shaki & Fischer, 2008; Shaki et al., 2012). Despite this mixed evidence, SNARC still constitutes a valuable hypothesis for the way attention could be triggered, in a way consistent with a valence-specific lateral bias (Fischer, 2003; Fischer & Shaki, 2016; Prpic et al., 2018; Shaki & Fischer, 2018).

Importantly, there is evidence that numerical and non-numerical magnitudes might elicit similar SNARC effects (Dalmaso & Vicovaro, 2019; Fumarola et al., 2014, 2016; Nuerk, Iversen, & Willmes, 2004; Prpic et al., 2016; Ren et al., 2011). One major implication of SNARC is a reversed ESC pattern for half-range digits/emotional pairs displayed in spatially incongruent positions (i.e., cutoff paired with *min* digits/faces; *max* paired with cutoff digits/faces), but not for for half-range digits/emotional pairs displayed in spatially congruent position (i.e., *min* paired with cutoff digits/faces; cutoff paired with *max* digit/face).

According to the SNARC, spatial incongruency should globally decrease response speed of extreme values relative to the cutoff of the series (i.e., *min* = 1 and *max* = 9), while the opposite would hold true for spatial congruency. Therefore, left-hand responses should be faster than right-hand responses for both spatially congruent and incongruent pairs with negative average intensity (e.g., 1-5, 5-1). Indeed, in the congruent couple (1-5), the digit 1, which is spatially congruent with SNARC, should facilitate left-hand responses compared to right-hand responses to the cutoff digit 5. Conversely, in the incongruent couple (5-1), the digit 1, which is spatially incongruent with SNARC, should now hinder right-hand responses compared to left-hand responses to the cutoff digit 5. The same reasoning could be applied to half-range digits pairs with positive average intensity (e.g., 5-9, 9-5), in which right-hand responses should be faster than left-hand responses for both spatially congruent and incongruent. As a consequence, a response encoding based on spatial and motor congruency with the left-to-right mental format of numerals should lead to a main effect of Spatial Congruency, further qualified by an Average Intensity × Response Side interaction on individual response speeds.

3.2 General Method

3.2.1 Participants

Eighty-seven students with normal/corrected-to-normal visual acuity of the University of Trieste served as participants either in Experiment 1 (*n*= 47, 37 females) or in Experiment 2 (*n*= 41, 29 females), in exchange for course credits. As backed by the sensitivity analyses, I conducted (G Power 3.1; Faul, Erdfelder, Lang, & Buchner, 2007) on our samples size with α err. Prob. = .05, Power (1 – β err. Prob.) = .8, both Minimal Detectable Effects for Experiment 1 and 2 resulted to be in the medium-to-large range (Cohen, 1988) with a f^2 = .18 and a critical 2-tale *t* of about 2.02 in Experiment 1 and a f^2 = .20 and a critical 2-tale *t* of about 2.03 in Experiment 2.

All participants gave oral informed consent prior to inclusion in the experimental sessions, during which they were treated in compliance with national legislation (approval of the Research Ethics Committee of the University of Trieste number 84c/2017), 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 were all Italian speakers (i.e., left-to-right reading direction), and naïve to the purpose of the study. Their average age was 21.09 (SD = ± 3.811; age range = [19 – 39]) in Experiment 1 and 19.93 (SD = ± 1.367; age range = [19 – 25]) in Experiment 2. Their handedness, as revealed by aggregating the individual scorings from the 10-item Edinburgh Handedness Inventory (Oldfield, 1971), was on average 62.152 (SD = ± 36.469; min. to max. range = [- 83 – + 100]) and 74.390 (SD = ± 28.496; min. to max. range= [-50 – +100]) in Experiment 1 and 2, respectively. Participants were randomly assigned to one of the two conditions of instruction ordering: with 23 participants in Experiment 1 performing the experiment in the "choose the smallest of the two digits" as the first block between the two, and 23 participants in Experiment 2 performing the experiment in the "choose the angriest of the two faces" as the first block between the two.

3.2.2 Apparatus, Stimuli, and Design

Both digit (in Experiment 1) and facial expression (in Experiment 2) stimuli were presented on a black background on a 22″ Dell P2214H monitor with 1920×1080 pixels resolution via PC, in a dimly lit laboratory with the participants comfortably sit facing the screen at an average distance of 38 cm. Such a viewing distance was selected in order to equate in term of visual size and eccentricity our stimuli to the face stimuli used in Study 1 which were presented on a 19″ monitor with 1024×768 resolution, which delivered a stimulus about 1.5 times larger than the one displayed with the current experimental apparatus. Both types of digit and emotional pairs (cross- and half-range) were treated in the exact same way of emotional pairs used in Study 1. Each digit/face of a pair was centred on the horizontal axis of the screen, occupied a visual vertical extent of 16.8°, and was displayed so that its distance from the flanking digit/face equal 19.6° (centre-to-centre distance), with the midline between the two digits/faces corresponding to the vertical midline of the screen. Responses were recorded using a QWERTY keyboard positioned on the desk between the participant and the monitor, with only the “d” and “j” keys (keys’ distance = 8 cm) activated during the experiment and centred along the participants’ sagittal axis. The distance of the keyboard was carefully adapted to the participant harm length in order to ensure a comfortable posture as in Fantoni & Gerbino (2014). Stimulus presentation and response recording were controlled by a custom-made E-Prime 2.0 program. In Experiment 1, the same set of digits was utilized to compose our stimulus pairs in the training and in the experimental sessions (as displayed in Figure 3.1), which were mid grey scale Arabic numerals in *Verdana* font. The brightness value was equal to the one of the face set used for the training session in both Study 1 and in the subsequent Experiment 2 (Brightness= 65), that in turn was almost equal to the average value of the experimental face set used in both Study 1 and in Experiment 2. As depicted in Figure 3.1A, I utilized only odd digits in the 1-to-9 continuum, i.e., 1, 3, 5, 7, and 9 in order to: (1) avoid a possible compound effect on the lateralization of motor reactivity due to the usage of odd and even numbers (MARC effect) with a possible response facilitation due to congruence in linguistic markedness (Hines, 1990; Nuerk et al., 2004); (2) obtain a digits continuum maximally similar in term of relative intensities to the one used in Study 1 in the domain of emotions, and in Experiment 2, (see subsection 3.1.1 for relative encoding of intensity).

As regards the facial stimulus set, I strictly followed the rationale of Study 1. I utilized the exact same set of black and light grey drawings faces from Medley (2012) in order to obtain the 6 stimulus pairs used during the training session. The facial stimulus set used in the experimental sessions of Experiment 2 was extracted from the same 8 color photographs of characters of the Radboud University Nijmegen set (Langner et al., 2010: 4 female Caucasia face 1, 4, 14, 19; 4 male Caucasia face 20, 30, 46, 71) validated and tested in Fantoni & Gerbino (2014, see also Fantoni et al., 2016). Following the exact same morphing technique, based on 75 key points implemented by

Fantoni & Gerbino (2014, see also Fantoni et al., 2016), for each of the 8 selected characters I utilized colour photographs displaying faces masked by an oval vignette hiding hair and ears expressing two full emotions (happiness and anger). The two full emotions, in turn, were used to extract 3 additional faces displaying intermediate valence emotions used to complete our discrete continuum of per cent happiness in the morph, with the ‘‘neutral’’/cutoff expression obtained by morphing the fully happy and fully angry expressions in equal percentages (50 per cent each), and the *half* negative (angry) and *half* positive (happy) face obtained by morphing the fully happy and fully angry expressions in complementary proportions with 25% happiness – 75% anger and vice-versa, respectively.

As depicted in Figure 3.1B and 3.1C, each set of 5 digits/facial expressions (belonging to the same character) was paired, in order to obtain 4 Types of half-range stimulus pairs coupling a *max/min* intensity with the cutoff digit/face (*min*, cutoff; cutoff , *max;* cutoff, *min*; *max*, cutoff), resulting from the combination of 2 Spatial Congruency conditions (spatially congruent; spatially incongruent) × 2 Average Intensity of the pair (negative [-2 in Experiment 1| -50 in Experiment 2]; positive [+2 in Experiment 1| +50 in Experiment 2]), and 4 Types of cross-range stimulus pairs coupling digits/faces with cross-range intensities over the cutoff (*min*, *max*; *half* negative, *half* positive; *max*, *min*; *half* positive, *half* negative) resulting from the combination of 2 Spatial Congruency × 2 Target Absolute Intensity (*min/max*; *half/half*). The combination of these 8 Types of Stimuli with Response Side (left; right) determined 16 experimental conditions common to our two Experiments. As in Study 1, our set of stimulus pairs determined a total of 64 digits/emotional pairs, which was the total of the stimuli presented during each experimental session. Such a number resulted by the following factorial combination: 8 repetitions (in Experiment 1)|characters (in Experiment 2) × 4 Type of Stimuli (2 half-range digits/emotional pairs differing in term of Average Intensity + 2 cross-range digits/emotional pairs differing in term of Target Absolute Intensity) × 2 Spatial Congruency (congruent, incongruent). Considering the two sequential tasks included in our experiments, both experiments were thus represented by the same 2 Task Ordering × 2 Spatial Congruency × 3 Average Intensity × 2 Response Side crossover design.

3.2.3 Procedure

The exact same procedure was applied in Experiment 1 and 2. Our procedure resembled the one used in Experiment 1 of Study 1, thus including the same direct comparison task (on digits in Experiment 1 and facial expressions of emotions in Experiment 2), as well as the same sequence of events: 1) Edinburgh handedness inventory; 2) oral instructions; 3) training on the task with instruction A or B depending on Task Ordering and Experimental session; 4) training on the task with instruction B or A depending on Task Ordering and experimental session (see Study 1 for details). For all participants, the complete experiment included 36 training trials, lasting about 3-4 min, and 128 experimental trials lasting about 12-13 min. (time for reading the instructions not included). Written instructions informed participants that they would be asked to select – between a pair of horizontally aligned digits/faces – which one of the two digits/faces was the smallest-angriest/largest-happiest, using the keys on the keyboard with the corresponding spatial position (i.e., “d” press if target on the left vs. “j” press if target on the right). The trial temporal structure was the same as Experiment 1 of Study 1, as illustrated in Figure 3.2.

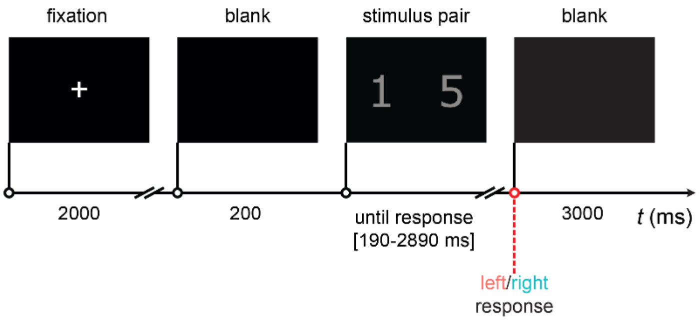

Figure 3.2. Trial temporal structure. This specific example illustrates the subset including a stimulus pair used in Experiment 1 with negative average digits intensity in spatially congruent position, (i.e., min-cutoff digit). Depending on the task ("choose the smallest/largest" in the pair), the target digit was either the one on the left or the one on the right (coinciding with the keyboard keys left/right). The stimulus was self-terminated by the participant response (lasting from a minimum to a maximum duration of 190 to 2890 ms). In Experiment 2, the temporal structure of the trial was exactly the same, with the exception of the stimulus pair that included a pair of facial expressions of emotions varying along the angry-to-happy per cent in the morph continuum.

3.2.4 Data Analysis

The same individual values of performance indices used in Study 1 were extracted from the pattern of individual responses in our direct digits/emotions comparison task. In particular, I focused our analysis on values of response speed calculated as the inverse of individual values of valid and correct Response Time, RT, in ms (i.e., 1000/RT). Such inverse transformation was motivated by: (1) its homology with actual speed and response accuracy; (2) its capacity to normalize the skewed distribution of RTs with the advantage of an increased statistical power and a reduced likelihood of outlier removal (Miller, 1991; Ratcliff, 1993; Whelan, 2008). Such a measure was in turn used to extract individual values of right-to-left response speed advantage (Δspeeds). The Δspeed synthetically quantifies how much the side of motor response (right- vs. left-hand) is affected in positive (if the response speed of the right-hand motor response was larger than the left-hand motor response) or negative (if the response speed of the left-hand motor response was larger than the right-hand motor response) directions by the average intensity of digits/emotions, depending on the Spatial Congruency of the pair with the left-to-right mental format of numbers/valence. In particular, I extracted 8 individual values of Δspeeds per participant, resulting from the difference between right and left response speeds associated to the 8 experimental displays. In particular, these displays result from the combination of 4 Type of Stimuli × 2 Spatial Congruency level of our experimental design. The average number of valid trials per condition over the 8 displays included in our experiment were equal to: 7.75 ± 0.51 SD range = [6, 8] in Experiment 1, and 7.64 ± 0.75 SD range = [3, 8] in Experiment 2.

As a third index, I analysed the individual proportion of correct responses calculated over the 8 displays for each condition of our design. In doing that, I transformed each individual proportion into the corresponding z-score for proportion, keeping the ratio between the deviations of the individual proportion from the hypothesized value of population proportion in the null hypothesis (p_0= .75), given our two alternative forced choice task with a guess rate= .5, and a standard deviation of the sampling distribution, σ , based on our sample size (*n*= 8), of $\sigma = \sqrt{\frac{p_0(1-p_0)}{n}} = \sqrt{\frac{0.75(1-0.75)}{8}} = 0.153$. Average accuracy and average z-score of proportion of correct responses, were equal to .97 (± .06 SD) and 1.43 (± 0.41 SD) in Experiment 1, and to .95 (± .09 SD) and 1.34 (± 0.61 SD), in Experiment 2, respectively. Exclusion criteria were the same as in Study 1, with valid trials being encoded as responses provided within the [200 ms, 2500 ms] time window (5789 trials, 98.319 % of all trials in Experiment 1 and 5117 trials; 97.503 % of all trials in Experiment 2), and falling within ± 3 standard deviations from the predicted value of the best fitting generalized linear mixed-effect (*lme*) regression model (86 trials, 1.49% of the total of correct responses in Experiment 1 and 96 trials, 1.88% of the total of correct responses in Experiment 2).

In both Experiments I analysed all three types of performance indices (response speed, Δspeed, z-score of proportions) using *lme* models. In order to keep our generalized causal inference less prone to the risk of Type I error inflation, I followed Barr, Levy, Scheepers, and Tily (2013) and selected for all our *lme* models the maximal random effects structure justified by our experimental design. This involves models with by-subject random intercepts and slopes with our balancing variable (the Task Ordering) used as an additional random intercept. I selected the fixed structure of our *lme* models according to a step-wise procedure contrasting *lme*s of increasing complexity depending on the number of fixed effects, modelled by the factors of our experimental design: Average Valence, Target Absolute Emotional Intensity, Spatial Congruency, Response Side[3]. Consistently with the results of Study 1, preliminary *lme* analyses revealed no reliable interaction between accuracy, handedness, speeds and other experimental factors neither in Experiment 1 [a reliable speed-accuracy positive correlation, $F(1, 364.03) = 13.317$, $p < .001$ with accuracy increasing of about 0.034 ± 0.008 per cent every unit increment of speed, , $t(432.2) = 4.379$, $p < .001$, $d = 0.421$, with no other main effects or interaction revealed $\chi^2_{14} = 24.717$, $p = .037$, when handedness was combined with response Side, Spatial Congruency and Average Digits Intensity as fixed effects], nor in Experiment 2 [a reliable speed-accuracy positive correlation, $F(1, 250.2) = 16.666$, $p < .001$ with accuracy increasing of about 0.040 ± 0.015 per cent every unit increment of speed, $t(219.9) = 4.086$, $p < .001$, $d = 0.55$, with no other reliable effects or interaction revealed $\chi^2(14) = 34.918$, $p < .001$, when handedness was combined with response Side, Spatial Congruency and Average Digits Intensity as fixed effects]. These preliminary results motivated our decision to focus the main analyses of our two Experiments on indices of comparative judgement performance based on speeds alone (i.e., individual response speeds and Δspeeds), beyond handedness.

3.3 Results and Discussion

3.3.1 Experiment 1: Comparative judgment of Arabic numbers

Figure 3.3 illustrates the patterns of average values of response speeds/times (Figure 3.3A and 3.3B *y*-axes left/right) and Δspeeds (Figure 3.3C and 3.3D) resulting from individual comparative judgements of digits self-terminated by observers' responses as in Experiment 1, respectively. Data are shown for targets presented in spatially congruent (Figure 3.3A) and incongruent (Figure 3.3B) positions, appearing in the leftmost (red filled circles) or the rightmost (blue filled circles) position,

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[3] see Study 1 for details on the procedure of *lme* fitting. The estimation of the goodness of fit was based on AIC-index, BIC-index, and χ^2. The estimates of significance of *lme*'s fixed effects and parameters were based on Type III *F*-tests; the estimates of effect size were based on the concordance correlation coefficient r_c, and Cohen's *d* supporting results of post-hoc tests were performed on *lme* estimated coefficients, with paired sample *t*-tests with unequal variance.

depending on whether the target was the smallest (continuous outline) or the largest (dotted outline) digit within the pair. Figure 3.3C depict the corresponding pattern of average Δspeeds as a function of average digit intensity, with the same pattern of Δspeeds remapped as a function of SIA based predictions shown in Figure 3.3D.

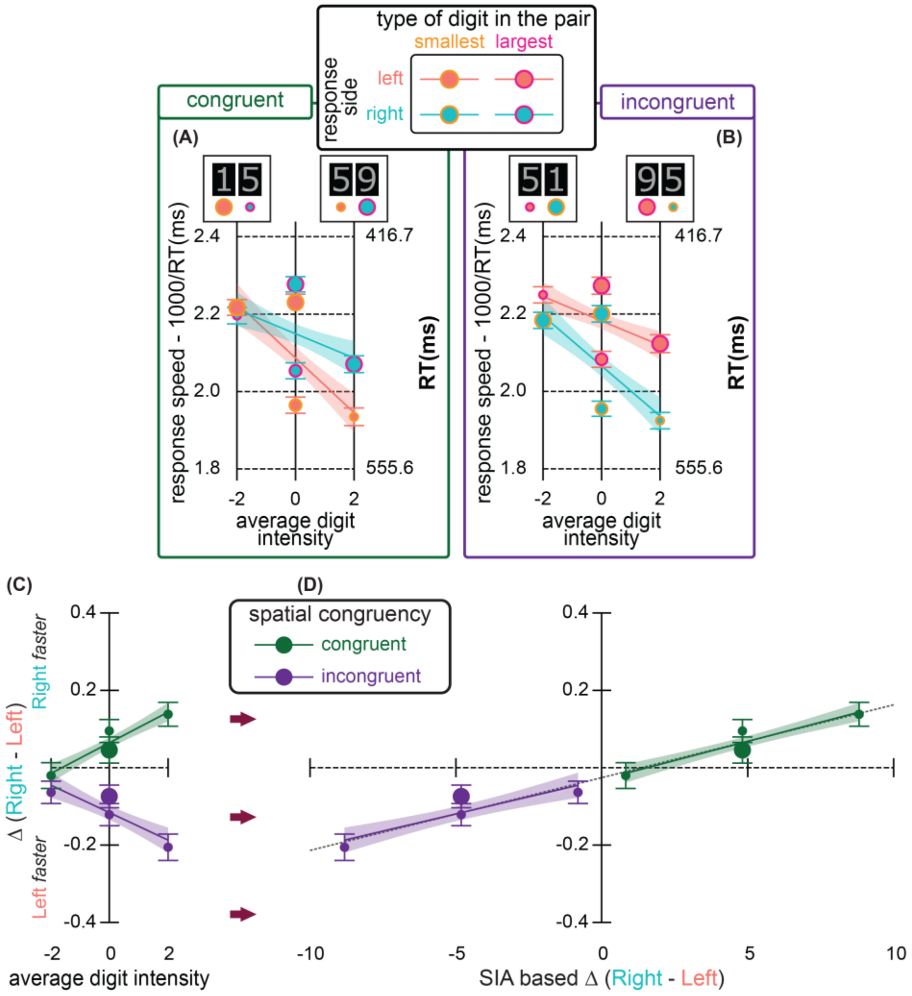

Figure 3.3. Comparative judgment of Arabic numbers. (A-B) illustrations of the average individual response speeds in spatially congruent (A) and spatially incongruent (B) conditions, as a function of average digit intensity. Error bars represent ± 1 standard error of the mean and the size of the circles the absolute emotion intensity (small = cutoff intensities of the continuum; medium = half intensities of the continuum; and large = min/max intensities of the continuum). The response side and the type of target digit are coded by the colour of the filling circles (red for left; blue for right) and by the outline (pink for largest; orange for smallest) bounding the circles, respectively (legend on top). Red and blue lines are the *lme* model regression lines for left/right response side conditions, with the shaded bands corresponding to ± 1 standard error of the regression. Panels C and D show average Δspeeds resulting from subtracting individual response speeds of left-hand responses from individual response speeds of right-hand responses in the ordinate either as a function of average digit intensity (C) or as a function of the best SIA model prediction for the pattern of right-to-left response speeds advantages (D) in the abscissa, with error bars representing ± 1 standard error of the mean. The size of circles represents the absolute distance of the pair along the considered intensity continuum (large: min-max; small: cutoff-min/max or half-half). The spatial congruency condition is coded by the colour of the circles (legend of panel C and D). Continuous green and purple lines in panels C and D are the *lme* model regression lines for congruent/incongruent conditions, with the shaded bands corresponding to ± 1 standard error of the regression, while dotted grey lines represent the SIA predictor as the covariate of average Δspeeds.

The patterns of response speeds/times (Figure 3.3A and 3.3B) and Δspeeds (Figure 3.3C) are in strong agreement with a general SC pattern consistent with AE1, but not with AE2. I corroborate this observation statistically through demonstrating the generality of the attentional capture phenomenon as occurring also in the numerical domain, thus in absence of motivational significance. The *lme* analysis on the individual choice speeds revealed a reliable Response Side × Spatial Congruency × Average Digits Intensity interaction [*F*(1, 133.627) = 34.874, *p* < .001], consistent with the *crossover* pattern expected on the basis of AE1 and predicted by SIA (Figure 3.3A and 3.3B). In particular, for pairs with positive Average Digits Intensity, the response speed was faster for the largest/*max* (2.099 ± 0.042) over the smallest/cutoff [1.926 ± 0.042, *t*(138.9) = 8.037, *p* < .001, *d* = 1.364] digit, with the response speed advantage being robust across Spatial Congruency conditions [$\text{M}_{\mathit{max}\text{/congruent}}$ = 2.069 ± 0.043 vs. $\text{M}_{\text{cutoff/congruent}}$ = 1.932 ± 0.043; *t*(57.912) = 42.271, *p* < .001, *d* = 1.17; $\text{M}_{\mathit{max}\text{/incongruent}}$ = 2.127 ± 0.045 vs. $\text{M}_{\text{cutoff/incongruent}}$ = 1.921 ± 0.045; *t*(44.91) = 6.041, *p* < .001, *d* = 1.803]. The reverse was not true for negative Average Digits Intensity pairs, in which the response speed was almost the same for the smallest/*min* (2.000 ± 0.040) and the largest/cutoff [2.222 ± 0.040; *t*(137.142) = 0.995, *p* = .321, *d* = 0.17] digit. The different response speed advantage of *max* and *min* digits over the cutoff was accounted for by a rather evident response speed unbalance across the two types of digit in the pair, with a reliably faster choice for the largest (estimated average speed for incongruent ⇒ left and congruent ⇒ right conditions= 2.241 ± 0.038), over the smallest [estimated average speed for congruent ⇒ left and incongruent ⇒ right conditions= 2.152 ± 0.038, *t*(137.043) = 6.093, *p* < .001, *d* = 1.041] digit. Such an unbalance was qualified by a significant Response Side × Spatial Congruency [*F*(1, 134.974) = 38.275, *p* < .001] interaction, consistent with a rather evident *funnelling* of the *crossover* patterns expected on the basis of AE1.2. This is due to the robust *intensity anisotropy*, which favoured the selection of largest over smallest digits. This anisotropy is elicited by a the negativity of the point of intersection between the two best fitting *lme* regressors in both spatially congruent (i.e., light grey “left response side” continuous *lme* model regression line intersecting the black “right response side” continuous *lme* model regression line in the point -1.659 in Figure 3.3A) and incongruent (-3.203 Figure 3.3B) conditions. Furthermore, I also found a main effect of Average Digit Intensity [$F(1, 45.334) = 174.837$, $p < .001$], consistent with a *size effect* consistent with AE1.1, due to a steady decrease of the response speed as Average Digit Intensity grew larger [$\beta = -0.050 \pm 0.003$, $t(45) = -13.25$, $p < .001$, $d = 3.933$], from negative to positive digit pairs [estimated speed decrement due to Average Digit Intensity increase = -0.199 ± 0.015, $t(232.879) = -12.97$, $p < .001$, $d = -1.7$].

A further *lme* analysis on the subset of individual judgements’ speeds, referred to cross-range digits pairs (with Average Digit Intensity = 0), revealed a Spatial Congruency × Response Side [$F(1, 135.794) = 14.429$, $p < .001$] significant interaction, further supporting our general *intensity anisotropy* (consistent with AE1.2) favouring the largest (9 and 7) over the smallest digits (1 and 3) within cross-range digits pairs of about 0.085 ± 0.015 [$t(138.127) = 5.518$, $p < .001$, $d = 0.939$]. This interaction was further qualified by a main effect of Target Absolute Intensity [$F(1, 44.963) = 231.607$, $p < .001$], which was in agreement with a *distance effect* as by-product of AE1.2: the speed of judgements increased as the difference between the pair of digits grew larger both for the “choose the smallest” [$M_{\text{Target Absolute Intensity} = 4} = 2.214 \pm 0.041$ vs. $M_{\text{Target Absolute Intensity} = 2} = 1.960 \pm 0.037$, $t(45.935) = 12.7$, $p < .001$, $d = 3.762$], and for the “choose the largest” [$M_{\text{Target Absolute Intensity} = 4} = 2.273 \pm 0.039$ vs. $M_{\text{Target Absolute Intensity} = 2} = 2.069 \pm 0.037$, $t(43.515) = 9.769$, $p < .001$, $d = 2.962$] task.

As in Study 1, I further analysed Δspeeds shown in Figure 3.3C for the 8 conditions of the experimental design in order to provide a synthetic converging measure of our effects. Again, the result of the *lme* analysis revealed the following set of reliable effects, common to the finding of Study 1 and consistent with AE1 but not AE2. The analysis revealed a reliable Spatial Congruency × Average Digit Intensity interaction [$F(1, 90) = 33.379$, $p < .001$], and a main effect of Spatial Congruency [$F(1, 90) = 31.341$, $p < .001$; spatially congruent positive *lme* estimated slope = 0.040 ± 0.009, $t(90) = 4.31$, $p < .001$, $d = 0.909$; vs. spatially incongruent negative *lme* estimated slope = -

0.035 ± 0.009, $t(90) = -3.861$, $p < .001$, $d = -0.814$]. This pattern of significant effects was consistent with a reliable right-to-left response speed advantage for negative over positive Average Digit Intensity in spatially congruent condition [$M_{\text{Average Digit Intensity} = -2} = -0.020 \pm 0.033$, vs. $M_{\text{Average Digit Intensity} = 2} = 0.138 \pm 0.031$, $t(47.276) = 4.145$, $p < .001$, $d = 1.207$], which was reversed into a left-to-right response speed advantage (against a SNARC effect), in the spatially incongruent condition [$M_{\text{Average Digit Intensity} = -2} = -0.020 \pm 0.033$, vs. $M_{\text{Average Digit Intensity} = 2} = 0.138 \pm 0.031$, $t(47.276) = 4.145$, $p < .001$, $d = 1.207$].

As a final *lme* analysis, I quantitatively tested the likelihood of predicting our pattern of response by means of a general representational format of relative intensities. In particular, this is quantifiable through the SIA-based linear combination of the target absolute intensity relative to the cutoff with the *size* and the *intensity anisotropy* weighted according to our empirically determined free parameters. In doing that, I recoded each single target number within a pair, in terms of the sum between its Absolute Intensity relative to the cutoff, the Average Intensity of the pair (weighted of about an empirically determined α factor of -2.77 corresponding to the minimum positive multiplying factor of Average Intensity optimizing the goodness of fit of individual speeds), and an empirically determined value standing for the *intensity anisotropy* signed according to its relative intensity polarity (± 2.41 corresponding to the intensity value of the pair in which the best fitting *lme* regressors of Δspeeds, for the congruent and incongruent condition intersected). Remarkably, such a SIA-based remapping of our digits stimuli fully accounts for the effects both when considering individual speeds and individual speeds deviations. The SIA predictor, when included in the *lme* analyses as a further covariate, beyond the fixed factors tested in our experimental design, was the only significant factor reliably affecting both individual speeds [$F(1, 85.44) = 202.16$, $p < .001$], and Δspeeds [$F(1, 172.88) = 35.479$, $p < .001$]. This result testifies that the SIA predictor behaves as in Study 1, also in the remapping of low motivational significance stimuli as Arabic numbers. Importantly, *lme* models including only the SIA predictor – as the covariate of individual speeds or individual Δspeeds –

resulted to achieve a higher goodness of fit of totally unconstrained models, including the full factorial combination of all our experimental conditions on individual speeds, $\chi^2(6) = 0.00$, $p = 1$; $\text{AIC}_{\text{SIA}} = 3291.3$, vs. $\text{AIC}_{\text{FULL}} = 3427.3$; $\text{BIC}_{\text{SIA}} = 3351.1$ vs. $\text{BIC}_{\text{FULL}} = 3527$; $r_{c\ \text{SIA}} = .622$, 95% CI [.608, .635], vs. $r_{c\ \text{FULL}} = .610$, 95% CI [.596, .624]; on Δspeed $\chi^2(2) = 0.165$, $p = .921$; $\text{AIC}_{\text{SIA}} = -154.94$ vs. $\text{AIC}_{\text{FULL}} = -151.11$; $\text{BIC}_{\text{SIA}} = -131.50$ vs. $\text{BIC}_{\text{FULL}} = -119.84$; $r_{c\ \text{SIA}} = .730$, 95% CI [.689, .766], vs. $r_{c\ \text{FULL}} = .746$, 95% CI [.708, .781].

3.3.2 Experiment 2: Comparative judgment of facial expressions of emotions

Would results be similar (as those of Experiment 1), when comparative judgements are supported by the exact same representation of relative intensities, but with totally different motivational significance?

The *lme* analyses on the individual response speeds and Δspeeds obtained in Experiment 2, on the comparative judgment of intensities with high motivational significance, provide a positive answer to such a question (Figure 3.4A, 3.4B, 3.4C, and 3.4D, with the pattern of average response speeds and average Δspeeds presented following the same rationale and variable encoding used in Figure 3.3). These results provide further support to AE1, beyond the similarity between the patterns of responses observed in Experiment 1 and those previously assessed in Study 1, with facial expressions varying in the anger-to-neutral-to-happiness per cent in the morph continuum.

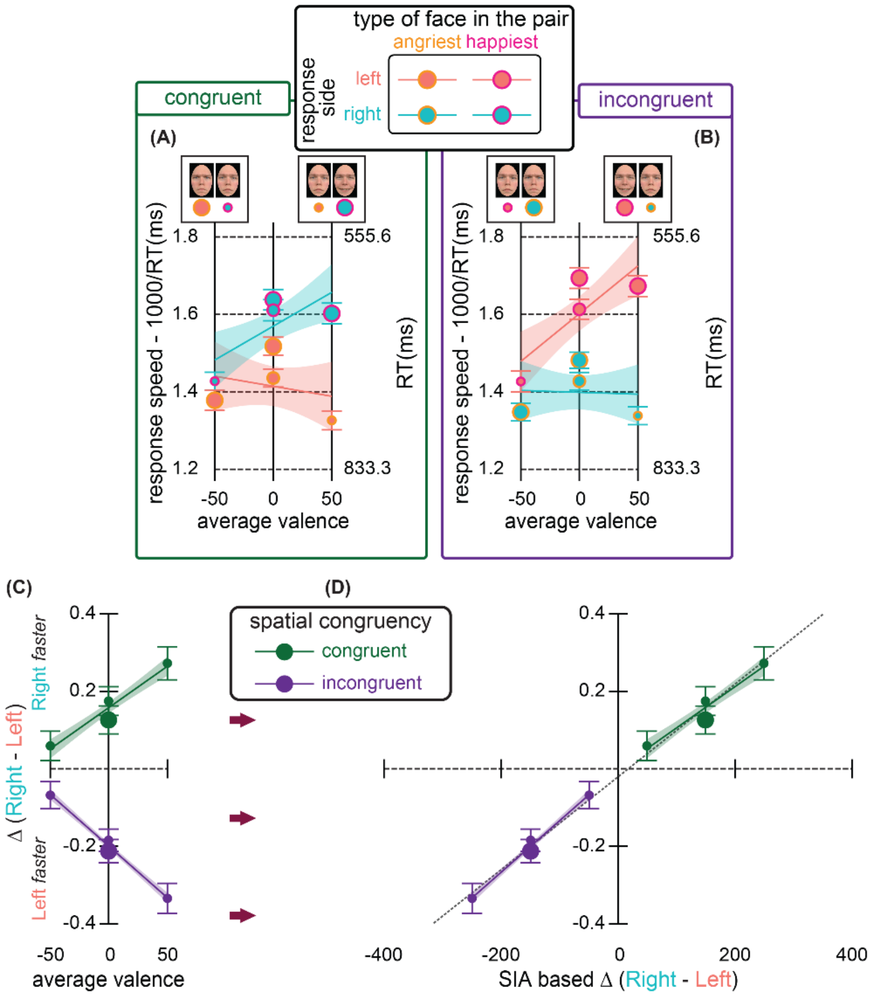

Figure 3.4. Comparative judgment of facial expressions of emotions. See caption of Figure 3.3 for further explanations. Panel A and B depicted the average individual response speeds in spatially congruent (A) and spatially incongruent (B) conditions, as a function of average valence. The response side and the type of target face are coded by the colour of the filling circles and by the outline (pink for happiest; orange for angriest) bounding the circles, respectively. Panels C and D show average Δspeeds in the ordinate either as a function of average valence (C) or as a function of the best SIA model prediction for the pattern of right-to-left response speeds advantages (D) in the abscissa.

Results of Experiment 2 closely mirrored results of Experiment 1. The key result on individual speeds was the similar Response Side × Spatial Congruency × Average Valence interaction [$F(1, 153.18) = 75.36$, $p < .001$], qualified by a rather large emotion anisotropy producing a robust *funnelling* of the *crossover* pattern, expected on the basis of AE1, in general, and AE1.2, in particular, with a reliable ESC effect for positive Average Valence pairs [happiest/*max* faster 1.634 ± 0.052 than angriest/cutoff 1.329 ± 0.052, $t(122.727) = 10.24$, $p < .001$, $d = 1.849$]. In particular, for pairs with positive Average Valence, choice was faster for emotional (i.e., *max*) over neutral (i.e., cutoff) targets (here characterized by an equal proportion of happiness and anger) in both spatially congruent

[$\mathrm{M}_{max/\mathrm{congruent}}$ = 1.598 ± 0.058 vs. $\mathrm{M}_{\mathrm{cutoff/congruent}}$ = 1.326 ± 0.058; *t*(39.934) = 6.362, *p* < .001, *d* = 2.013], and spatially incongruent conditions [$\mathrm{M}_{max/\mathrm{incongruent}}$ = 1.668 ± 0.054 vs. $\mathrm{M}_{\mathrm{cutoff/incongruent}}$ = 1.333 ± 0.054, *t*(40.194) = 8.567, *p* < .001, *d* = 2.703], but not for negative Average Valence pairs [angriest/*min* slower 1.358 ± 0.047, than happiest/cutoff, 1.419 ± 0.047 *t*(114.009) = 2.697, *p* = .008, *d* = 0.505, with $\mathrm{M}_{min/\mathrm{congruent}}$ = 1.367 ± 0.050, vs. $\mathrm{M}_{\mathrm{cutoff/congruent} =}$ 1.422 ± 0.050, *t*(37.398) = 1.503, *p* = .141, *d* = 0.491; $\mathrm{M}_{min/\mathrm{incongruent}}$ = 1.347 ± 0.051, vs. $\mathrm{M}_{\mathrm{cutoff/incongruent}}$ = 1.417 ± 0.051, *t*(39.184) = 2.03, *p* = .049, *d* = 0.649].

Also, the response speed unbalance across the two types of task and the *size effect* were similar to those observed in Experiment 1, thus corroborating AE1.2 and AE1.1. These effects were qualified by: (1) a significant Response Side × Spatial Congruency [*F*(1, 124.65) = 95.423, *p* < .001] interaction, favouring the selection of the happiest over angriest face of about 0.136 ± 0.018 [*t*(118.263) = 7.599, *p* < .001, *d* = 1.398]; (2) a main effect of Average Valence [*F*(1, 112.98) = 38.599, *p* < .001], with judgements' speeds increasing as the Average Valence grew larger [β = 0.0009 ± 0.0001, *t*(123.5) = 5.17, *p* < .001, *d* = 0.93], from negative to positive [estimated speed increment due to Average Valence = 0.093 ± 0.017, *t*(141.755) = 5.365, *p* < .001, *d* = 0.901].

As for cross-range emotional pairs, a similar Spatial Congruency × Response Side interaction [*F*(1, 496.96) = 25.283, *p* < .001], and a similar main effect of Target Absolute Emotional Intensity [*F*(1, 215.49) = 22.516, *p* < .001], emerged in Experiment 2. In particular, the interaction was consistent with a rather strong emotion anisotropy favouring the happiest over the angriest face of about 0.175 ± 0.019 [*t*(125.173) = 9.173, *p* < .001, *d* = 1.64]. The main effect was consistent with a *distance effect* in the domain of emotions, similar to that originally observed in Study 1. In particular, the speed of judgements increased as the difference between the emotional faces grew larger both for the "choose the angriest" [$\mathrm{M}_{\mathrm{Target\ Emotional\ Intensity} = 100}$ = 1.496 ± 0.049 vs. $\mathrm{M}_{\mathrm{Target\ Emotional\ Intensity} = 50}$ = 1.430 ± 0.048, *t*(76.438) = 3.825, *p* < .001, *d* = 1.457], and for the "choose the happiest" [$\mathrm{M}_{\mathrm{Target}}$

$_{\text{Emotional Intensity = 100}}$ = 1.666 ± 0.061 vs. $\text{M}_{\text{Target Emotional Intensity = 50}}$ = 1.611 ± 0.057, *t*(161.183) = 2.978, *p* = .001, *d* = 0.469] tasks.

The *lme* analysis on the pattern of individual Δspeeds (Figure 3.4E) revealed the exact same set of significant effects observed in Experiment 1 and in Study 1: a reliable Spatial Congruency × Average Valence interaction [*F*(1, 79.905) = 64.842, *p* < .001], and a main effect of Spatial Congruency [*F*(1, 77.863)= 74.77, *p* < .001; spatially congruent positive *lme* estimated slope = 0.0021 ± 0.0005, *t*(79.905) = 5.063, *p* < .001, *d* = 1.133; vs. spatially incongruent negative *lme* estimated slope = -0.0027 ± 0.0004, *t*(73.91) = -6.324, *p* < .001, *d* = - 1.415]. The pattern of individual Δspeeds was again consistent with a right-to-left response speed advantage for negative over positive Average Valence in Spatially Congruent condition [$\text{M}_{\text{Average Valence = -50}}$ = 0.059 ± 0.038, vs. $\text{M}_{\text{Average Valence = 50}}$ = 0.272 ± 0.043, *t*(40.07) = 5.06, *p* < .001, *d* = 1.599] *vs.* a left-to-right response speed advantage (against a SNARC-like effect in the domain of emotion replicating the results of Study 1) in Spatially Incongruent condition [$\text{M}_{\text{Average Valence = -50}}$ = -0.068 ± 0.035, vs. $\text{M}_{\text{Average Valence = 50}}$ = -0.335 ± 0.039, *t*(39.92) = 6.326, *p* < .001, *d* = 2]. Again, such a pattern was consistent with 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 76.14 %. This was signalled by the point of intersection between the two-best fitting *lme* estimated regressors for spatially congruent and incongruent pairs.

Finally, as in Experiment 1, I tested the goodness of SIA predictions on our rather novel continuum of motivationally significant stimuli (anger-to-happiness per cent in the morph continuum vs. the anger-to-neutral-to-happy per cent in the morph continuum tested in Study 1). I used the same procedure applied in Experiment 1 to remap our stimulus conditions into a SIA-based code of relative intensities, now including the larger value of global emotion anisotropy (76.14% instead of the 2.77 corresponding to the 60.2% of our number continuum), as well as the smaller though positive value of the weight modulating the average intensity of the pair that formalized a *size effect* in the domain of emotion obtained from the data of Experiment 2 (1.42 instead of the -2.69 of Experiment 1).

Remarkably, the SIA predictor behaves as in Study 1 and in Experiment 1, despite now being applied for the remapping of high motivational significance stimuli not including a real neutral face as the cutoff but rather a morphed face (mixing in equal proportion anger and happiness). Namely, when included as a further covariate in the *lme* analyses of individual speeds and Δspeeds, SIA resulted to be the only significant factor reliably affecting the comparative judgment performance [$F(1, 61.7) = 62.465$, $p < .001$ on individual speeds and $F(1, 148.16) = 80.671$, $p < .001$ on Δspeeds]. The SIA predictor alone provided a higher goodness of fit than a totally unconstrained models including the full factorial combination of all our experimental conditions on individual speeds, $\chi^2(6) = 0.0$, $p = 1.00$; $AIC_{SIA} = 2652.3$ vs. $AIC_{FULL} = 2731.7$; $BIC_{SIA} = 2710.9$ vs. $BIC_{FULL} = 2829.4$; $r_{c\_SIA} = .712$, 95% CI [.700, .725] vs.; $r_{c\_FULL} = .719$, 95% CI [.706, .730]; on Δspeed $\chi^2(2) = 3.069$, $p = .216$; $AIC_{SIA} = -141.29$ vs. $AIC_{FULL} = -140.36$; $BIC_{SIA} = -118.53$ vs. $BIC_{FULL} = -110.01$; $r_{c\_SIA} = .900$, 95% CI [.879, .917] vs. $r_{c\_FULL} = .919$, 95% CI [.917, .933].

3.3.3 Joining results of Experiment 1 and 2: Comparing numbers with emotions

The data also revealed that performing the comparative judgements on a perceptually complex stimulus set (as the face stimuli used in Experiment 2) produces an overall loss in response speed and accuracy. This finding is consistent with previous evidence, showing a slowing down of comparative judgement speeds for perceptually complex stimuli (like pictures) vs. perceptually simpler stimuli (like Arabic numbers, e.g., Banks & Flora, 1977). This is confirmed by the overall lower choice accuracy with an average *lme* estimated per-cent accuracy of judgements of about 0.953 ± 0.005 vs. 0.969 ± 0.005 in Experiment 2 vs. Experiment 1 respectively, and the overall lower choice speeds with an average *lme* estimated speed of about 1.480 ± 0.044 (Figure 3.4A and 3.4B) vs. 2.120 ± 0.042 (Figure 3.3A and 3.3B) in Experiment 2 vs. Experiment 1, respectively.

Running a further *lme* analysis, I obtained strong evidence for the general conclusions on the close relationship between the two experiments revealing a common magnitude representation for the comparison of emotions and numbers, despite their different motivational significance (consistent with AE1). I compared the patterns of individual speeds in Experiment 2 directly to those of Experiment 1, including the Experiment as an additional fixed factor in the *lme* analysis, and encoding the levels of Average Intensity through the following common code: negative (standing for -50 or -2), null (standing 0) or positive (standing for +50 or +2).

Beyond the main effect of the Experiment, supported by the analysis reported in the preceding paragraph [$F(1, 85.19) = 110.907$, $p < .001$], the *lme* analyses revealed that the type of stimuli (Faces in Experiment 2 vs. Arabic numbers in Experiment 1) somehow modulates the *size* and the *crossover effect*. This observation is supported by the following two additional significant interactions.

The first one is Experiment × Average Intensity [$F(1, 945.08) = 104.754$, $p < .001$], consistent with a smaller *size effect* in the domain of emotions than in the domain of numbers. The *lme* estimated difference between negative and positive average intensity pairs quantifies the *size effect* in both domains. In the domain of emotion, this difference was almost half (0.094 ± 0.020) and, as expected, was reversed compared to the difference in the domain of numbers [-0.199 ± 0.019, $t(609.659) = 10.708$, $p < .001$, $d = 0.867$].

The second significant interaction is Experiment × Response Side × Spatial Congruency [$F(1, 976.58) = 26.692$, $p < .001$], consistent with a larger *intensity anisotropy* in the domain of emotion compared to the domain of numbers. The *lme* estimated difference between the happiest/largest and angriest/smallest target within a pair quantifies the *intensity anisotropy* in both domains. In the domain of emotion, this difference was almost twice (0.181 ± 0.014) the difference observed in the domain of numbers [0.091 ± 0.014, $t(876.087) = 4.414$, $p < .001$, $d = 0.305$].

3.4 General Discussion

I reported two experiments on the commonality of the speed and accuracy of spatially distributed responses over spatially distributed numbers and emotion. According to a common representation for the comparison of digits and facial expressions, I found that the direct comparison of pairs of simultaneously presented digits (in Experiment 1) and facial expressions (in Experiment

2) elicit similar patterns of right-to-left response speed deviations. I indeed observed similar *funnelling* of the *crossover* of speed deviations for digits/emotions presented in spatially congruent vs. incongruent positions (relative to the left-to-right mental format of numbers/valence) across small/negative to large/positive pairs: a result consistent with a general SC pattern. Notably, differently from the interpretation on isolated facial expressions and numbers experiments (Holmes & Lourenco, 2011; Pitt & Casasanto, 2017), such a general SC pattern did not involve any compatibility bias, known as SNARC or SNARC-like effects. This was indeed expected to produce a right-to-left response speed deviation increasing steadily from small/negative to large/positive pairs in both spatially congruent and incongruent pairs: not a crossover. Consequently, our pattern of results is not always in line with the spatial-response compatibility predicted by SNARC. Indeed, when the digits or emotions are in an incongruent spatial position, a reversed SNARC/SNARC-like pattern was observed, with right-hand responses (digit 1 and 100% angry faces) resulting to be *faster* than left-hand (digit 5 and 50% angry – 50% happy faces) responses, for small/negative pairs, and vice-versa for large/positive pairs (digit 9 and 100% happy faces on the left *faster* than digit 5 and 50% angry – 50% happy faces on the right, respectively).

The key feature of our common pattern of results is the direct relationship between the speed of lateralized motor reactivity and the absolute intensity value of the target number/emotion relative to the cutoff of the (numerical or valence defined) series, which was first proposed in Study 1: namely the SIA. Such a consistency across domains suggest that the psychological format of quantities regulating lateralized motor reactivity in our direct comparison tasks was based on *relative intensities* characterized along a bipolar unidimensional intensity continuum. This continuum is likely to be defined on opposite sides by a neutral midpoint providing a reference position for establishing extreme values for both emotional magnitudes, as well as for numerical magnitudes, studied in Experiment 2 and 1, respectively. Results of our two Experiments are indeed fully accounted for by the SIA remapping of emotion and digits intensities, with large numbers producing similar effects to positive emotions (as being on top of the world) and small numbers producing similar effects to negative emotions (as hitting the roof).

Importantly, the SIA remapping was found to be predictive of an attentional capture effect by the motivational salience of facial expressions of emotions in the anger-to-neutral-to-happiness per cent in the morph continuum originally found in Study 1. In particular, responses in an emotion comparison task (equal to the one used in Experiment 2) were speeded up when the target face was emotional and slowed down when the target face was neutral, as a by-product of emotional stimuli exerting a strong exogenous (‘bottom-up’) pull on attention. According to such an interpretation of the effect, emotional stimuli captured observer’s motor behaviour because of their intrinsic motivational significance, through making them act like attentional attractors (Carretié, 2014; Ferrari et al., 2008; Reeck & Egner, 2015). In Experiment 2, I found the exact same results but with facial expressions of emotions in the anger-to-happiness per cent in the morph continuum. The speeds of choice similarly increased as the absolute emotional intensity of the target face – relative to an empirically determined cutoff emotion – grew larger. This increase also grew larger with the average intensity of the pair (from negative to positive emotions), irrespective of the compatibility between the valence and the side of motor response. This pattern was globally consistent with an attentional capture effect predicted by SIA remapping. The interesting point is that a similar effect occurred also in the case of the direct comparison of Arabic numbers in the 1-to-9 continuum of Experiment 1. In this case, speeds of choice increased as the absolute digit magnitude – relative to an empirically determined cutoff number – grew larger, together with the average intensity of the pair (from large to small numbers). On the basis of the pattern of both individual speeds and right-to-left response speed deviations collected in Experiment 1 and Experiment 2, there is no evidence that other factors beyond attentional capture as modelled by the general remapping of magnitudes (both motivationally significant and not) – operated through the linear combination of relative intensities at the basis of SIA– may have accounted for comparative judgements performance in our direct comparison tasks.

Our common results for number and emotions constitute a first tentative to positively answer to our *research question*. They suggest that SIA can be generalized to different domains as predicting the speed advantage within a pair from the difference between their absolute intensities relative to the cutoff of the series. This evidence points to a rather general process regulating comparative judgments. This general process could be based on the way spatial attention is captured toward locations containing the stimulus which is closest to the extremal values of a series, in terms of relative intensity. Extremal values of a continuum, defined on opposite sides by a neutral midpoint, appear to act as attentional attractors within a relative magnitude reference frame, that potentially could be extracted from any type of quantity continuum.

Our finding thus bridge two rather different, though complementary, fields of research. Namely (1) the emerging field of emotion regulation research, regarding how bottom-up exogenous (i.e., stimulus-driven) and top-down endogenous (i.e., goal-directed) factors together might exert their influence on emotional signals, in order to shape motor reactivity to displays characterized by emotions' combinations (Delgado et al., 2008); and (2) the long standing field of numerical cognition, based on studies investigating magnitude comparison and the culturally, developmentally and evolutionarily independent computations necessary to relate mental magnitudes to one another along a continuum (e.g., Dehaene, 2003; Fischer & Shaki, 2016; Gallistel & Gelman, 1992; Izard & Dehaene, 2008; Patro & Shaki, 2016; Shaki & Fischer, 2008, 2018).

In particular, following emotion regulation, the pattern of response speeds found in Study 1 – that I fully replicated in our Experiment 2 – is consistent with a great amount of evidence showing a prioritization in early sensory processing of affective emotional over neutral stimuli (Fox, 2002; Hansen & Hansen, 1994; Lane et al., 1999; Morris et al., 1998; Öhman, Flykt, et al., 2001; Öhman, Lundqvist, et al., 2001; Sabatinelli et al., 2005; Vuilleumier et al., 2003). However, the pattern of response speeds of Experiment 1 was homologous to that of Experiment 2, being similarly accounted for by the SIA remapping, despite the stimuli (numbers) were void of motivational significance. Here

I thus put forth the idea that the joint evaluation – distinctive of our comparison tasks – involves attentional capture by *magnitudes* rather than *perceptual* salience of facial features shaping motivational significance. Attentional capture by magnitude can indeed be explained by the formation of an intrinsic reference frame (Audley & Wallis, 1964; Holyoak, 1978; Hsee, 1996; Hsee & Leclerc, 1998; Shafir et al., 1993). In particular, the reference frame would rise from a direct comparison of one option against the other with the more extreme option of the pair, in terms of intensity relative to the cutoff of the series constituting an attentional attractor. Notably, such ideas reconcile pioneering reference point models of comparative judgements (Greenberg, 1963; Holyoak, & Mah, 1982; Holyoak & Walker, 1976; Jamieson & Petrusic, 1975; Petrusic, 1992 –see also Chen et al., 2014 and Lu et al., 2012 for more recent computational implementations), with exogenous theories of spatial attention. The major difference is that, as the anchor for comparisons along a given continuum, the SIA remapping use a single reference point at cutoff (i.e., task independent) rather than extreme reference values (defined implicitly or explicitly by the task, i.e., the smallest or largest). This is consistent with our previous results showing no reliable effects of the type of task (direct vs. indirect) on the general pattern of emotion comparison (Study 1).

Thus, the commonality of results between Experiment 1 and 2 suggests for a general principle to account for the well-known flexibility of the SC effects, with a pattern of response reactivity strictly similar to the one I found in the current study. Indeed, SC effects have been shown to be not unique to the numerical and emotional domain, being instead found in a wide variety of stimuli, when compared along a single dimension (Audley & Wallis, 1964; Banks et al., 1975, 1976; Banks & Flora, 1977; Clark et al., 1973; Ellis, 1972; Friend, 1973; Holyoak, 1978; Holyoak, & Mah, 1982; Holyoak & Walker, 1976; Marks, 1972; Patro & Haman, 2012; Petrusic, 1992; Shaki & Algom, 2002; Zhou et al., 2017). Furthermore, they are not unique for human species (Cantlon & Brannon, 2005; Jones et al., 2010).

Importantly, similar results were found on comparative judgements of quantities in adults with different specific reading directional habits (Hebrew and Polish) by Patro and Shaki (2016; see also Fischer, 2003; Lee et al., 2016; Shaki & Fischer, 2008; Shaki et al., 2012, for similar interpretations of comparative judgement performances on different domains). Patro and Shaki (2016) interpreted their results as a mixed SNARC like pattern claiming in favour of a *SNARC-like effect* driven by *instructional flexibility* (i.e., with a flexible response encoding depending on the task). However, recoding their data using the spatial congruency of the pair relative to the right-to-left mental format (as suggested in Study 1), rather than using the type of task ("choose fewer" vs. "choose more"), reveals a fully consistent RTs pattern with SC, not a SNARC-like effect (and in particular a reversed SNARC in spatially incongruent pairs). In this recoding, I considered the pattern of RTs associated to Small (range 2-4) and Large (range 5-10) displays published by Patro and Shaki (2016). In Table 1 of their original work, Global RTs referring to spatially incongruent pairs are encoded by Small and Large RTs pairs belonging to the "Choose more" task and left-hand responses ($\text{Small}_{\text{choose more, left}}$= 575 or 637; $\text{Large}_{\text{choose more, left}}$= 587 or 664), and RTs from the "Choose fewer" task and right-hand responses ($\text{Small}_{\text{choose fewer, right}}$= 667 or 681; $\text{Large}_{\text{choose fewer, right}}$= 712 or 762). In order to recode the data of their spatially incongruent pairs, I transformed RTs in response speeds and calculated the right-to-left speed deviation [i.e., $1000/(\text{Small}|\text{Large}_{\text{choose fewer, right}})$ $-1000/(\text{Small}|\text{Large}_{\text{choose more, left}})$]. Though being globally negative, right-to-left speed deviation decreased steadily, as the average intensity of the pairs increased from small to large. In particular, for the Polish group, the deviation changes from -0.24 (for the 2-4 pair) to -0.30 (for the 10-5 pair), corresponding, in terms of RTs, to 92 ms and 125 ms, respectively. Conversely, for the Hebrew group, the deviation changes from -0.10 to -0.19, corresponding, in terms of RTs, to 44 ms and 98 ms, respectively. Thus, when recoded these results are fully consistent with our finding and with SIA predictions (i.e., the extreme values of the series are faster, with 2 to the right being faster than 4 to the left, and 10 to the left being faster than 5 to the right). This further suggests its generalizability to different domains.

A further operative achievement of our study regards the generalization of the SC effect in the domain of Emotion (the ESC), originally found in Study 1, to an emotional continuum that – although being optimized in terms of its comparability to the continuum of digits – was less favourable, in terms of the easiness of the perceptual categorization of the cutoff faces. While in the case of Study 1, the cutoff faces were all real neutral, in the current study I used morphed faces, leading to a reduced realism consistency. Following the MacDorman and Chattopadhay (2016) theory of realism inconsistency, and accordingly with our results, the reduced consistency in realism involved in our morphed cutoff faces significantly increased their eeriness. This could have produced their assimilation to the negative emotional feelings produced by the angry faces of the continuum. This assimilation might have produced a larger emotion anisotropy than the one originally observed in Study 1. Such larger anisotropy resulted in a more evident *funnelling* of the *crossover* pattern expected on the basis of a pure ESC effect, with a rather large unbalance across our two types of faces in the pair characterized by a reliably larger response speed advantage for the happiest over the angriest face. Notably, a similar process of categorical uncertainty might account for the similarly large *funnelling* of the *crossover* pattern I found in Experiment 1 on Arabic numbers. The number 5 in our 1-to-9 digit continuum was likely to be roughly categorized as a balanced cutoff digit. As a consequence, it was probably experienced as having a small intensity, according to a well-known effect on the discrimination of visual numbers and objects - the subitizing effect (Kaufman, Lord, Reese, & Volkmann, 1949; Trick & Pylyshyn, 1994).

Humans seem to possess a universal system to represent magnitudes of environmental objects that goes well beyond cultural, developmental and evolutionary factors. These magnitudes are used to compare and rank almost all concrete aspects of the environment, irrespective of explicit numerical knowledge (e.g., Brannon, 2006; Bueti & Walsh, 2009; Cantlon et al., 2009; Dehaene, Izard, Spelke, & Pica, 2008; Frank, Everett, Fedorenko, & Gibson, 2008; Pica, Lemer, Izard, & Dehaene, 2004; Verguts & Fias, 2004; Walsh, 2003). According to this evidence, our findings on a similar motor reactivity for emotional expressions and Arabic digits point to a common magnitude system for the representation of discrete objects or events populating our environment as relative intensities (Lourenco & Aulet, 2019; Lourenco, Ayzenberg, & Lyu, 2016). Although I focused only on numbers and facial expressions of emotions, our findings, together with the research by Fantoni et al. (2019), suggest that a common (SIA-based) representation of intensity may extend to other dimensions that can be captured in terms of smaller/larger relations, when the stimuli are simultaneously presented. The present work indicates that different typology of magnitudes (independently from their motivational salience) have a common format of representation: a mental direct speed to relative intensity association.

4 Study 3

I receive an upside-down image of the outside world through the pinholes of our eyes. Despite that from the discovery of the blindness to local facial feature changes in upside-down faces – best known as the Thatcher effect (Thompson, 1980) – growing evidences supported the idea that the mechanisms held responsible for familiar face recognition are orientation dependent (McKone & Yovel, 2009). Being faces a special object of our visual experience they are thought to be processed as wholes (i.e., holistically), with upside-down faces being more difficult to be identified and discriminated than upright faces that are part-based processed like other non-living objects (Davidoff & Donnelly, 1990; Donnelly & Davidoff, 1999; Hochberg & Galper, 1967; Piepers & Robbins, 2012; Tanaka & Sengco, 1997; Tanaka & Farah, 1993; Taubert, Apthorp, Aagten-Murphy, & Alais, 2011; Valentine, 1988; Wagemans et al., 2012; Yin, 1969). This effect, is known as the *Face Inversion Effect* (FI), and has been shown to generalize to facial expression of emotion (Calvo & Nummenmaa, 2008; Derntl, Seidel, Kainz, & Carbon, 2009; Fallshore & Bartholow, 2003; Freire, Lee, & Symons, 2000; Goren & Wilson, 2006; Jacques, d'Arripe, & Rossion, 2007; McKelvie, 1995; Pallett & Meng, 2015; Prkachin, 2003), as well as to bodies in a way dependent from gender (Bernard, Gervais, Allen, Campomizzi, & Klein, 2012; Cogoni et al., 2018).

Here I asked for the first time whether FI, which has been prominently studied with isolated faces and emotions (Taubert, Golde, & Verstraten, 2016), may affect a typical pattern of motor reactivity rising from attentional capture discovered in Study 1.

In particular, the comparison among two simultaneously presented facial expressions of emotion involves visual spatial attention. In this task, faces are shown side-by-side and participants are required to choose the most positive (e.g., choose the happiest) or negative (e.g., choose the angriest) face within the pair. Differently from isolated facial expression stimuli, in this task there is both a lateralization of the stimuli (one face is presented in the left and one in the right visual hemifield), and of the responses (left/right hand response depending on the left/right spatial position of the target face). Typically, in studies involving isolated emotion that are centrally displayed, the observed outcome is a lateralized motor reactivity depending on the spatial congruency with the left-to-right mental representation of emotions: left hand responses are faster than right hand responses when associated with negative valence emotion, and vice-versa for positive valence emotion (Holmes et al., 2019; Holmes & Lourenco, 2011; Pitt & Casasanto, 2017). Such a pattern, which is best known as SNARC-like effect, is not observed in the emotion comparison task used in Study 1 and 2, in which a typical pattern rising from attentional capture is observed instead and modelled by the direct mapping between response speeds and relative emotion intensities: a Speed-Intensity Association, SIA.

In particular, when pairs of emotional faces are presented simultaneously randomizing the presentation of stimuli including/not-including the cutoff face of the emotional series (i.e., the neutral), like half-range (i.e., a neutral face paired with a fully happy or angry face) and cross-range (i.e., an angry face paired with a happy face with equal emotional intensity) emotional pairs, the most intense emotional face is recognized faster than intermediate faces (i.e., Emotional Semantic Congruency effect - ESC). Furthermore, a global response speed advantage for emotional pairs with a positive rather than negative average valence is observed (i.e., Emotional Size effect - ES), with the choice for the happiest face resulting in a faster response than the choice for the angriest face within the pair (i.e., happiness advantage - HA). This pattern of motor reactivity predicted by SIA is consistent with evidence showing how emotional distractors capture exogenous attention to a significantly greater extent than neutral distractors do (Carretié, 2014; Ferrari et al., 2008; Reeck & Egner, 2015).

Currently, I do not know whether a similar pattern of attentional capture from motivational salience predicted by SIA holds true when using an emotional comparison task with emotional pairs presented in inverted orientation, namely, with the faces presented upside down. It is noteworthy that this modality of face presentation should modify the way faces are processed. Given the FI, faces in upright position should be efficiently processed as wholes vs. part-based, while the reverse should apply to faces in inverted orientation. FI should thus alter the *modalities* humans use to process facial expression of emotion (holistic vs. part-based), leading to an overall impairment of emotion recognition in upright vs. inverted orientation. This impairment should cause an overall slowing down of motor reactivity in the emotion comparison task with emotional pairs in inverted orientation. However, little is known about whether the face orientation manipulation, which should cause FI, may also alter spatial attention involved in emotion comparison, by for instance reducing its by-products. In particular, the attentional capture by motivational salience in the emotion comparison task and the effects rising from it: namely the ESC, the ES and the HA.

These observations lead us to the following *research question*: is the typical pattern rising from attentional capture in emotion comparison orientation dependent? As for the *attentional capture* phenomenon, I can hypothesise two different scenarios in the case of the comparison among two simultaneously presented facial expressions:

If *attentional capture* is orientation independent, it should hold true also for inverted emotional pairs, being it independent from the type of processing (holistic or part-based), with SIA predictions that could be generalized to both upright and inverted faces.

If *attentional capture* is orientation dependent, it should not hold true for inverted emotional pairs, being it dependent from the type of processing (would hold only for holistic processing), with SIA predictions that could not be generalized to inverted faces.

4.1 Experiment 1: Emotion comparison with half-range emotional pairs

In order to address our *research question*, I run an experiment using the same emotional comparison task employed in Study 1. Different from the original study (in which only facial expressions in upright orientation were used), in the present study I used emotional pairs with faces both in upright and in inverted orientation (see Figure 4.1). Another important difference is related the type of stimulus pairs. Indeed, in the previous study, these were randomized across two types: 1) half-range emotional pairs, with a real neutral face paired with a real/fully emotional face (with 100% anger or happiness in the anger-to-neutral-to-happiness in the morph continuum); and 2) cross-range emotional pairs, with an emotional face (with either 50% or 100% happiness/anger) paired with another emotional face of the same intensity, but with the opposite emotional valence (50% or 100% anger/happiness). In the present study, given that I needed to present the same stimulus pairs twice (in upright and inverted orientation), I decided to use only the half-range emotional pairs (neutral paired with emotional faces) to avoid doubling the duration of the original study. Importantly, the full set of half-range emotional pairs I used in this experiment allowed us to fully investigate the typical pattern of response speeds rising from attentional capture in emotion comparison, expected on the basis of Study 1' results, which should be characterized by ESC, ES, and HA as predicted by the SIA.

In this experiment, I tested whether this typical pattern is orientation independent, thus suggesting for a type of stimulus processing (part-based vs. holistic) independence of attentional capture in emotion comparison. If orientation independence does occur, the three effects revealed as by-product of attentional capture (ESC, ES, and HA) should similarly occur with emotional pairs in upright and inverted orientation.

4.1.1 Method

4.1.1.1 Participants

Forty-five participants took part in the experiment in exchange of course credits. They were Italian speakers (i.e., left-to-right reading direction), naïve to the purpose of the study, and had normal/corrected-to-normal visual acuity. Data from 3 participants were excluded from the analysis because of technical problems during data collection. Consequently, data from 42 participants (35 females; average age = 19.71 ± 2.12 SD; age range = [18 – 32]) were analysed. I conducted a sensitivity analysis with G Power 3.1 (Faul et al., 2007) on our sample size with α err. Prob. = .05, Power ($1 - \beta$ err. Prob.) = .8 in order to establish the Minimal Detectable Effects resulting from our experimental design. These resulted to be in the medium-to-large range with a critical *F*= 4.22, a η_p^2 = .15 and a critical 2-tale *t* of about 2.02.

Participant's handedness was measured with the 10-item Edinburgh Handedness Inventory (Oldfield, 1971), which revealed an average of 55.48 (SD = ± 49.14; min. to max. range= [-70 – 100]). Participants were randomly assigned to one of the two conditions of instruction order (A or B). The participants assigned to the order A did the task following the instruction "choose the angriest face of the two" in the first block and the instruction "choose the happiest face of the two" in the second block; the participants assigned to the order B did the opposite. Twenty participants completed the experiment in the order A, and 22 completed it in the order B.

Participants were given informed consent prior to inclusion in the study. They were treated in compliance with national legislation, the Ethical Code of the Italian Association of Psychology (approval of the Research Ethics Committee of the University of Trieste number 84c/2017), and the Code of Ethical Principles for Medical Research Involving Human Subjects of the World Medical Association (Declaration of Helsinki).

4.1.1.2 Apparatus.

Stimulus presentation and response recording were controlled by a custom-made E-Prime 2.0 program. Emotional pairs were presented on a 22″ Dell P2214H monitor with 1920×1080 pixels resolution via PC, in a dimly lit laboratory with the participant comfortably sit facing the screen at an average distance of 38 cm. A QWERTY keyboard was used for collecting responses and it was positioned on the desk between the participant and the monitor. In order to ensure a comfortable posture, the distance between the participant and the keyboard was adapted to the participant harm length, with only the "d" and "j" keys (keys' distance = 8 cm) activated during the experiment and centred along the participants' sagittal axis.

4.1.1.3 Stimuli.

I used two different sets of facial expressions of emotions in order to create our emotional pairs: line-drawn faces in the training session and coloured photographs in the experimental session. All emotional pairs consisted of two faces: both displayed either in upright or in inverted orientation, centred on the horizontal axis of the screen (i.e., the midline of the two faces corresponding to the vertical midline of the screen), with a centre-to-centre (i.e., nose-to-nose) distance equal to 19.6° (at the average viewing distance of 38 cm used during the experiment). Faces in upright orientation were the same used in Study 1, while faces in inverted orientation were the same set of upright faces rotated 180 degrees. Each face was masked by an oval vignette hiding hair and ears, was presented on a black surround, and had a horizontal × vertical extent of 12.0° × 16.8°.

In the training sessions I used a set of 6 black and light grey drawn facial stimuli (3 in upright and 3 in inverted orientation) with a single unisexual model reproducing an angry, a neutral or a happy face (crated according to an on-line tutorial, see subsection 2.2.3 for details). I used 8 emotional pairs resulting from the combination of 2 Types of Stimuli (angry-neutral, neutral-happy) × 2 Spatial Congruency with the left -to-right mental representation of valence of emotion (congruent - with the happy/positive face on the right, incongruent - with the angry/negative face on the right) × 2 Face Orientation (inverted, upright). The training session lasted 16 trials, with the full random presentation of the 8 emotional pairs repeated for about 2 times.

In the experimental session I used the same set of coloured photographs used by Fantoni et al. (2019): 8 Caucasian Characters (4 female and 4 male) selected from the Radboud University Nijmegen set (Langner et al., 2010, Character numbers: 1, 2, 4, 19, 20, 30, 46, and 71). As depicted in Figure 1A, for each Character I obtained a set of 6 facial stimuli (i.e., 3 in upright and 3 in inverted orientation), belonging to the anger-to-neutral-to-happiness continuum, with 4 facial expressions displaying basic emotions (i.e., real and full facial expression of emotion in upright/inverted orientation) and 2 real neutral facial expressions (upright/inverted). As depicted in Figure 1B and 1C, the neutral face of each Character was paired with the fully emotional faces in order to obtain 8 types of half-range emotional pairs resulting by the combination of 2 Face Orientation × 2 Spatial Congruency × 2 Average Valence relative to the cutoff (-50, 50). These 8 types of half-range emotional pairs, when combined with our the two conditions of Response Side resulting from the manipulation of the type of instruction (“choose the happiest”, “choose the angriest”) defined our 2 × 2 × 2 × 2 cross-over design, with 2 Face Orientation × 2 Response Side × 2 Spatial Congruency × 2 Average Valence. Instruction Ordering was treated as a balancing variable (“choose the angriest” first, “choose the happiest” first).

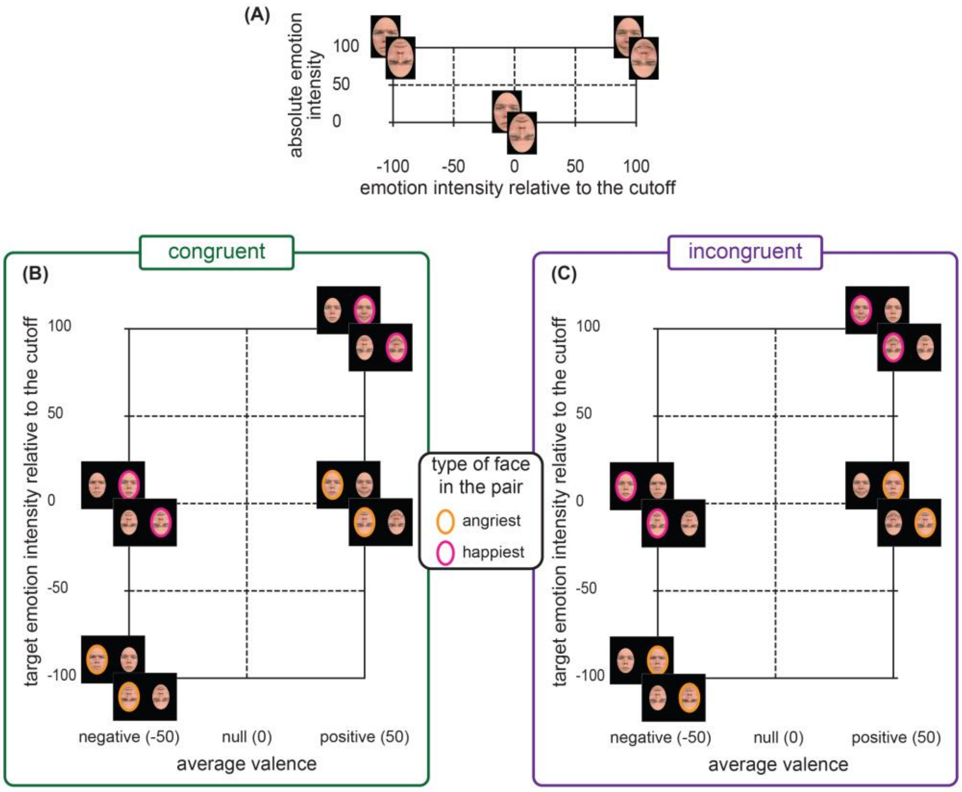

Figure 4.1. Facial stimuli and emotional pairs used in Study 3, Experiment 1. Face stimuli (A) and half-range emotional pairs used in Study 3, Experiment 1 for the congruent (B) and incongruent (C) spatial position in both upright and inverted orientation (identity gave permission for the usage of his image but not used in our experiments). In (A), stimuli are depicted in a Cartesian space, with the emotion intensity relative to the cutoff face along the *x*-axis and the absolute emotion intensity relative to the cutoff along the *y*-axis. On the *x*-axis the real/fully angry and the real/fully happy face define the negative and the positive extreme values of the continuum, respectively, with the neutral face defining the intermediate emotion with null intensity value (i.e., the cutoff splitting in two the emotion continuum). In (B) and (C) the half-range emotional pairs that results from the pairings of the cutoff face and the fully emotional faces shown in (A). (B) depicts emotional pairs in spatially congruent condition (the rightmost face in the pair is the happiest) and (C) in spatially incongruent condition (the rightmost face in the pair is the angriest). In (B) and (C) emotional pairs are represented in the average valence (*x*-axis) × target intensity relative to the cutoff (*y*-axis) Cartesian space. The type of target face in the pair is coded by the colour of the surrounding ellipses (orange for the angriest; pink for the happiest). Notably, the 8 type of

half-range emotional pairs (4 congruent in B and 4 incongruent in C) in the two face orientation conditions combines into 16 half-range emotional pairs that I tested in our experiment.

During each experimental session I presented a total of 64 emotional pairs resulting from the factorial combination of 8 Characters × 2 Average Valence × 2 Spatial Congruency × 2 Face Orientation. Each emotional pair appeared once per experimental session.

4.1.1.4 Procedure.

Our procedure resembled the one used in Fantoni et al. (2019). It included a sequence of six events: 1) Edinburgh Handedness Inventory; 2) general oral instructions about the experiment; 3) a first training session introduced by on-screen instruction ("choose the angriest/happiest", depending on Instruction Ordering); 4) a first experimental session introduced by the same on-screen instruction of the first training session; 5) a second training session introduced by on-screen instruction which was different from the instruction of the first training session; 6) a second experimental session introduced by the same on-screen instruction of the second training session. On-screen instructions informed participants that they have to choose among a pair of horizontally aligned faces which of the two appear to be the angriest/happiest, using the keys on keyboard with the corresponding spatial position ("d" press if target on the left vs. "j" press if target on the right). The experiment was composed of a total of 32 training trials and 128 experimental trials. The trial temporal structure was the same as Study 1, with a fixation screen (a white cross on a black background) lasting about 2000 ms, followed by a blank screen lasting 200 ms, and in turn by a stimulus screen which was self-terminated by the participant response (minimum to a maximum duration, 190 to 2890 ms, respectively). A blank masking screen lasting about 3000 ms terminated the trial after participant response.

4.1.1.5 Data analysis.

From a total collection of 5362 responses, I excluded: (1) 221 incorrect responses (e.g., the choice of the angriest face when the instruction required to "choose the happiest face in the pair" or vice-versa); (2) 7 correct responses falling outside the [200 ms, 2500 ms] Response Time, RT, limit; (3) 96 correct responses falling outside ± 3 SD from the predicted value of the best *linear mixed effect* model, *lme*, with all experimental factors and their interactions as fixed structure (Average Valence, Response Side, and Spatial Congruency), and participants as random intercepts. I transformed the remaining 5038 values of RT into values of response speeds (1000/RT). Following Miller (1991; Ratcliff, 1993; Whelan, 2008), such a transformation was motivated by the homology between actual speed and response accuracy, and by its capacity to normalize the skewed distribution of RTs increasing statistical power and reducing the likelihood of spurious outlier removal.

Considering the 16 experimental conditions of our experimental design (2 Average Valence × 2 Face Orientation × 2 Response Side × 2 Spatial Congruency), the average number of valid trials per participant was equal to: 14.99 ± 1.30 SD, range = [9, 16], corresponding to an average accuracy of about 0.94 ± 0.06 SD and an average *z*-score of proportion of correct responses of 1.22 ± 0.42 SD. Average *z*-score of proportion were calculated keeping the ratio between the deviations of the individual proportion from the hypothesized value of population proportion in the null hypothesis, $p_0 = .75$, with a guess rate = .5, and a SD of the sampling distribution, $\sigma = 0.153$.

Individual values of response speeds were used to extract for each participant 4 individual synthetic index of happiness advantage: one for each condition resulting by the combination of 2 Face Orientation × 2 Spatial Congruency conditions. Each individual index of happiness advantage was calculated subtracting the individual value of the best fitting *lme* regressor's intercept for the selection of the angriest faces calculated across two pairs from the individual value of the best fitting *lme* regressor's intercept for the selection of the happiest faces[4], in both upright and inverted Face

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[4] For spatially congruent pairs these regressors correspond to the line connecting the average response speed of a left hand response to a fully angry face flanked by a neutral face and the line connecting the average response speed of a left hand response to a neutral face flanked by a fully happy face. For spatially incongruent pairs they correspond to the line connecting the average response speed of a right hand response to a fully angry face flanked by a neutral face and the line connecting the average response speed of a right hand response to a neutral face flanked by a fully happy face.

orientation conditions. Happiness Advantage’ indices synthetically quantify how much the motor reactivity is biased by the selection of the most positive vs. negative face within the pair, with positive values indicating an unbalance in favour of the selection of the most positive face (when the average valence is null), depending on the Spatial Congruency of the pair and on the Face Orientation.

I selected for all our *lme* models the maximal random effects structure justified by our experimental design (Barr et al., 2013). Our models involved by-subject random intercepts and slopes with our balancing variable (the Instruction Ordering) used as an additional random intercept. I selected the fixed structure of our *lme* models according to a step-wise procedure contrasting *lmes* of increasing complexity depending on the number of fixed factors, modelled by the factors of our experimental design: Average Valence, Spatial Congruency, Response Side, and Orientation. Handedness was categorized according to median split (i.e., small vs. large) and used as a covariate in our preliminary *lme* analyses. Consistently with the results of Fantoni et al. (2019), preliminary *lme* analyses revealed no reliable interaction between accuracy, handedness, speeds and other experimental factors. A *lme* model including a reliable speed-accuracy positive correlation, $F(1, 343.75) = 74.95$, $p < .001$, $\eta_p^2 = .118$, 95% CI [.061, .146], with accuracy increasing of about 0.11 ± 0.01 per cent every unit increment of speed, $t(343.75) = 8.66$, $p < .001$, $d = 0.93$, indeed achieve a larger goodness of fit than a model combining Handedness with all other factors of our experimental design, $\chi^2(62) = 110.12$, $p < .001$, AIC(6) = -1296.8, vs. AIC(68) = -1282.9, BIC(6) = -1269.76, vs. BIC(68) = -976.24. Due to these preliminary results, I decided to focus the main analyses on individual response speeds and the happiness advantage indices.

As statistical inferential measures I provided: (1) type III-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; (2) estimates of the *lme* goodness of fit based on AIC-index, BIC-index, and χ^2; (3) estimates of effect size based on the concordance correlation coefficient r_c, Partial eta squared η_p^2 (for the interactions and main effects of the F-tests), and Cohen’s *d* (for the post-hoc analyses performed on *lme* estimated coefficients with paired two sample *t*-tests with unequal variance).

4.1.2 Results

Figure 4.2 illustrates the patterns of average values of response speeds (Figure 4.2A, 4.2B, 4.2C, and 4.2D) and happiness advantage (Figure 4.2E and 4.2F) for half-range emotional pairs. The pattern of average values of response speeds separately displayed for half-range emotional pairs in upright (Figure 4.2A and 4.2B, for individual speeds in spatially congruent and incongruent pairs, respectively; Figure 4.2E for happiness advantages) and inverted (4.2C and 4.2D, for individual speeds in spatially congruent and incongruent pairs, respectively; Figure 4.2F for happiness advantages) orientation is fully consistent with an orientation independent emotional capture effect evoked by our emotion comparison task.

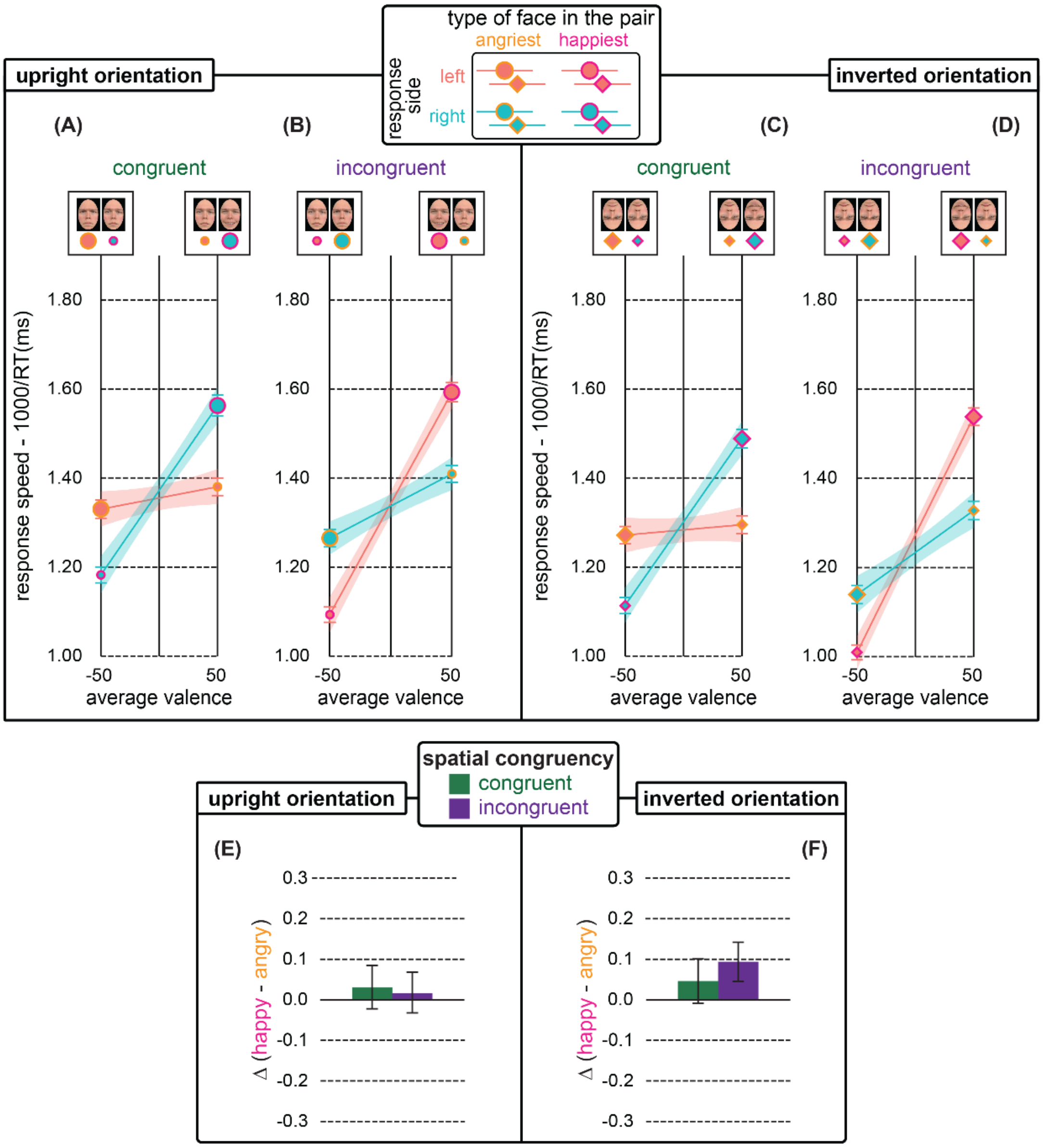

Figure 4.2. Comparative judgements performance in Study 3, Experiment 1. Emotion comparison performance indexed by response speeds (in panels from A to D) and happiness advantages (in panels E and D) with half-range emotional pairs of Study 3, Experiment 1. Error bars represent ± 1 Standard Error of the Mean, SEM. (A-D) Illustration of the average response speeds in Spatially Congruent (A and C) and Spatially Incongruent (B and D) conditions, as a function of average valence (*x*-axis), with the shape of the symbols encoding for (see the legends on top) the Face Orientation condition (upright - circles in panels A and B; inverted - diamonds in panels C and D): the colour filling the symbols encoding for the response side (red for left; blue for right), and the outline colour of the symbols encoding the type of target face (orange for angriest; pink for happiest). The size of the symbols represents the absolute emotion intensity (small for neutral = cutoff face of the continuum; large for fully angry/happy emotional face of the continuum). Mid grey and black lines are the *lme* model regression lines for left/right response side conditions, with the shaded bands corresponding to ± 1 SEM of the regression. Panels (E) and (F) depict average happiness advantage for spatial congruent and incongruent conditions as encoded by the colour of the bar (see the legends on top).

The *lme* analysis on individual values of response speeds including Average Valence, Face Orientation, Response Side, and Spatial Congruency as fixed effects , r_c = .72, 95% CI [.71, .73] corroborated our observation. The analysis indeed revealed an Average Valence × Response Side ×

Spatial Congruency interaction, $F(1, 284.90) = 310.14$, $p < .001$, $\eta_p^2 = .521$, 95% CI [.445, .583], consistent with ESC, with faster responses for the emotional (Figure 2, large symbols) rather than neutral (Figure 2, small symbols) targets. Such an advantage produced by emotion occurred for both emotional pairs with negative, $M_{angriest/emotional} = 1.25 \pm 0.03$, vs. $M_{happiest/neutral} = 1.10 \pm 0.03$, $t(291.71) = 10.23$, $p < .001$, $d = 1.20$, and positive, $M_{angriest/neutral} = 1.35 \pm 0.04$, vs. $M_{happiest/emotional} = 1.55 \pm 0.04$, $t(289.98) = 11.37$, $p < .001$, $d = 1.34$, Average Valence. Importantly, the ESC held true for facial expressions pairs displayed in: (1) upright (Figure 2A and 2B), with negative, $M_{angriest/emotional} = 1.30 \pm 0.03$, vs. $M_{happiest/neutral} = 1.14 \pm 0.03$, $t(125.33) = 7.92$, $p < .001$, $d = 1.42$, and positive, $M_{angriest/neutral} = 1.40 \pm 0.04$, vs. $M_{happiest/emotional} = 1.58 \pm 0.04$, $t(122.66) = 7.45$, $p < .001$, $d = 1.35$, Average Emotion Intensity; and (2) inverted face orientation (Figure 2C and 2D), with negative, $M_{angriest/emotional} = 1.20 \pm 0.03$, vs. $M_{happiest/neutral} = 1.06 \pm 0.03$, $t(123.87) = 6.79$, $p < .001$, $d = 1.22$, and positive, $M_{angriest/neutral} = 1.30 \pm 0.04$, vs. $M_{happiest/emotional} = 1.51 \pm 0.04$, $t(123.81) = 8.66$, $p < .001$, $d = 1.56$, Average Emotion Intensity. As consistent with results of Study 1, ESC held true across spatial congruency, and in particular for emotional pairs displayed in both: (1) spatially congruent condition (Figure 2A and 2C), with negative, $M_{angriest/emotional} = 1.30 \pm 0.04$, vs. $M_{happiest/neutral} = 1.14 \pm 0.04$, $t(124.97) = 7.75$, $p < .001$, $d = 1.39$, and positive, $M_{angriest/neutral} = 1.34 \pm 0.04$, vs. $M_{happiest/emotional} = 1.52 \pm 0.04$, $t(123.47) = 7.76$, $p < .001$, $d = 1.40$, Average Valence; and (2) spatially incongruent condition (Figure 2B and 2D), with negative, $M_{angriest/emotional} = 1.10 \pm 0.03$, vs. $M_{happiest/neutral} = 1.06 \pm 0.03$, $t(123.95) = 7.57$, $p < .001$, $d = 1.36$, and positive, $M_{angriest/neutral} = 1.37 \pm 0.04$, vs. $M_{happiest/emotional} = 1.57 \pm 0.04$, $t(124.16) = 8.68$, $p < .001$, $d = 1.56$, Average Valence.

As regard the ES, the *lme* analysis consistently revealed a main effect of Average Valence, $F(1, 36.21) = 195.26$, $p < .001$, $\eta_p^2 = .844$, 95% CI [.731, .891], with response speeds increasing steadily as Average Valence grew larger, $\beta = 0.0027 \pm 0.0002$, $t(41.47) = 14.37$, $p < 0.001$, $d = 4.46$, from negative to positive Average Valence.

As consistent with the FI, the *lme* analysis revealed a main effect of Face Orientation, $F(1, 284.62) = 55.77$, $p < .001$, $\eta_p^2 = .164$, 95% CI [.093, .240], with faster responses for half-range emotional pairs in upright (Figure 2, circles) over inverted (Figure 2, diamonds) orientation, $M_{Upright} = 1.24 \pm 0.04$, vs. $M_{Inverted} = 1.13 \pm 0.03$, $t(293.93) = 7.52$, $p < .001$, $d = 0.88$.

Finally, the *lme* analysis revealed two unexpected though marginally significant effects: (1) an Average Valence × Spatial Congruency interaction, $F(1, 284.92) = 40.54$, $p < .001$, $\eta_p^2 = .124$, 95% CI [.061, .197]. This interaction consisted in a *lme* estimated gain from negative to positive Average Valence of about 0.21 ± 0.03 for spatially congruent half-range emotional pairs, and an additional *lme* estimated gain for spatially incongruent half-range emotional pairs of about 0.13 ± 0.04, $t(168.9) = 3.27$, $p < .001$, $d = 0.50$; and (2) a main effect of Spatial Congruency, $F(1, 284.80) = 5.42$, $p < .05$, $\eta_p^2 = .019$, 95% CI [.000, .060], with faster responses for half-range emotional pairs in spatially incongruent over congruent position, $M_{Incongruent} = 1.23 \pm 0.03$, vs. $M_{Congruent} = 1.17 \pm 0.03$, $t(291.69) = 3.08$, $p < .01$, $d = 0.36$.

No other main effects or interaction resulted to be significant (*p*s > .06). Notably, the Spatial Congruency × Response Side interaction, that according to the HA should have revealed an unbalanced motor reactivity in favour of the most positive face within the pair, was not significant $F(1, 284.79) = 3.61$, $p = .06$. This suggested that when the emotion comparison task included only half-range emotional pairs, not a mixture of half-and cross-range pairs as in Study 1, the lateralized motor reactivity gets globally balanced over response sides, with a similar speed of the choice for positive (*lme* estimated average speed for incongruent/left and congruent/right conditions, $M_{happiest}= 1.13 \pm 0.03$) over negative (*lme* estimated average speed for congruent/left and incongruent/right conditions, $M_{angriest}= 1.13 \pm 0.03$) emotions across Spatial Congruency conditions $t(293.49) = 0.47$, $p = .60$.

As a final *lme* analysis I better address such an unexpected lack of effect analysing the individual values of happiness advantage, with a *lme* model including Face Orientation and Spatial

Congruency as fixed factors. The results of the analysis were confirmatory. They indeed revealed no significant interactions or main effects, r_c = .58, 95% CI [.50, .63]. I then contrasted individual values of happiness advantage against the reference null value standing for a full balance between responses given to the happiest and the angriest faces: no significant differences were found for both the subset of half-range emotional pairs in upright, $M_{\text{values of happiness advantage}} = 0.006 \pm 0.012$, vs. 0, $t(41) = 0.51$, $p = .62$, $d = 0.15$, and inverted, $M_{\text{values of happiness advantage}} = 0.034 \pm 0.022$, vs. 0, $t(41) = 1.53$, $p = .13$, $d = 0.50$, face orientation. Such results demonstrated the absence of an HA with the set of half-range emotional pairs studied in the current experiment: namely, emotional pairs including a real neutral face in both inverted and upright orientation.

4.1.3 Discussion

In Experiment 1 I aimed to assess whether the attentional capture phenomenon elicited by the emotion comparison task used in Study 1 holds true also in the case of the comparison among two simultaneously presented facial expressions displayed in inverted orientation. The results of Experiment 1 allow to provide a first positive answer to such a question. They indeed revealed a rather robust orientation independence of the typical pattern rising from attentional capture in emotion comparison characterized by ESC and SE. This suggests that the spatial attention mechanisms regulating the performance in our emotion comparison task are rather independent from the type of facial stimulus processing whether part-based, as likely occurring when faces are presented in upside-down orientation, or holistic, as likely occurring when faces are presented in upright orientation. In particular, a similar pattern of response speeds was found when half-range emotional pairs were presented in either upright or inverted orientation. Beyond a general slowing-down of response speeds due to FI, both patterns of response speeds were characterized by ESC and ES, as expected on the basis of an orientation independent attentional capture effect and predicted by the SIA model.

However, differently from Study 1, in the present experiment I did not found a reliable HA. A possible explanation for this result might be the different types of stimulus pairs I used, compared to the original study. In the previous study, the objective cutoff of the emotional continuum necessary for balancing the response reactivity to positive and negative facial expressions of emotions probably needed to be extrapolated as the series of experimental stimuli equally included half- and cross-range emotional pairs, explicitly and not-explicitly displaying the real/neutral cutoff face, respectively. Conversely, in our set of stimuli including only half-emotional pairs, the objective cutoff of the emotional continuum did not need to be extrapolated being always displayed in the emotional pair (corresponding with the real/neutral face). I thus further explored the occurrence of HA depending on the absence/presence of an explicit cutoff face and its dependence on face orientation in Experiment 2.

4.2 Experiment 2: Emotion comparison with cross-range emotional pairs

In Experiment 2, I used a set of emotional pairs that – differently from those of Experiment 1 – never displayed the objective cutoff of our emotional series, namely cross-range emotional pairs. Notably, in Study 1, half-range emotional pairs were randomized within the same block, explicitly including the objective cutoff face (a neutral face), and cross-range emotional pairs not including the objective cutoff face but rather two emotional faces with opposite valence (one happy and one angry), with either intermediate or fully absolute emotion intensity (50, or 100). In the present experiment, after testing orientation dependence with half-range emotional pairs in Experiment 1, I tested orientation dependence with those type of stimulus pairs that has not yet been employed, thus, the set of stimulus pairs in which the cutoff was not explicitly displayed: cross-range emotional pairs only. Notably, I kept constant the number of trials as the one used in Study 1 - Experiment 1 as well as in Study 3 - Experiment 1. I indeed tested two levels of target absolute emotion intensity with intermediate and fully happy and angry faces, as in the original study. Beyond a similar FI to the one observed in Experiment 1 was expected to occur on cross-range emotional pairs, the experimental design of Experiment 2 allowed us to test for a further effect: namely an emotional distance effect (ED), which was originally found in the previous study. According to ED, response speeds should increase as the absolute difference between the emotions expressed by the two faces within the pair increases. Faster responses are expected for cross-range emotional pairs displaying fully rather than intermediate emotion expression, as the absolute emotional distance along the valence continuum between a fully (100) happy and a fully (-100) angry face equals 200 which is two times the absolute distance between an intermediate (50) happy and an intermediate (-50) angry face which is equals to 100.

With Experiment 2 I finally seek to answer to a further research question: *does the HA depend on how emotional magnitude are represented and in particular by the type of cutoff of the emotional series (explicit vs. implicit within the pair)?* If HA is dependent on the type of cutoff, it should be more evident in cross-range rather than half-range emotional pairs, given that, only in the former one the cutoff needs to be implicitly inferred from the pair being not explicitly displayed. It is likely that the implicit cutoff will be biased toward negative, rather than positive emotion, thus producing in this case - only - a HA. Such hypothesis is inspired by the idea that the attentional strategy used by participants in a comparison task could be based on the establishment of either an implicit or an explicit reference point producing in turn flexible effects on lateralized motor reactivity (Chen et al., 2014; Holyoak, 1978; Holyoak & Mah, 1982; Holyoak & Walker, 1976; Jamieson & Petrusic, 1975; Lu et al., 2012). According to the pioneering studies of Holyoak (1978), the establishment of an explicit reference point ("Choose the stimulus close to X"), induces a global unbalance in response speeds in favour of the smallest element within the pair ("Choose the stimulus close to 9" was globally slower than "Choose the stimulus close to 1"). Such a bias is opposed to the global unbalance in favour of the largest element within the pair observed when the reference point is instead established implicitly, as originally revealed by Banks et al. (1976) on numbers, and by results of Study 1 on emotions with the HA ("choose the happiest/largest" was globally faster than "choose the angriest/smallest").

4.2.1 Method

4.2.1.1 Participants.

Data from 46 participants (different from those of Experiment 1; 36 females and 10 males; average age = 20.91 ± 6.10 SD; age range = [18 – 49]; mean Edinburgh Handedness Inventory = 63.35, SD = ± 36.05; min. to max. range = [-47 – 100]) were analysed in Experiment 2. The same sensitivity analysis conducted in Experiment 1 but including a sample size = 46 established similar medium-to-large Minimal Detectable Effects with a critical $F= 4.17$, $\eta_p^2 = .15$ and a critical 2-tale t of about 2.01. Participants were randomly assigned to one of the two conditions of instruction order (A or B, see Participant subsection of Experiment 1). Twenty-five participants completed the experiment in the order A, and 21 completed it in the order B.

4.2.1.2 Apparatus.

The apparatus was the same as in Experiment 1.

4.2.1.3 Stimuli.

As in Experiment 1, I used two different sets of facial expressions of emotions in order to compose our emotional pairs: line-drawn faces in the training session and coloured photographs in the experimental session.

Cross-range emotional pairs of Experiment 2 had the same geometrical proprieties of half-range emotional pairs of Experiment 1. In the training session, I used 4 emotional pairs (pairing an angry and a happy face) resulting from the combination of 2 Spatial Congruency × 2 Face Orientation. The training session lasted 16 trials (4 emotional pairs × 4 repetitions).

In the experimental session I used a set of emotional faces extracted from the same set of characters used in Experiment 1. As depicted in Figure 3A, for each Character I obtained a set of 8 face stimuli (i.e., 4 in upright and 4 in inverted orientation), belonging to the anger-to-neutral-to-happiness continuum: four fully emotional faces displaying basic emotions (the *real* facial expression of anger/happiness in upright/inverted orientation – these were the same used in Experiment 1), four morphed facial expressions displaying intermediate emotions (a mixture of 50% anger/happiness and 50% neutral in upright/inverted orientation). For a detailed description of morphing technique see Fantoni et al., 2016). As depicted in Figure 3B and 3C the faces with opposite valence emotion but equal intensity of each Character were paired in order to obtain the 8 types of cross-range emotional pairs resulting by the combination of 2 Face Orientation × 2 Spatial Congruency × 2 Target Absolute Emotion Intensity (50, 100). Notably, differently from Experiment 1 in which I tested half-range emotional pairs with non-null Average Valence but constant absolute emotional distance along the valence continuum between the fully emotional and the neutral face (i.e., 100), in Experiment 2 I tested cross-range emotional pairs with null Average Valence, though variable absolute emotional distance along the valence continuum between the faces within the pair: 100 for pairs with a target absolute emotion intensity equal to 50, and 200 for pairs with a target absolute emotion intensity equal to 100. Such a difference is appreciable in panels 3B and 3C in which our 16 types of cross-range emotional pairs cut in two the common Cartesian space used to represent the half-range emotional pairs of Experiment 1 now all laying along the vertical line through the origin. The 8 types of cross-range emotional pairs when combined with our two conditions of Response Side defined a 2 × 2 × 2 × 2 cross-over design as resulting from the combination of 2 Face Orientation × 2 Response Side × 2 Spatial Congruency × 2 Target Absolute Emotion Intensity, with Instruction Ordering used (as in Experiment 1) as a balancing variable.

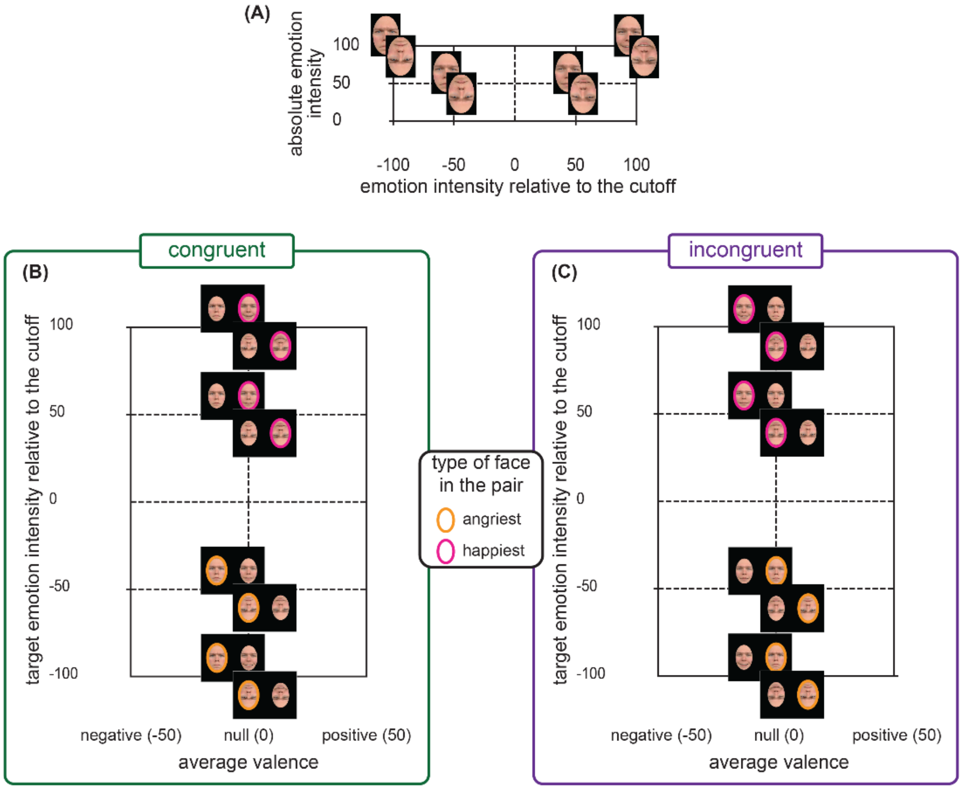

Figure 4.3. Facial stimuli and emotional stimulus pairs used in Study 3, Experiment 2. Face stimuli (A) and cross-range emotional pairs used in Study 3, Experiment 2 for the congruent (B) and incongruent (C) spatial position in both upright and inverted orientation (identity gave permission for the usage of his image but not used in our experiments). See caption of Figure 4.2 for further explanation.

The number of trials characterizing each experimental session was the same as Experiment 1 as involving the unique presentation of 64 emotional pairs (8 Characters × 2 Absolute Emotion Intensity × 2 Spatial Congruency × 2 Face Orientation).

4.2.1.4 Procedure.

The procedure was the same as in Experiment 1.

4.2.1.5 Data analysis.

I analysed the same indices of emotion comparison performance using the same *lme* analyses based on the maximal random effects structure justified by our experimental design and used the same estimates of significance, of the goodness of fit and of effect size.

From a total collection of 5877 responses, I applied the same exclusion criteria used in Experiment 1 and excluded (1) 129 incorrect responses, (2) 6 correct responses falling outside the

[200 ms, 2500 ms] RT limit, and (3) 106 correct responses falling outside ± 3 SD from the predicted value of the best generalized *lme* regression model. I similarly transformed the remaining 5636 individual values of RT into individual values of response speeds (i.e., 1000/RT). The average number of valid trials per experimental condition resulted to be equal to: 15.32 ± 1.11 SD range = [9, 16] (corresponding to a global average accuracy of about 0.96 ± 0.05 SD and an average *z*-score of proportion of correct responses of 1.35 ± 0.36 SD).

As in Experiment 1, individual values of response speeds were used to extract, for each participant, 8 individual synthetic index of happiness advantage: 4 for the Target Absolute Intensity condition equal to 50 (resulting from the combination of 2 Face Orientation × 2 Spatial Congruency) and 4 for the Target Absolute Intensity condition equal to 100. Each individual index of happiness advantage was calculated so to be fully homologous to the value extrapolated in Experiment 1 (from the intercept of the best fitting *lme* regressors of average responses to half-range emotional pairs with non-null average valence). In the case of cross-range emotional pair, however, given that the average valence was null no such extrapolation was needed, and individual index of happiness advantage was directly calculated on the basis of actual average response speeds. In particular, I subtracted the individual average response speed for the selection of the angriest and the happiest face within the same pair, in both upright and inverted face orientation conditions for pairs displaying both full emotional (Target Absolute Intensity condition equal to 100) and intermediate emotions (Target Absolute Intensity condition equal to 50). Notably, only the Happiness Advantage' indices calculated on cross-range emotional pair with the intermediate emotions were fully comparable to those extrapolated from responses to half-range emotional pairs studied in Experiment 1, as these two types of emotional pairs were equal in terms of absolute emotional distance along the valence continuum (|-50| + |50| = |0| + |±100|).

As in Experiment 1 our preliminary analysis on the speed accuracy correlation and on the effect of handedness justify the rationale of focusing the main analyses on individual response speeds and happiness advantages. In particular, a *lme* model including a reliable speed-accuracy positive correlation, $F(1, 285.99) = 95.04$, $p < .001$, $\eta_p^2 = .120$, 95% CI [.073, .160], with accuracy increasing of about 0.09 ± 0.01 per cent every unit increment of speed, $t(286) = 9,75$, $p < .001$, $d = 1.15$, indeed achieve a larger goodness of fit than a model combining Handedness with all other factors of our experimental design, $\chi^2(30) = 34.90$, $p = .25$, AIC(6) = -1621.6, vs. AIC(36) = -1596.5, BIC(6) = -1594, vs. BIC(36) = -1430.8.

4.2.2 Results

The *lme* analysis on individual values of response speeds and happiness advantages obtained in Experiment 2 was again consistent with our expectations. In particular, as depicted in Figure 4.4 (same rationale and variable encoding used in Figure 4.3), the pattern of motor reactivity is consistent with the occurrence of FI (circles in Figure 4.4A and 4.4B globally higher than diamonds in Figure 4.4 C and 4.4D), HA (Figure 4.4E to 4.4H) and ED (smaller symbols globally lower than larger symbols in Figure 4.4A to 4.4D). Furthermore the pattern of data shown in Figure 4 suggests that the HA and the ED effects was orientation independent being similarly present in both upright (in Figure 4.4, circles) and inverted (in Figure 4.4, diamonds) faces orientation condition: again in favour of the occurrence of an attentional capture in emotion comparison which is orientation independent.

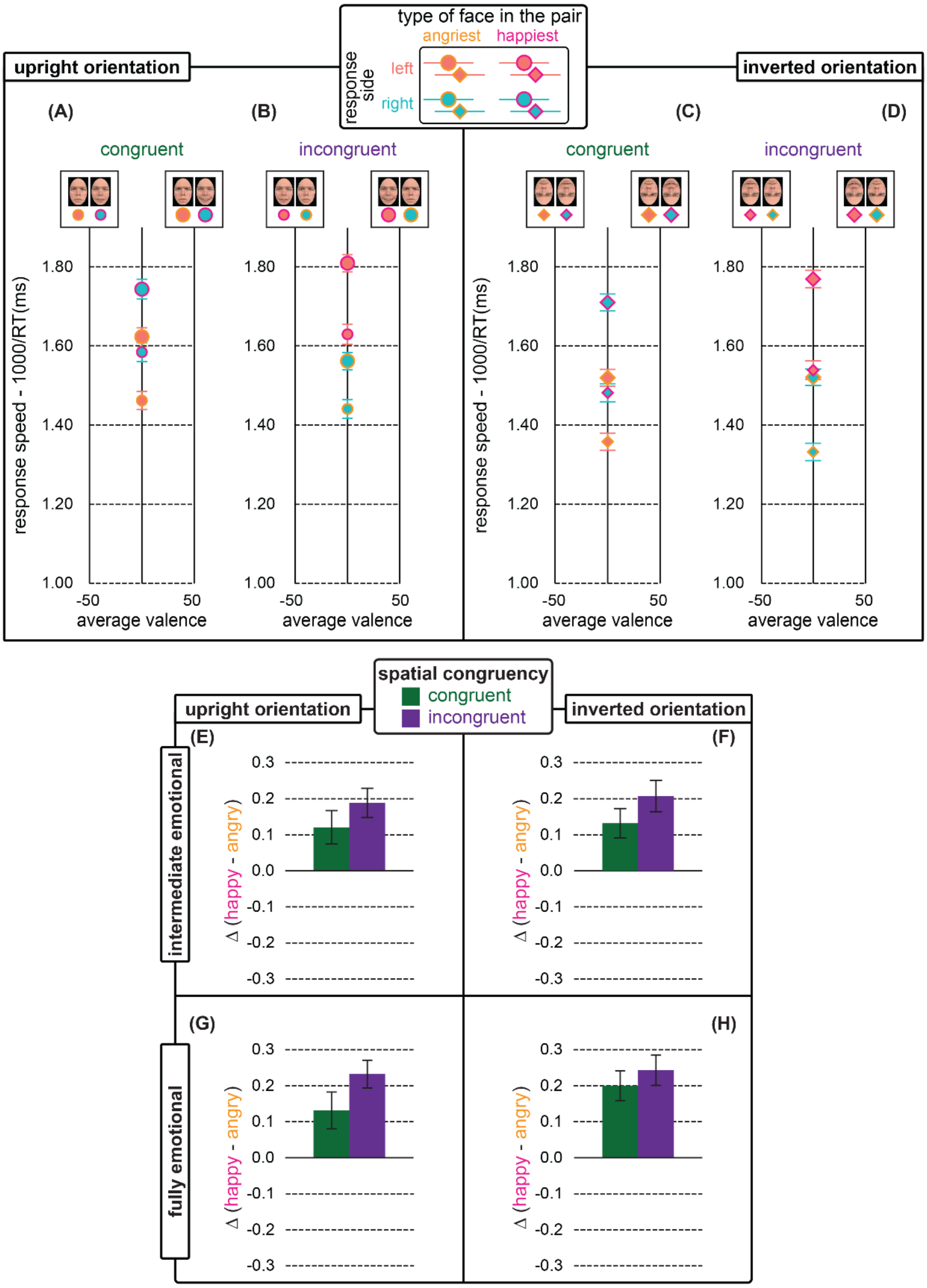

Figure 4.4. Comparative judgements performance in Study 3, Experiment 2. Emotion comparison performance indexed by response speeds (in panels from A to D) and happiness advantages (in panels E to H) with cross-range emotional pairs of Study 3, Experiment 2. Error bars represent ± 1 SEM See caption of Figure 4.3 for further explanation on variable encoding and legends.

These set of effects were corroborated by the *lme* analysis on individual values of response speeds including Average Target Intensity, Face Orientation, Response Side, and Spatial Congruency as fixed effects, r_c = .70, 95% CI [.69, 0.71].The *lme* analysis on indeed revealed the following three significant effects. First, a reliable FI consistent with results of Experiment 1 signalled by a main effect of Face Orientation $F(1, 208.93) = 13.52$, $p < .001$, $\eta_p^2 = .061$, 95% CI [.013, .132], with faster *lme* estimated responses for cross-range emotional pairs in upright over inverted orientation, $M_{\text{Upright}} = 1.33 \pm 0.03$, vs. $M_{\text{Inverted}} = 1.25 \pm 0.03$, $t(277.95) = 3.79$, $p < .001$, $d = 0.45$. Second, an expected ED signalled by the main effect of Target Absolute Emotional Intensity, $F(1, 98.33) = 304.03$, $p < .001$, $\eta_p^2 = .756$, 95% CI [.671, .808]. In particular, the speed of judgements increased with the Target Absolute Emotion Intensity both for the “choose the angriest” task, $M_{\text{Target Absolute Emotional Intensity = 50}} = 1.39 \pm 0.04$, vs. $M_{\text{Target Absolute Emotional Intensity = 100}} = 1.55 \pm 0.04$, $t(154.10) = 13.32$, $p < .001$, $d = 2.14$, and “choose the happiest” task, $M_{\text{Target Absolute Emotional Intensity = 50}} = 1.54 \pm 0.10$, vs. $M_{\text{Target Absolute Emotional Intensity = 100}} = 1.75 \pm 0.09$, $t(24.17) = 12.87$, $p < .001$, $d = 4.94$. Third, an HA, not observed on half-range emotional pairs of Experiment 1, signalled by the significant Response Side × Spatial Congruency interaction, $F(1, 208.95) = 10.24$, $p < .01$, $\eta_p^2 = .047$, 95% CI [.007, .113], with faster response for the selection of the happiest, *lme* estimated average speed for incongruent/left and congruent/right conditions, $M_{\text{happiest}} = 1.39 \pm 0.03$, over the angriest face within the pair, *lme* estimated average speed for congruent/left and incongruent/right conditions, $M_{\text{angriest}} = 1.20 \pm 0.02$, $t(311.76) = 10.73$, $p < .001$, $d = 1.21$.

As a final *lme* analysis I better address the rather strong HA I found on our cross-range emotional pair analysing the individual values of happiness advantage, with a *lme* model including Face Orientation, Spatial Congruency and Target Absolute Emotional Intensity as fixed factors r_c = 0.89, 95% CI [0.87, 0.91]. As for Experiment 1, the *lme* model did not revealed significant interactions or main effects neither for upright, r_c = 0.75, 95% CI [0.70, 0.80], nor for inverted face orientations, r_c = 0.80, 95% CI [0.75, 0.84]: consistent with HA orientation independence. However, differently from Experiment 1, with the cross-range emotional pair of Experiment 2 I found a rather strong HA. This result is evidenced by contrasting individual values of happiness advantage against the reference null value standing for an unbiased motor reactivity ($M_{\text{values of happiness advantage}} = 0.18 \pm 0.03$, vs. 0, $t(45) = 5.22$, $p < .001$, $d = 1.56$). All our experimental conditions indeed revealed a rather robust HA: fully emotional pairs (Figure 4G and 4H), $M_{\text{Fully emotional}} = 0.20 \pm 0.04$, vs. 0, $t(45) = 5.50$, $p < .001$, $d = 1.64$, displayed in both upright, $M_{\text{Upright/Fully emotional}} = 0.18 \pm 0.04$, $t(45) = 4.73$, $p < .001$, $d = 1.41$, and inverted, $M_{\text{Inverted/Fully emotional}} = 0.22 \pm 0.04$, $t(45) = 5.93$, $p < .001$, $d = 1.77$, orientation; as well as intermediate emotional pairs (Figure 4E and 4F), $M_{\text{Intermediate emotional}} = 0.16 \pm 0.03$, vs. 0, $t(45) = 4.64$, $p < .001$, $d = 1.38$, displayed in both upright, $M_{\text{Upright/Intermediate emotional}} = 0.15 \pm 0.04$, $t(45) = 4.21$, $p < .001$, $d = 1.26$, and inverted, $M_{\text{Inverted/Intermediate emotional}} = 0.17 \pm 0.04$, $t(45) = 4.60$, $p < .001$, $d = 1.37$, orientation.

4.2.3 Discussion

The results of Experiment 2 serve multiple purposes. Indeed they suggest: (1) that the ED, a further component of the typical pattern of motor reactivity rising from attentional capture in emotion comparison, beyond those investigated in Experiment 1 (like the ESC and ES), can rise in a blocked design in which only cross-range emotional pair are presented (rather than a randomized mixture of half- and cross-range emotional pair as originally found in Study 1); (2) that the manipulation of face orientation produces similar FI effect in cross-range emotional pair to the FI observed in the half-range emotional pairs of Experiment 1; (3) that the ED is immaterial on the manipulation of face orientation, which is again in favour of a type of orientation independence of attentional capture in emotion comparison; (4) that HA, although being independent on face orientation (consistently with Experiment 1), depends on the type of cutoff (whether explicit or implicit within the pair), being evident in cross-range emotional pairs of Experiment 2, but not in half-range emotional pairs of Experiment 1. This latter result is likely due to the fact that being in the former case the neutral/cutoff face not explicitly displayed within the pair, a reference cutoff needs to be implicitly inferred from each pair as necessary to perform the comparative judgment (Holyoak, 1978; Banks et al., 1976), which results to be biased towards the negative pole of the valence continuum.

I obtained stronger evidence from the general conclusion on the close relationship between the common attentional capture mechanism governing motor reactivity in our two Experiments with half- and cross-range emotional pairs, running a further *lme* analysis replicating the one performed in Study 1, in which half- and cross-range emotional pairs were studied within the same randomized block. In particular, I joined the patterns of individual response speeds resulting from Experiment 1 and Experiment 2, including the Experiment (Experiment 1, Experiment 2) as an additional fixed factor together with Average Valence, Face Orientation, Response Side and Spatial Congruency (the random structure now included also the Experiment, beyond the factors included in the analysis of Experiment 1). The key result was that the fixed structure of the best fitting *lme* model resulted to be simplest than the one including the full interaction between the whole set of experimental factors entered into the analysis with 31 *df*, $r_c = .74$, 95% CI [.73, .74] as not including the main effects of Response Side and Spatial Congruency. In particular, the best fitting *lme* was one with 20 *df* which accounted for the exact same amount of variance of the full fixed structure *lme* model but optimizing the goodness of fit ($\chi^2(11) = 5.25$, $p = 0.92$, AIC(20)= 5826.1 vs. AIC(31)= 5842.8; BIC(20) = 5971.6, vs. BIC(31) = 6068.3) through including only the:

(1) the Average Emotion Intensity × Response Side × Spatial Congruency component modelling the typical pattern rising from attentional capture in our joined emotion comparison tasks involving ESC, $F(1, 227.98) = 292.82$, $p < .001$, $\eta_p^2 = .562$, 95% CI [.480, .626], and ES, $F(1, 22.29) = 162.76$, $p < .001$, $\eta_p^2 = .879$, 95% CI [.749, .922];

(2) the Face Orientation component included as an additive factor, $F(1, 767.03) = 63.37$, $p < .001$, $\eta_p^2 = .073$, 95% CI [.041, .110], modelling the global orientation dependence of motor reactivity in emotion comparison due to FI;

(3) the Experiment × Response Side × Spatial Congruency component modelling the dependence of the HA from the *type of cutoff* (absent if explicitly displayed as in Experiment 1 vs. present if implicitly extrapolated as in Experiment 2), $F(1, 777.68) = 54.16$, $p < .001$, $\eta_p^2 = .064$, 95% CI [.036, .101];

(4) a main effect of the Experiment $F(1, 22.54) = 11.19$, $p < .01$, $\eta_p^2 = .332$, 95% CI [.049, .0552], consistent with an overall slowing down of responses in half-range rather than cross-range emotional pairs [*lme* estimated $M_{\text{Experiment 1}} = 1.13 \pm 0.03$, vs. $M_{\text{Experiment 2}} = 1.56 \pm 0.06$, $t(85.14) = 8.45$, $p < .001$, $d = 1.83$].

Notably, the main effect of Experiment is in line with results by Bimler, Skwarek, and Paramei (2013) , supporting the idea that the inclusion of a neutral face in an emotional pair impair motor reactivity in emotion comparisons relative to the case in which both faces are emotional. This is consistent with the possibility that categorical perception may have played a role in shaping motor reactivity in our emotion comparison task (Cheetham et al., 2015; MacDorman & Chattopadhyay, 2016). I indeed consistently found that pair of faces with the same emotional distance of half-range emotional pairs but belonging to ostensibly different emotions as in the case of cross-range emotional pairs (with Target Absolute Emotional Intensity = 50) were chosen markedly faster of about 0.15 ± 0.05 unit of speeds, $t(85.40) = 2.83$, $p < .01$, $d = 0.61$.

Finally, I compared individual values of happiness advantage in Experiment 1 and Experiment 2 for emotional pairs which were comparable in terms of emotional distance (i.e., removing from the dataset of Experiment 2 the responses to cross-range emotional pairs with Target Absolute Emotional Intensity = 100). Results on individual values of happiness corroborated the strong vs. null HA observed in Experiment 2 vs. 1, with a main effect of Experiment $F(1, 86) = 12.87$, $p < .001$, $\eta_p^2 = .130$, 95% CI [.026, .263], characterized by larger HA for cross-range emotional pairs of Experiment 2 compared to half-range emotional pairs of Experiment 1, 0.16 ± 0.03, vs. 0.02 ± 0.03, $t(86) = 3.59$, *p* < .001, *d* = 1.00. No other main effects or interactions were found included Face Orientation (all *p*s > .06), which further demonstrate that the HA in our Experiments was orientation independent.

4.3 General Discussion

In the present study, I investigated whether the capture of visual spatial attention from emotional salience found in Study 1 in emotion comparison depends on face orientation (upright eliciting an holistic vs. upside-down eliciting a part-based processing of facial expressions), and on the type of emotional pairs (whether half-range explicitly including the neutral cutoff face vs. cross-range not including it).

In Experiment 1, using half-range emotional pairs both displayed in upright or in inverted orientation, I found that attentional capture occurs independently from the face orientation: an evidence in favour of the idea that attentional capture in emotion comparison is orientation independent. In particular, with both emotional pairs presented in upside and inverted orientation I found similar patterns of lateralized motor reactivity that according to the finding of Fantoni et al. (2019) are interpretable as by-products of a prioritization in early sensory processing of highly emotional over slightly emotional (e.g., neutral) faces (Öhman, Flykt, et al., 2001; Sabatinelli et al., 2005; Vuilleumier et al., 2003). Such a prioritization is likely to have produced a speeding up of responses in our task when the target face was emotional, as opposed to a slowing down of responses when the target face was neutral as the emotional/flanking face irresistibly captured visual spatial attention. Such an attentional capture phenomenon is consistent with our finding of an orientation independent ESC with faster responses for emotional over neutral, upright and inverted faces (regardless from the compatibility between the side of responses and the polarity of target emotion expected on the basis of a SNARC-like pattern). Furthermore, our finding is well consistent with an orientation independent ES with globally faster responses for emotional pairs with positive rather than negative average valence displayed in upright and inverted orientation. However, differently from the results of Study 1 in which half-range and cross-range emotional pairs were randomized within the same experimental block, in Experiment 1 I found no evidence for an HA.

In Experiment 2, using cross-range emotional pairs in both orientations, I found similar orientation independence effects, but a rather strong HA, similar to the one observed by Fantoni et al. 2019: an evidence in favour that HA depends on the type of cutoff, whether explicitly displayed in the pair or implicitly inferred from the pair, being more evident in the cross-range emotional pair of Experiment 2, rather than the half-range emotional pairs of Experiment 1. This result is probably due to the fact that in cross-range emotional pairs of Experiment 2 the neutral/cutoff face was not explicitly displayed and a reference cutoff needed to be implicitly inferred in order to perform the comparative judgment (Holyoak, 1978; Banks et al., 1976). According to the happiness advantage generally observed with realistic faces as those used in the current experiments (Becker et al., 2011, 2012; Calvo & Nummenmaa, 2008; Fantoni & Gerbino, 2014; Fantoni, Rigutti, & Gerbino, 2016), it is likely that the inferred cutoff with cross-range pairs of Experiment 2 resulted to be biased towards the negative pole of the emotion continuum, thus producing a reliable, though orientation independent HA.

Relative to Study 1, the present study further confirms the central role of attentional capture in emotion comparison, through deepening for the first time its orientation independence which is relevant for a full understanding of whether the type of perceptual processing impact spatial attention when performing in presence of motivationally salient stimuli. All together our results supported the orientation independence of attentional capture in emotion comparison predicted by the direct relationship between absolute emotion intensity and motor reactivity modelled through the SIA. In particular regardless from the type of perceptual processing, being either holistic, as likely occurring for faces displayed in upright orientation, or part-based, as likely occurring for faces displayed in inverted orientation (Piepers & Robbins, 2012; Valentine, 1988), similar pattern of attentional capture in emotion comparison are observed. Attentional capture in emotion comparison is thus likely to be independent from the modalities in which human process facial expressions.

This finding contributes significantly to cognitive science as suggesting that spatial attention in simultaneous comparison tasks is more likely to be penetrated by expressive qualities involving motivational salience, rather than by pure featural or configural stimulus properties. This is consistent with the Gestalt literature that conceived expressive qualities, though subjective, as phenomenally objective (i.e., perceived as belonging to the object; e.g., Köhler, 1929), with a remarkable – though not exclusive – dependence on configural and featural stimulus properties.

5 Conclusion

In the present thesis, through three Studies, I deeply investigated the mechanism regulating a direct valence comparison task. In this task, two facial expressions are simultaneously presented side-by-side, with participants required to choose, as fast and accurate as possible, the most positive (e.g., the happiest) or negative (e.g., the angriest) face within the pair. I used two types of stimulus pairs: (1) half-range emotional pairs (i.e., a neutral face paired with a 100% emotional angry/happy face); and (2) cross-range emotional pairs (i.e., a 50% or 100% emotional face paired with another emotional face of the same emotional intensity, but with the opposite emotional valence). The direct valence comparison task is a particular experimental paradigm in which there is both a lateralization of the stimuli (i.e., one face is presented at the left-side and one at the right-side of the screen) and a lateralization of the responses (i.e., participants respond with the left- and the right-hands). To the best of my knowledge, emotional magnitude have never been tested in a comparison task, in contrast to other numerical (e.g., Banks et al., 1976; Lee et al., 2016) or non-numerical (e.g., Audley & Wallis, 1964; Banks et al., 1975; Banks & Flora, 1977; Clark et al., 1973; Patro & Shaki, 2016; Shaki et al., 2012; Zhou et al., 2017) magnitudes.

In Experiment 1 of Study 1, I have demonstrated that the motor reactivity, in a direct valence comparison task, is explained in terms of an attentional capture phenomenon, with an increase of the response speed when the target intensity is the extremal value (i.e., the happiest/angriest face) of a considered intensity continuum and a decrease of the response speed when the target intensity is the central value (i.e., the cutoff neutral face) of the same intensity continuum, namely ESC. The occurrence of ESC is consistent with a stimulus-driven theoretical framework and a capture of visual spatial attention due to emotional stimuli (Carretié, 2014; Ferrari et al., 2008; Reeck & Egner, 2015; Sawada & Sato, 2015). This pattern of motor reactivity was robust for emotional pairs displayed both in spatially congruent and spatially incongruent conditions, with the left-to-right mental format of valence, contradicting the idea that participants, while performing a direct valence comparison task, mentally represent emotional stimuli in terms of valence, with negative and positive stimuli associated with the left and right sides of space, respectively (e.g., Casasanto, 2009; Root et al., 2006). Differently from experimental results on isolated facial expressions (e.g., Holmes & Lourenco, 2011; Pitt & Casasanto, 2017), the occurrence of ESC did not involve any intensity-specific lateral bias.

According to the intensity-specific lateral bias, it was expected a right-to-left response speed deviation, characterized by a steadily increase of motor reactivity from negative to positive emotional pairs in both spatially congruent and incongruent conditions (i.e., SNARC-like pattern). However, in Experiment 1 a SNARC-like pattern was observed only when emotional pairs were displayed in spatially congruent condition: in particular, left-hand (angry faces) responses resulting to be faster than right-hand (neutral faces) responses, for negative emotional pairs, and left-hand (neutral faces) responses resulting to be slower than right-hand (happy faces) responses, for positive emotional pairs. Conversely, a reversed SNARC-like pattern was observed when emotional pairs were displayed in spatially incongruent condition: right-hand (angry faces) responses resulting to be faster than left-hand (neutral faces) responses, for negative emotional pairs, and right-hand (neutral faces) responses resulting to be slower than left-hand (happy faces) responses, for positive emotional pairs.

The pattern of motor reactivity that I found in Experiment 1 of Study 1 is regulated by a magnitude representation of emotions, modelled as a direct Speed-Intensity Association, SIA, that fully predicts the attentional capture phenomenon. According to the SIA model, response speeds in the choice of the angriest/happiest face within the pair depend on three factors: 1) the target absolute emotional intensity relative to the cutoff face, with response speeds increasing for the extreme rather than the central (i.e., neutral) facial expressions of the emotional continuum; 2) the average valence of the pair, with faster response speeds for emotional pairs with positive rather than negative average valence; and 3) and an additive/subtractive constant which formalizes an *emotion anisotropy*, that produces a general improvement of the performance for relatively positive vs. negative emotion intensities (i.e., happiness advantage). Furthermore, in the remaining six Experiments of the thesis I provided further demonstration about whether ESC (1) holds true both in presence or absence of stimulus foveation (Study 1, Experiment 2), (2) is purely stimulus-driven, being independently on task demands (Study 1, Experiment 3), (3) is independent from motivational significance of the stimuli (Study 2, Experiment 1 and Experiment 2), and (4) is independent from perceptual components due to the type of stimulus processing (Study 3, Experiment 1 and Experiment 2). These six Experiments thus allowed me to answer the five research questions that I introduced in the section "Introduction".

(1) *Would ESC hold when the direct valence comparison task is not supported by foveation?*

The results of Experiment 2 of Study 1 allow to answer positively to the question. ESC is independent from lateralization of emotions and it occurs under tachistoscopic presentation of stimuli, when the performance in a direct valence comparison task is not supported by foveation. In order to answer to the first research question, I used a direct valence comparison task with different visual spatial attention requirements. Stimuli were tachistoscopically presented (Bourne, 2006), in order to hinder stimulus foveation. This technique is relevant in order to investigate whether hemispheric specialization of visual perception of facial expressions of emotions might relate with performance in a direct valence comparison task. In presence (Study 1, Experiment 1) or absence (Study 1, Experiment 2) of stimulus foveation, the pattern of response speeds was similarly consistent with ESC, being it independent from the lateralization of emotion.

(2) *Is ESC really stimulus-driven as dependent on bottom-up exogenous attention (and not goal-directed as dependent on top-down endogenous attention)?*

The results of Experiment 3 of Study 1 allow to answer positively to the question. ESC is stimulus-driven, as dependent on bottom-up exogenous attention, and it occurs also when the valence dimension is task irrelevant. In order to answer to the second research question, I used an emotion identification task, with the same free viewing conditions of Experiment 1 of Study

1 (i.e., self-terminating stimulus duration), but under different task demands. In the present Experiment, I used an indirect task, in which the valence intensity was task irrelevant (i.e., requiring participants to choose the emotional/neutral face in the emotional pair). The pattern of response speeds was fully consistent with ESC. The occurrence of ESC in Experiment 3 is consistent with evidence showing a prioritization in early sensory processing of emotional over neutral stimuli, with emotional stimuli evoking greater activation in relevant early visual cortical regions (e.g., Vuilleumier et al., 2003), and being more likely to capture visual spatial attention (e.g., Öhman, Flykt, et al., 2001; Öhman, Lundqvist, et al., 2001).

(3) *Is ESC independent from motivational significance of the stimuli and should occur in the symbolic domain, as in the case of Arabic numbers?*

Taken together the results of Experiment 1 and Experiment 2 of Study 2 allow to answer positively to the question. ESC is independent from motivational significance of the stimuli and it is generalizable to the symbolic domain, as in the case of Arabic numbers. In order to answer to the third research question, I run two complementary experiments: a direct comparison of simultaneously presented digits (Experiment 1) and a direct valence comparison of simultaneously presented facial expressions (Experiment 2). Results showed that digits (Experiment 1) and facial expressions (Experiment 2), whether simultaneously presented, elicit similar patterns of motor reactivity. The finding of Study 2 allows to connect two complementary fields of research (1) the one studying numerical cognition and magnitude comparison, and, in particular how mental magnitudes are related with each other along a continuum and (2) the one studying how motor reactivity is shaped by both bottom-up exogenous (i.e., stimulus-driven) and top-down endogenous (i.e., goal-directed) factors while participants are exposed to emotional stimuli. The homologous pattern of motor reactivity found in Experiment 1 and Experiment 2 suggests that the attentional capture phenomenon is elicited purely by magnitudes rather than perceptual salience of facial features shaping motivational significance.

(4) *Is ESC independent from perceptual components due to the type of stimulus processing (part-based vs. holistic)?*

The results of Experiment 1 of Study 3 allow to answer positively to the question. ESC is independent from the type of perceptual processing, being either holistic, as likely occurring for faces displayed in upright orientation, or part-based, as likely occurring for faces displayed in inverted orientation. In order to answer to the fourth research question, I used a direct valence comparison task with half-range emotional pairs, with both faces displayed either in upright or in inverted orientation. A similar pattern was found when emotional pairs were presented in both upright and inverted orientation, beyond a general slowing-down of response speeds due to face inversion effect (Bartholow, 2003; Derntl et al., 2009Jacques et al., 2007; Pallett & Meng, 2015; Prkachin, 2003; Yin, 1969). Experiment 1 confirms the central role of the attentional capture phenomenon in the direct valence comparison task, being it independent from the modalities in which human process facial expressions, as predicted by the direct relationship between absolute emotion intensity and motor reactivity. Surprisingly, differently from results of Study 1, the happiness advantage did not occur in the current Experiment, independently from the orientation of the emotional pairs. An explanation for this result resides into the different types of emotional pairs I used compared to Study 1, in which the cutoff face was not always explicitly displayed, thus suggesting that the cutoff of the continuum needed to be extrapolated by participants. In Experiment 1, the cutoff face was always explicitly displayed (i.e., the neutral face was shown in all stimulus pairs), thus (in principle) the cutoff of the continuum did not need to be extrapolated by participants. Therefore, the presence/absence of an explicit cutoff might affect the happiness advantage. The happiness advantage would emerge only when the cutoff is not explicitly displayed (or not-constantly displayed as in Study 1). I confirmed such hypothesis in the last Experiment of the thesis.

(5) *Is the emotion anisotropy dependent on how emotional magnitudes are represented and in particular by the type of cutoff of the emotional series (explicit vs. implicit within the pair)?* The results of Experiment 2 of Study 3 allow to answer positively to the question. The *emotion anisotropy* is cutoff dependent, and it occurs only in the case in which the cutoff need to be extrapolated from image pairs. In order to answer to the fifth research question, I compared a condition in which the cutoff face was always present because explicitly displayed (i.e., Study 3, Experiment 1), with a condition in which the cutoff face was never present and it need to be implicitly extrapolated (i.e., Study 3, Experiment 2). From such comparison, the occurrence of happiness advantage emerged only in the case of an implicit cutoff face, supporting the idea that the presence of a neutral face in the pair negatively affect the performance in a direct valence comparison task (e.g., Bimler, et al., 2013). This evidence indicates that the absence of an explicit face within the pair corresponding with the cutoff of the continuum might have led participants to extrapolate it. In the case of cross-range emotional pairs, the cutoff being not displayed is extrapolated being implicitly inferred from the pair. Such an inference might have determined a shift of the extrapolated cutoff towards the negative pole (i.e., the angriest face). Therefore, the perceived distance between the extrapolated cutoff and the extremal values (attentional attractors) of the emotional continuum gets not equal. Considering that the larger the distance between the cutoff and the attentional attractor, the larger the response speed, the different distance between the extrapolated cutoff and the negative/positive pole now determines an emotional anisotropy (i.e., the happiness advantage).

All together the three Studies shed light on the attentional mechanism involved during a direct comparison task of intensities, based on a capture of visual spatial attention by the extremal values of a series. The way in which the attentional capture phenomenon is elicited can be explained in terms of a formation of an intrinsic reference frame (Audley & Wallis, 1964; Holyoak, 1978; Hsee, 1996; Hsee & Leclerc, 1998; Shafir et al., 1993) placed at the cutoff of the magnitude continuum. This idea reconciles pioneering reference point models of comparative judgements (e.g., Chen et al., 2014; Greenberg, 1963; Holyoak, & Mah, 1982; Petrusic, 1992), with theories of exogenous spatial attention. The major difference is that, as the anchor for comparisons along a given continuum, participants use a single reference point placed at the cutoff of the magnitude continuum, rather than values placed at the extremal position in the continuum (that is defined either implicitly or explicitly by the task, i.e., the angriest or the happiest). This mechanism is shared by both emotional and numerical magnitude, and it would be generalized to other magnitude domains (e.g., luminance) or other modalities of stimulus presentation (e.g., auditory). Of interest, it should be understanding more directly where attention is deployed throughout a direct comparison task (e.g., with eye tracker measurement). More studies are needed to deeply explore the attentional capture phenomenon described in the present thesis.

6 Acknowledgements

I would like to express my gratitude and appreciation to all those who gave me the possibility to complete the doctoral studies. A special thanks go to Professor Carlo Fantoni for providing his guidance, comments and suggestions throughout the course of the studies, and to my Supervisor, Professor Tiziano Agostini, whose have given his full effort in guiding the research group. I would like to acknowledge the crucial roles of Professor Valter Prpic, Ph.D. Mauro Murgia, and Ph.D. Sara Rigutti, whose advice, stimulating suggestions and encouragement, helped me during the studies. I would also to thanks Professor Dražen Domijan for supporting my studies at the University of Rijeka. My doctoral studies were supported by an International Fellowship within the European Social Fund 2014-2020 programme of Regione Autonoma Friuli-Venezia Giulia.

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