Giulio Baldassi[1], Mauro Murgia[1], Valter Prpic[2], Sara Rigutti[1], Dražen Domijan[3], Tiziano Agostini[1], & Carlo Fantoni[1]*

Large as being on top of the world and small as hitting the roof: A shared magnitude representation for the comparison of emotions and numbers

1. Department of Life Sciences, Psychology Unit "Gaetano Kanizsa", University of Trieste, Via E. Weiss 21, 34128 Trieste, Italy; 2. Faculty of Health and Life Sciences, Institute for Psychological Science, De Montfort University, The Gateway, LE1 9BH Leicester, United Kingdom; 3. Department of Psychology, Faculty of Humanities and Social Sciences, University of Rijeka, Sveucilisna avenija 4, 51000 Rijeka, Croatia

*Correspondence concerning this article should be addressed to Carlo Fantoni, Department of Life Sciences, University of Trieste, Via E. Weiss 21, 34128 Trieste, Italy. E-mail: cfantoni@units.it; phone: 00390405588871; fax: 00390405584220; ORCID ID: 0000-0002-7749-1771

Contacts:

Giulio Baldassi: giulio.baldassi@phd.units.it ORCID ID: 0000-0002-2114-3567
Mauro Murgia: mmurgia@units.it ORCID ID: 0000-0002-8450-1157
Valter Prpic: valter.prpic@dmu.ac.uk ORCID ID: 0000-0002-1382-0951
Sara Rigutti: srigutti@units.it
Dražen Domijan: ddomijan@ffri.hr ORCID ID: 0000-0003-2589-3397
Tiziano Agostini: agostini@units.it ORCID ID: 0000-0003-0105-2999

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Abstract

Previous work on the direct Speed–Intensity Association (SIA) on comparative judgment tasks involved spatially distributed responses over spatially distributed stimuli with high motivational significance like facial expressions of emotions. This raises the possibility that the inferred stimulus-driven regulation of lateralized motor reactivity described by SIA, which was against the one expected on the basis of a valence-specific lateral bias, was entirely due to attentional capture from motivational significance (beyond numerical cognition). In order to establish the relevance of numerical cognition on the regulation of attentional capture we ran two complementary experiments. These involved the same direct comparison task on stimulus pairs that were fully comparable in terms of their analog representation of intensity *but* with different representational domain and motivational significance: symbolic magnitudes with low motivational significance in experiment 1 vs. emotions with rather high motivational significance in experiment 2. The results reveal a general SIA and point to a general mechanism regulating comparative judgments. This is based on the way spatial attention is captured toward locations that contain the stimulus which is closest in term of relative intensity to the extremal values of the series, regardless from its representational domain being it symbolic or emotional.

Keywords: emotion, numerical cognition, spatial attention, magnitude comparison, semantic congruity, SNARC effect

Introduction

In a world without comparisons, quantities would be worthless in the absence of the possibility to establish more/less relations: we 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, Lundqvist, & Esteves, 2001; Treisman, 1982). In a recent study from our group (Fantoni et al., 2019) we 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, 2018). The effect of Fantoni et al.(2019) 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[1]). Here we 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 shared magnitude representation for the comparison of emotions and numbers.

In our previous study (Fantoni et al., 2019) we 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

[1] Abbreviations: ESC: Emotional Semantic Congruency effect; SC: Semantic Congruity effect; AE: Alternative Expectation; RT: Response Time; SIA: Speed-Intensity Association

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). We 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, Clark, and Lucy (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 by Fantoni et al. (2019) on mixed-facial expression 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 emotional intensity. Conversely, the left angriest cutoff face gets *slower* than the right happiest emotional face, at high average emotional intensity. In spatially incongruent pairs, the left happiest cutoff face gets *slower* than the right angriest emotional face, at low average emotional intensity. Conversely, the left happiest emotional face gets *faster* than the right angriest cutoff face, at high average emotional intensity. An analogous pattern was observed in many studies in different domains (Audley & Wallis, 1964; Banks & Flora, 1977; Banks et al., 1975; Banks, Fujii, & Kayra-Stuart, 1976; Clark, Carpenter, & Just, 1973; Ellis, 1972; Friend, 1973; Holyoak, 1978; Marks, 1972; Patro & Haman, 2012; Zhou, Ho, & Watanabe, 2017).

Notably, as predicted by the SIA model (Fantoni et al., 2019) 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 by Fantoni et al. (2019) 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, Chua, & Dolan, 1999; Morris et al., 1998; Sabatinelli, Bradley, Fitzsimmons, & Lang, 2005; Vuilleumier, Armony, Driver, & Dolan, 2003), with spatial attention being spontaneously captured by emotions (Fox, 2002; Hansen & Hansen, 1994; Öhman, Flykt, & Esteves, 2001; Öhman 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, Codispoti, Cardinale, & Bradley, 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 by Fantoni et al. (2019) was due to a shared magnitude representation for the comparison of emotions and numbers based on SIA, or to the specific emotional salience of facial expression stimuli eliciting the ESC.

Consequently we 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 an analog magnitude representation? Answering positively to such a question would be twofold in order to: (1) generalize the causal inference resulting from Fantoni et al. (2019) finding 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 SC, 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 shared magnitude representation for the comparison of emotions and numbers. This is demonstrated by the high predictive power of the SIA model[2] on the pattern of individual choice speeds shown by Fantoni et al. (2019), as mainly based on the extraction of relative emotion intensity values from emotional stimulus pairs. Indeed, the model remaps response speeds into general *analog magnitudes* that are conceived as 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 complete-facial expressions 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] Fantoni et al. (2019) showed in three Experiments how SIA model provided a thoughtful and effective predictor for speed performances in comparative judgement of facial expressions of emotions, when valence was either task relevant (Experiment 1 and 2) or task irrelevant (Experiment 3) and in both presence (Experiment 1 and 3) or absence (Experiment 2) of foveal emotion presentation conditions (Experiment 1, with a direct valence comparison task in presence of foveation: r_c = .69, 95% CI [.68, .71]; Experiment 2, with a direct valence comparison task in absence of foveation: r_c = .75, 95% CI [.73, .76]; and in Experiment 3, with an indirect emotion identification task in presence of foveation: r_c =.73, 95% CI [.72, .75]).

(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 by Fantoni et al. (2019), inducing different motivational significance, or to a shared *magnitude* representation for the comparison of emotions and numbers remapped 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 Fantoni et al., 2019), similar effects should be expected across domains.

The present study: Conceptual framework and expectations

Here we put forth two complementary experiments in order to answer to our *research question*. Our two Experiments fully replicate the comparative judgement technique used by Fantoni et al. (2019), though generalizing the direct comparison task they used to stimulus pairs that were fully comparable in terms of their *analog magnitude* representation (at the ordinal level). It is noteworthy that the stimuli we 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, we 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 *analog 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 we 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 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 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 1A *x*-axis on bottom).

Notably, the emotion intensities were the same as the ones used by Fantoni et al. (2019). 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) We 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 by Fantoni et al. (2019). By purpose, we 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, we 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 studied by Fantoni et al. (2019). Following the MacDorman & 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 Fantoni et al. (2019) – 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 by Fantoni et al. (2019). Such an unbalance would result in a more evident *funnelling* of the *crossover* pattern expected on the basis of a pure ESC effect.

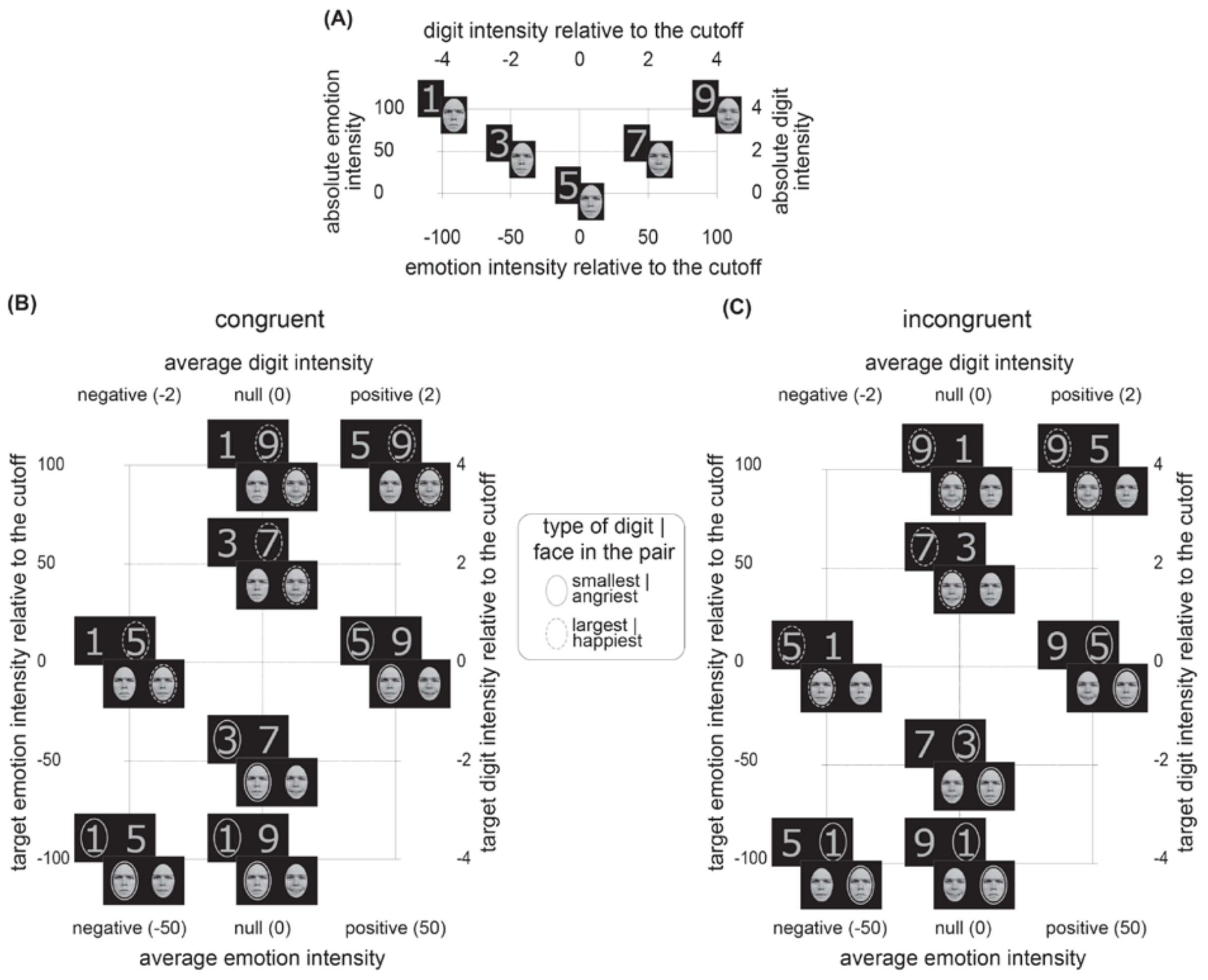

Figure 1. Digits/faces stimuli and digits/facial expressions stimulus pairs used in Experiment 1 and 2, respectively. (A) Exemplar of digits and facial stimuli (identity not used in our experiments who gave permission for the usage of his image) used for the generation of the 8 types of digits/facial expressions stimulus pairs used in Experiment 1 and 2 (B and C for the congruent and incongruent spatial position respectively). 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 (emotion 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, as in Fantoni et al. (2019), our 8 types of digit/face stimuli, depending on the type of target digit/face (smallest/angriest coded by continuous surrounding ellipses or largest/happiest coded by dotted surrounding ellipses), determined 16 experimental conditions (8 congruent in panel B and 8 incongruent in panel C).

Globally, we replicated the experimental design of Fantoni et al. (2019) 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 1B (smallest intensity displayed to the leftmost position), and spatially incongruent positions, as in Figure 1C (smallest intensity displayed to the rightmost position), relative to the left-to-right mental format of intensities. In particular, we have two types of pairs: (1) the mixed-digits/facial expressions 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 1B, 1C, negative and positive average digit/emotion intensity); (2) the complete-digits/facial expressions 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 1B, 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/largest number of a presented pair; in the second block they were required to choose largest/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/happiest face of a presented pair; in the second block they were required to choose happiest/angriest face (thus, in counterbalanced order).

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

(AE1) A shared magnitude representation: a general SC pattern

If attentional capture, in our comparative judgment task, is regulated by a shared analog 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 by Fantoni et al. (2019, i.e., the ESC) is expected to occur in the case of the comparative judgement of Arabic numbers in Experiment 1. 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 access an *analog magnitude* representation necessary to produce fast comparative judgements (e.g., Banks & Flora, 1977; Banks, Fujii, & Kayra-Stuart, 1976; Banks et al., 1976; Patro & Shaki, 2016; Shaki, Petrusic, & Leth-Steensen, 2012).

AE1 is motivated by the fact that intensities conveyed by digits can be explicitly remapped into *analog magnitudes* similar to those implicitly representing emotional valence. In any case these values can equally serve the purpose of predicting motor reactivity through the general magnitude code 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 conceptual 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 Fantoni et al. (2019), 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 *analog 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 1B, 1C). If AE1 holds, a similar pattern of response choice speeds is expected in Experiment 1 and 2: following Fantoni et al. (2019), such a 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 (and specifically with the ESC found by Fantoni et al., 2019), 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 we 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 Fantoni et al., 2019);

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. Notably, the *intensity anisotropy* should be reflected also on complete-digits/facial expressions pairs, with the addition of a main effect of target absolute digits/emotion intensity, consistent with a general (across domains) *distance effect*.

(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 shared magnitude representation), then a different pattern of lateralized motor reactivity than the one observed by Fantoni et al. (2019, 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 by Fantoni et al. (2019) 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 we 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 (Caessens & Fias, 2006; Dehaene, Bossini, & Giraux, 1993; Fias, 1996; Gevers, Verguts, Reynvoet, Proctor & Xiong, 2015; Shaki & Fischer, 2008;

Shaki, Fischer, & Petrusic, 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, Chun, & Cho, 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, Wood, & Willmes, 2005; Prpic et al., 2016; Ren et al., 2011). One major implication of SNARC is a reversed ESC pattern for mixed-digits/facial expressions pairs displayed in spatially incongruent positions (i.e., cutoff paired with *min* digits/faces; *max* paired with cutoff digits/faces), but not for mixed-digits/facial expressions 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 mixed-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.

General Method

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, we 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 questionnaire (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.

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 by Fantoni et al. (2019) 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. In particular, both types of digit and facial expression pairs (complete and mixed) were treated in the exact same way of face stimulus pairs used by Fantoni et al. (2019). 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; see also Fantoni et al., 2019). 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 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 Fantoni et al. (2019) 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 Fantoni et al. (2019, as well as in Experiment 2). As depicted in Figure 1A, we 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, with even–right, odd–left, over incongruence (Hines, 1990; Nuerk, Iversen, & Willmes, 2004) and (2) obtain a digits continuum maximally similar in term of analog relative intensities to the one studied by Fantoni et al. (2019) in the domain of emotions, and in Experiment 2, (see subsection “*The present study: Conceptual framework and expectations*” for relative encoding of intensity). As regards the facial stimulus set, we strictly followed the rationale of Fantoni et al. (2019). We 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 (see Fantoni et al., 2019 for details). 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, Rigutti, & Gerbino, 2016), and used in the comparative judgement of emotion study of Fantoni, et al. (2019). 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 we 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 1B-1C, each set of 5 digits/facial expressions (belonging to the same character) was paired, in order to obtain 4 Types of mixed 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 complete 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 Fantoni et al. (2019), our set of stimulus pairs determined a total of 64 digits/facial expressions 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 mixed-digits/facial expressions pairs differing in term of Average Intensity + 2 complete-digits/facial expressions pairs differing in term of Target Absolute Intensity) × 2 Spatial Congruency (congruent, incongruent). Following Fantoni et al. (2019) and 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.

Procedure

The exact same procedure was applied in Experiment 1 and 2. Our procedure resembled the one used in the Experiment 1 of Fantoni et al. (2019), 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 Fantoni et al., 2019 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 is 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 in Fantoni et al. (2019), as illustrated in Figure 2.

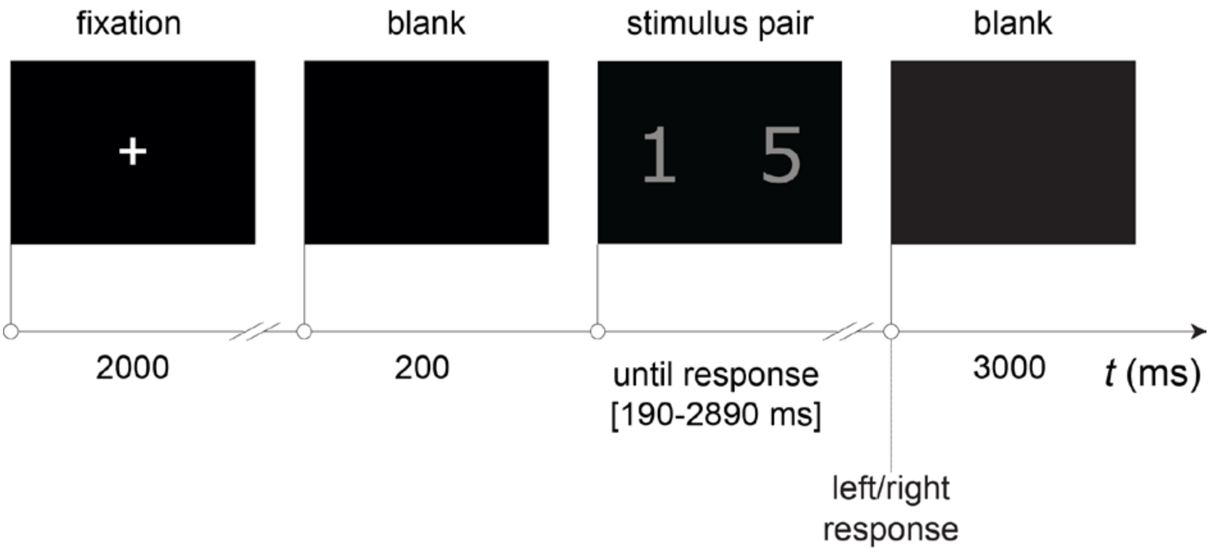

Figure 2. Trial temporal structure**.** This specific example illustrates the subset including a stimulus pair used in Experiment 1 with negative average digits intensity in spatially congruent position, (i.e., *min*-cutoff digit). Depending on the task (“choose the smallest/largest” in the pair), the 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.

Data Analysis

The same individual values of performance indices used by Fantoni et al. (2019) were extracted from the pattern of individual responses in our digits/emotional valence comparison task. In particular, we 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, and (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, we 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, we analysed the individual proportion of correct responses calculated over the 8 displays for each condition of our design. In doing that, we 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), with $\sigma = \sqrt{\frac{p_0(1-p_0)}{n}} = \sqrt{\frac{0.75(1-0.75)}{8}} = 0.153$. 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 Fantoni et al. (2019) 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 we analysed all three types of performance indices (response speed, Δspeed, z-score of proportion correct) using *lme* models. In order to keep our generalized causal inference less prone to the risk of Type I error inflation, we followed Barr, Levy, Sheepers 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. We 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 Emotion Intensity, Target Absolute Emotional Intensity, Spatial Congruency, Response Side[3]. Consistently with the results of Fantoni et al. (2019), preliminary *lme* analyses revealed no reliable interaction between accuracy, and handedness with 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] see Fantoni et al., 2019, 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.

All raw data generated in this study are included in this published article as supplementary information file (Online Resource 1).

Online Resource 1. Data for: Large as being on top of the world and small as hitting the roof. Raw Dataset in Excel format of the two experiments reported in the manuscript. The file included three worksheets: 1.Variables Encoding: including a full description of the code necessary to interpret the variables/columns of the subsequent Raw Datasets; 2.Experiment 1: including the Raw Dataset of Experiment 1 in which the set of Comparative judgements collected on Arabic numbers are reported; 3.Experiment 2: including the Raw Dataset of Experiment 2 in which the set of Comparative judgements collected on facial expressions of emotions are reported.

Results and Discussion

Experiment 1: Comparative judgment of Arabic numbers

Figure 3 illustrates the patterns of average values of response speeds/times (Figure 3A and B *y*-axes left/right) and Δspeeds (Figure 3C and 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 3A) and incongruent (Figure 3B) positions, appearing in the leftmost (grey filled circles) or the rightmost (black filled circles) position, depending on whether the target was the smallest (continuous outline) or the largest (dotted outline) digit within the pair, with average values of speeds/times plotted in a Cartesian system with double *y*-axes: the two ordinates encoding the average response speeds (left *y*-axis) and the corresponding response time (right *y*-axis) as a function of average digit intensity (*x*-axis). Figure 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 3D.

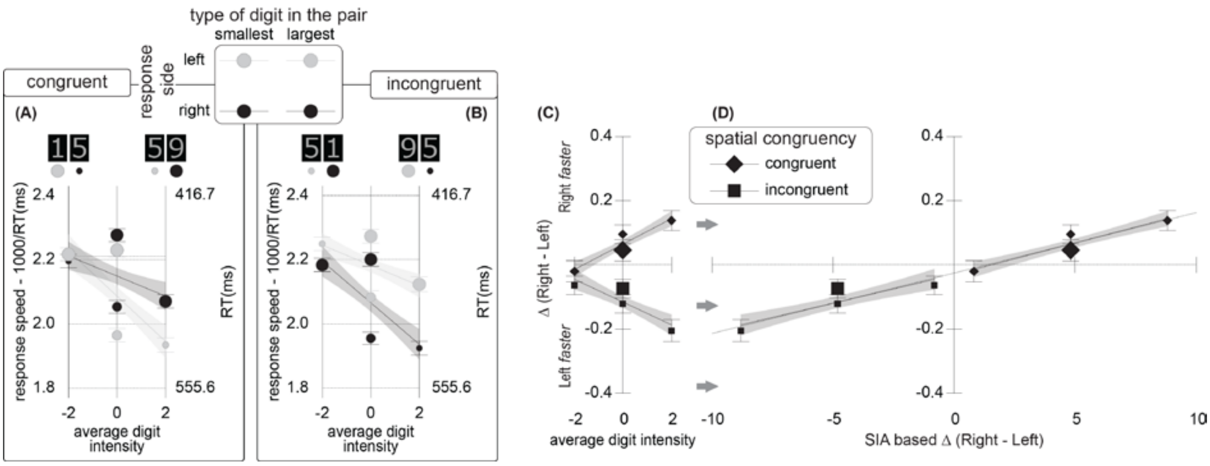

Figure 3. Comparative judgment of Arabic numbers. (A-B) illustrations of the average individual response speeds in spatially congruent (A) and spatially incongruent (B) conditions, as a function of average digit intensity. Error bars represent ± 1 standard error of the mean and the size of the circles 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 shade of grey filling the circles (mid grey for left; black for right) and by the outline (dashed for largest; continuous for smallest) bounding the circles, respectively (legend on top). Black/light grey 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 squares/ diamonds 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 squares/ diamonds (legend of panel C and D). Continuous black 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 3A and 3B) and Δspeeds (Figure 3C) are in strong agreement with AE1, but not with AE2. We corroborate this observation statistically through demonstrating the generality of the attentional capture phenomenon, first reported by Fantoni et al. (2019), as occurring also in the numerical domain, thus in absence of motivational significance. The 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 3A and 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 [$M_{max/\text{congruent}} = 2.069 \pm$

0.043 vs. $M_{cutoff/congruent}$ = 1.932 ± 0.043; $t(57.912) = 42.271$, $p < .001$, $d = 1.17$; $M_{max/incongruent}$ = 2.127 ± 0.045 vs. $M_{cutoff/incongruent}$ = 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 3A) and incongruent (-3.203 Figure 3B) conditions. Furthermore, we 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 complete-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 complete-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, with the speed of judgements increasing 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 Fantoni et al. (2019), we further analysed Δspeeds shown in Figure 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 Fantoni et al. (2019) in the comparative judgement of emotion 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, we 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, we followed the procedure of Fantoni et al. (2019) and 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 Fantoni et al. (2019), 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 $\chi^2(6) = 0.00$, $p = 1$; $AIC_{SIA} = 3291.3$, vs. $AIC_{FULL} = 3427.3$; $BIC_{SIA} = 3351.1$ vs. $BIC_{FULL} = 3527$; $r_{c\ SIA} = .622$, 95% CI [.608, .635], vs. $r_{c\ FULL} = .610$, 95% CI [.596, .624]; on Δspeed $\chi^2(2) = 0.165$, $p = .921$; $AIC_{SIA} = -154.94$ vs. AIC_{FULL} = -

151.11; BIC_{SIA} = -131.50 vs. BIC_{FULL} = -119.84; $r_{c\ SIA}$ = .730, 95% CI [.689, .766], vs. $r_{c\ FULL}$ = .746, 95% CI [.708, .781]}.

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 analog 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 4A, 4B, 4C, and 4D, with the pattern of average response speeds and average Δspeeds presented following the same rationale and variable encoding used in Figure 3). These results provide further support to AE1, beyond the similarity between the patterns of responses observed in Experiment 1 and those previously assessed by Fantoni et al. (2019), with facial expressions varying in the anger-to-neutral-to-happiness per cent in the morph continuum.

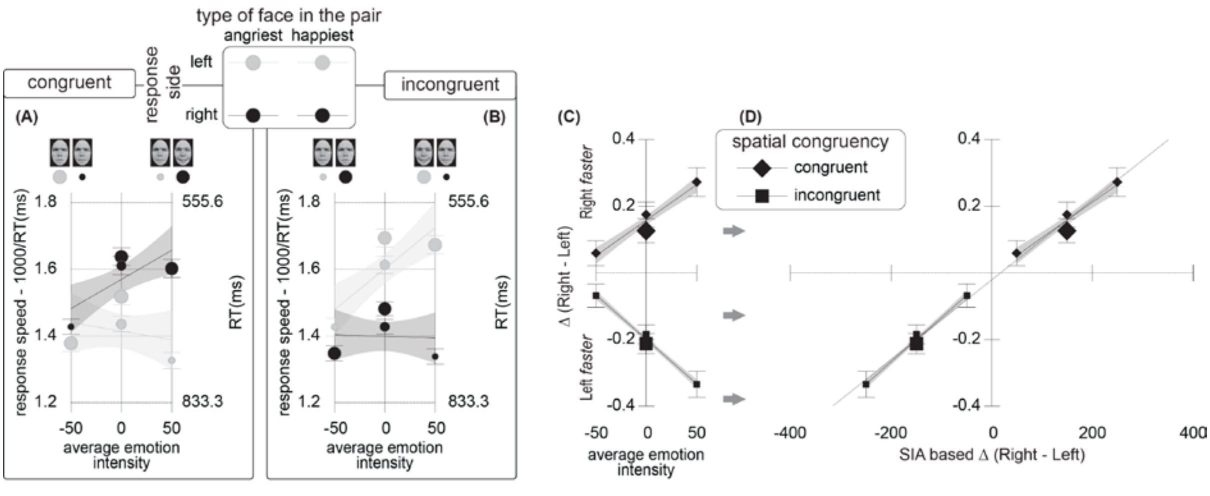

Figure 4. Comparative judgment of of facial expressions of emotions. See caption of Figure 3 for further explanations. Panel A and B depicted the average individual response speeds in spatially congruent (A) and spatially incongruent (B) conditions, as a function of average emotion intensity. The response side and the type of target face are coded by the shade of grey filling the circles and by the outline (dashed for happiest; continuous for angriest) bounding the circles, respectively. Panels C and D show average Δspeeds in the ordinate either as a function of average emotion 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.

Indeed, results of Experiment 2 closely mirrored results of Experiment 1. The key result on individual speeds is the similar Response Side × Spatial Congruency × Average Emotion Intensity 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 Emotion Intensity 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 Emotion Intensity, 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 [$M_{max\text{/congruent}} = 1.598 \pm 0.058$ vs. $M_{\text{cutoff/congruent}} = 1.326 \pm 0.058$; $t(39.934) = 6.362$, $p < .001$, $d = 2.013$], and spatially incongruent conditions [$M_{max\text{/incongruent}} = 1.668 \pm 0.054$ vs. $M_{\text{cutoff/incongruent}} = 1.333 \pm 0.054$, $t(40.194) = 8.567$, $p < .001$, $d = 2.703$], but not for negative Average Emotion Intensity 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 $M_{min\text{/congruent}} = 1.367 \pm 0.050$, vs. $M_{\text{cutoff/congruent}} = 1.422 \pm 0.050$, $t(37.398) = 1.503$, $p = .141$, $d = 0.491$; $M_{min\text{/incongruent}} = 1.347 \pm 0.051$, vs. $M_{\text{cutoff/incongruent}} = 1.417 \pm 0.051$, $t(39.184) = 2.03$, $p = .049$, $d = 0.649$].

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 Emotion Intensity [$F(1, 112.98) = 38.599$, $p < .001$], with judgements' speeds increasing as the Average Emotion Intensity grew larger [$\beta = 0.0009 \pm 0.0001$, $t(123.5) = 5.17$, $p < .001$, d

= 0.93], from negative to positive [estimated speed increment due to Average Emotion Intensity = 0.093 ± 0.017, t(141.755) = 5.365, $p < .001$, d = 0.901].

As for complete-facial expressions 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], and the main effect was consistent with a *distance effect* in the domain of emotions, similar to that originally observed by Fantoni et al. (2019). In particular, the speed of judgements increased as the difference between the emotional faces grew larger both for the “choose the angriest” [$M_{\text{Target Emotional Intensity = 100}}$ = 1.496 ± 0.049 vs. $M_{\text{Target Emotional Intensity = 50}}$ = 1.430 ± 0.048, t(76.438) = 3.825, $p < .001$, d = 1.457], and for the “choose the happiest” [$M_{\text{Target Emotional Intensity = 100}}$ = 1.666 ± 0.061 vs. $M_{\text{Target Emotional Intensity = 50}}$ = 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 4E) revealed the exact same set of significant effects observed in Experiment 1 and in Fantoni et al. (2019): a reliable Spatial Congruency × Average Emotion Intensity 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 Emotion Intensity in Spatially Congruent condition [$M_{\text{Average Emotion Intensity = -50}}$ = 0.059 ± 0.038, vs. $M_{\text{Average Emotion Intensity = 50}}$ = 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 Fantoni et al., 2019) in Spatially Incongruent condition [$M_{\text{Average Emotion Intensity = -50}}$ = -0.068 ± 0.035, vs. $M_{\text{Average Emotion Intensity = 50}}$ = -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 %, as signalled by the point of intersection between the two *lme* estimated slopes for spatially congruent and incongruent pairs.

Finally, as in Experiment 1, we 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 Fantoni et al., 2019). We 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 average intensity of the pair, formalizing 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 Fantoni et al. (2019) 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]}.

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 percent 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 4A and 4B) vs. 2.120 ± 0.042 (Figure 3A and 3B) in Experiment 2 vs. Experiment 1, respectively.

Running a further *lme* analysis, we obtained strong evidence for the general conclusions on the close relationship between the two experiments revealing a shared magnitude representation for the comparison of emotions and numbers, despite their different motivational significance (consistent with AE1). We 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, $t(876.087) = 4.414$, $p < .001$, $d = 0.305$].

General discussion

We reported two experiments on the commonality of the general analog code of intensity, underlying the speed and accuracy of spatially distributed responses over spatially distributed numbers and emotion. According to a shared representation for the comparison of Analog digits and facial expressions, we 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. We indeed observed similar *funneling* 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. Notably, differently from the interpretation on isolated facial expressions and numbers experiments (Holmes & Lourenco, 2011; Pitt & Casasanto, 2017), such a shared magnitude representation did not produce any lateral 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. 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 *relative intensity* continuum is defined on opposite sides by a neutral midpoint providing a reference position for establishing extreme values for both emotional intensities (though perceptually complex stimuli, with rather high motivational significance), as well as for symbolic magnitudes (though perceptually simpler stimuli, with low motivational significance), studied in Experiment 2 and 1, respectively. Such a continuum is well established by the direct mapping between absolute and represented intensities relative to the cutoff of a series provided for by the direct Speed-Intensity Association (SIA) model, originally proposed by Fantoni et al.

(2019). Results of our two Experiments are fully consistent with such a direct remapping of emotion and digits quantities, 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).

According to Fantoni et al. (2019), remapping models an attentional capture phenomenon on the comparative judgement of facial expressions of emotions in the anger-to-neutral-to-happiness per cent in the morph continuum (namely the ESC effect). We coherently found that also in the anger-to-happiness per cent in the morph continuum of Experiment 2, the speeds of choice in our direct comparisons task 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. The interesting point is that such regularity occurred also in the case of direct comparison task 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 the general remapping of magnitudes (both motivationally significant and not) – operated through the linear combination of relative analog intensities modelled through the SIA model – may have affected comparative judgements performance in our direct comparison tasks.

These results constitute a first tentative to positively answer to our *research question*. They suggest that SIA can be generalized to different domains and predict 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 would 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.

These findings 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, Nearing, LeDoux, & Phelps, 2008; Fantoni et al., 2019); 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 occurrence of the emotional semantic congruity effect in Fantoni et al. (2019) – that we 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 et al., 2001; Öhman et al., 2001; Sabatinelli et al., 2005; Vuilleumier et al., 2003). Consistent with the present work, these studies show that responses speed up when the target face is emotional and slow down when the target face is neutral, as a by-product of emotional stimuli exerting a strong exogenous ('bottom-up') pull on attention. Emotional stimuli would capture 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).

However, the pattern of response speeds of Experiment 1 was homologous to that of Experiment 2, being similarly accounted for by the SIA remapping. Here we 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 associated to different emotions, based on 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, we 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 consistent with our previous results showing no reliable effects of the type of task (direct vs. indirect) on the general pattern of emotion comparison (Fantoni et al., 2019).

Thus, such a bridge might provide 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 we 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 & Flora, 1977; Banks et al., 1975; Banks et al., 1976; 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, Cantlon, Merritt, & Brannon, 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 by Fantoni et al. 2019 and implemented in the current study), rather than using the type of task ("choose fewer" vs. "choose more"), reveals a fully consistent RTs pattern with SC, but not a SNARC-like effect (and in particular a reversed SNARC in spatially incongruent pairs). In this recoding, we 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, we transformed RTs in response speeds and calculated the right-to-left speed deviation [i.e., 1000/($\text{Small|Large}_{\text{choose fewer, right}}$) - 1000/($\text{Small|Large}_{\text{choose more, left}}$)]. 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 ESC effect, originally found by Fantoni et al. (2019), 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 originally studied by Fantoni et al. (2019) the cutoff faces were all real neutral, in the current study we used morphed faces, leading to a reduced realism consistency. Following the McDorman 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 by Fantoni et al. (2019). 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 we 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 shared motor reactivity for emotional expressions and Arabic digits point to a common and general magnitude system for the representation of discrete objects or events populating our environment at relative intensities (Laurenco et al., 2016; Laurenco & Aulet, 2018). Although we focused only on numbers and facial expressions of emotions, our findings, together with the research by Fantoni et al. (2019), suggest that a general analog (SIA-based) representation of intensity may extend to any dimension 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.

Ethical standards

The present study was approved by the Research Ethics Committee of the University of Trieste in compliance with national legislation (Approval Number 84c/2017), the Ethical Code of the Italian Association of Psychology, and the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments.

Conflicts of Interest

The authors declare no conflict of interest.

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