Do spatial processes support transitive reasoning in depression and sad mood?

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Abstract

People in states of mild depression have difficulties in reasoning tasks that demand the flexible integration of piecemeal information into mental representations. Previous research found inferior performance levels in depressed participants compared to nondepressed controls when constructing mental models of linear orders (LOC task). The present research investigates whether depressed individuals show evidence for reduced functionality of spatial processes during LOC execution. We tested three groups of participants in an LOC task: Nondepressed controls, mildly depressed, and episodically sad controls (via mood manipulation). We found spatial processes to be involved in model construction for the control group, in a magnitude as previously reported for similar tasks. However, both depressed and sad groups showed evidence for the absence of spatial processes being part of their reasoning in this task. These results are discussed in the context of cognitive and neurophysiological theories about depressed participants’ performance impairments when it comes to reason spatially, reliably construct mental representations from piecemeal information and flexibly reason on the basis of them. We also relate the results in the episodically sad group within the context of parallel cognitive marker symptoms in sadness and mild depression.

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**Open Science Framework link** (data and R code for results): https://osf.io/ye79f/?view\_only=3f00aa6758da44fa9cc53cd6bac4f4cb

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Depression will remain, by 2020, the second most important cause of disability adjusted life years, and is predicted to be the second leading cause of world disability by 2030 in people aged between 15 and 44 years old. Overall, depression is projected to become the second biggest health challenge in the world after cancer (World Health Organization, 2019). Roughly two thirds of adults will experience at least one prolonged period of depressed mood at some point in their lives, severe enough to impair their daily activities (Murray & Lopez, 1996). Prolonged sadness (mildly depressed state) is correlated with onset of severe, clinical depression in later life and is often characterized by impairments in flexible, generative reasoning (Ellis & Ashbrook, 1988; Sedek & von Hecker, 2004; von Hecker & Sedek, 1999). Possibly sharing cognitive markers with clinical syndromes, periods of prolonged sadness are observed in the population as less severe, but frequently occurring instances on a continuum ranging from mild mood disturbance to severe clinical depression (Flett, Vredenburg, & Krames, 1997). A key cognitive marker of reasoning in mild depression (from now on: “depression” since we focus exclusively on mild states of depression) is a difficulty that depressed individuals experience when they construct *mental models*, that is, when they engage in on-line integration of piecemeal information into a common, comprehensive representation. Construction of a mental model amounts to first learn about, and represent, piecemeal information that is relevant to a given episodic context, for example, a social setting, an event, a geographic layout, or a logical problem. As across time, each bit of information comes in, it will be integrated into the mental model as it is being constructed so far, in an on-line fashion (see van Dijk, 1983; Zwaan & Radvansky, 1998). The construction of a mental model is a malleable, ongoing cognitive process that aims at an overall, comprehensive representation of the total set of relevant information, thereby facilitating reasoning and new conclusions to be derived from it (Johnson-Laird, 1996; Glenberg, 1997). Deficits in this type of reasoning are likely to lie at the heart of some cognitive problems found in those with depression, such as loss of creativity and inferior ability to solve problems in the social domain (Gotlib & Hammen, 1992; Lee, Hermens, Porter, & Redoblado-Hodge, 2012; Marx, Williams, & Claridge, 1992; von Hecker, Sedek, & McIntosh, 2000; von Hecker, Sedek, & Brzezicka, 2013).

**What mental processes may be involved in construction?**

One candidate as core process underlying mental model construction is spatial processing. Theories of mental modelling emphasise the representation of relations holding between the to-be-modelled entities in reality on the one hand, as achieved by establishing, during reasoning, spatial relations between the corresponding entities in mental space on the other hand (e.g., Huttenlocher, 1968; Zwaan & Radvansky, 1998; Kaup & Zwaan, 2003; Knauff, Mulack, Kassubek, Salih, & Greenlee, 2002; Knauff, 2013). No empirical test has so far been conducted to investigate whether depression or sad mood have any impact on the functioning of spatial processes in reasoning. The present research addresses this question, as such an impact could, in consequence, lie at the heart of more downstream problems with the construction of mental models, as explained above.

In our own previous research, the issue of spatial processing was not addressed. Rather, we had focused on a particular paradigm to investigate the construction of mental models in depressed states (Sedek & von Hecker, 2004), linear order construction (LOC). This paradigm is diagnostic of integrative processing, that is, the construcion of a mental model out of given piecemeal information. It does, however, not address spatial processing, as explained in the following. The LOC paradigm involves the integration of pairwise relational information via transitivity and has long been studied in cognitive psychology and cognitive developmental psychology (Piaget & Inhelder, 1974; Potts, 1972; Sternberg, 1980). In each trial of an LOC procedure participants study a number of pairs of relations, e.g., “A > B”, “B > C”, and “D> E”, with “A”...“E” standing for first names, and “>” standing for a transitive relation such as “taller”, “older”. An integrated mental model (Johnson-Laird, 1983) of such a set of pairs would be a linear order "A > B > C > D > E". Immediately after presentation of the three pairs, participants are tested on all possible pairs, that is, in the above example, AB, BC, CD (adjacent pairs, which had been learned), AC, BD (two-step relations), AD, BE (four-step relations), and AE (end-point relation). Participants are asked for verification of statements in either correct (e. g., “A > D”) or false format (e. g., “D > A”). Using the LOC paradigm, we found (Sedek & von Hecker, 2004, Experiment 1) that a group of nondepressed participants displayed a constant high level of accuracy across pair distances (adjacent – end point), suggesting that in this group, participants tended to retrieve their answers from an integrated mental model, as queries on inferred end point relations (maximal pair distance on the hypothetical order) were answered with no less accuracy than explicitly learned, adjacent ones (minimal pair distance). On the other hand, in the depressed group, accuracy decreased from minimal to maximal pair distance. Depressed individuals presumably did not spontaneously integrate the pairs during learning, but retrieved the pairs at the time of the query in order to make transitive inferences from single propositions at this later point in time1. Such a strategy, being more error-prone the more propositions have to be chained with each other, would then yield inferences to allow the generation of a response.

In the classical literature, opinions are divided as to the question whether the LOC design, although indicative of *integration*, is also diagnostic of *spatial processing*, and we argue it is not. The often-reported Symbolic Distance Effect (SDE) is an example. Many studies using LOC designs have shown that test queries about pairs that span wider distances on the hypothetical mental order model are generally responded to more quickly than pairs that span narrower distances. For example, participants showed faster correct responses to a query on the pair AD compared to a query on the pair AC, or to a query on AC compared to one on AB (Symbolic Distance Effect, SDE, De Soto, London, & Handel, 1965; Potts, 1974; K. H. Smith & Foos, 1975; Pohl & Schumacher, 1991). Regarding such findings, some researchers have leaned towards a spatial interpretation, arguing that a response can be read off from the activated spatial representation A > B > C > D with wider distances being easier discriminable than narrower distances (e.g., Holyoak & Patterson, 1981; Huttenlocher, 1968). On the other hand, this spatial interpretation, although plausible, is not the only one amenable to the SDE. The SDE has been equally well explained by assuming integration into an analogue model without any reference to spatial representation. For example, if the overall (neural) activation of each stimulus within A > B > C > D corresponds to the proportion of comparisons in which it dominates another, then after learning, the activation levels will represent the rank order with differences in activation representing the distances between stimuli (see Birnbaum & Jou, 1990; Schwarz & Stein, 1998; Leth-Steensen & Marley, 2000, for such types of models). Identically to the spatial interpretation, the prediction here, as well, is that that there should be more immediate and stronger response tendencies to queries on wider pairs than to queries on narrower pairs. As much as, therefore, the SDE can be seen as valid indicator for the *integration* of piecemeal information into a mental model (see Sedek & von Hecker, 2004), it is not, more specifically, indicative of this integration being based on *spatial processing*. The present research addresses this latter question as we use a modified paradigm, one that can be seen as validly indicating spatial processing.

**Anchoring as indicator for spatial support in order construction**

To answer the question more conclusively whether spatial processes in order construction are reduced in depressed states, we resort to a modified version of the LOC paradigm. The idea rests on the argument that evidence for the contribution of spatial processes in constructing a mental model might more convincingly consist in the demonstration of lateral asymmetries (von Hecker, Klauer, & Aßfalg, 2019). A wide range of data show lateral biases in linear ordering, that is, according to the learned reading/writing (R/W) habit. In Western populations, there is a rightward oriented representation of numbers with the origin placed on the left (Dehaene, Bossini, & Giraux, 1993; Gevers, Verguts, Reynvoet, Caessens, & Fias, 2006; Ito & Hatta, 2004), and the mental time line (Gevers, Reynvoet, & Fias, 2003; Gevers, Caessens, & Fias, 2005; Ouellet, Santiago, Funes, & Lupiánez, 2010). We call this “anchoring”. Experimentally, in the type of studies cited above anchoring effects are demonstrated, for example, by participants placing earlier events in cartoon sorting on the left side of later events, in Western populations (Tversky, Kugelmass, & Winter, 1991; for an overview see Suitner & Maass, 2016). That is, the more dominant element is placed closer to the hypothetical origin of the mentally constructed order than the less dominant element.

Suitner and Maass (2016) define the so-called “Spatial Agency Bias” as the tendency to imagine the trajectory of movement of an action or event that is perceived as “agentic” (i.e., strong, intense, initiative, vital, etc.) as proceeding, in Westerners, rightwards from a left origin (see also Chatterjee, 2001). They argue that the dimension of “agency” might be represented in an embodied way, implying a motion schema proceeding from left to right, as adapted from the learned reading/writing schema. The authors also report evidence that this bias reverses when studied amongst populations that live in a right-left reading/writing environment (e.g., Maass, Suitner, Favaretto, & Cignacchi, 2009; Maass & Russo, 2003; Maass, Suitner, & Nadhmi, 2014).

In the LOC paradigm as discussed above, anchoring effects are demonstrated in an analogous way, which provides the paradigm for the present research. We assume here, as well, that suitable evidence for the contribution of spatial processes in forming mental representations might consist in the demonstration of a lateral asymmetry. Participants who are used to read from left to right are predicted and found to be faster to respond and, perhaps, more accurate, when asked to indicate the dominant element in a pair from the linear order (e.g., the oldest, fastest etc., out of A B) when the dominant element appears on the left side, compared to the right side, within the presented pair (von Hecker, Klauer, Wolf, & Fazilat-Pour, 2016). In other words, processing is faster when the spatial orientation of the dominant element in the display is congruent, as compared to incongruent, with the side of the dominant element as represented in the hypothetically constructed mental model. These effects do not interact with the SDE, that is, the size of the anchoring effect does not differ as a function of pair distance on the hypothetical linear order (von Hecker, Klauer, & Sankaran, 2013). Hence, anchoring effects of the described sort can be seen as independent indicators of spatial processing.

Crucially, anchoring effects (ours and the ones cited further above) reverse when tested in populations with right-to-left reading/writing background (Fuhrman & Boroditsky, 2010; Suitner & Maass, 2016; Tversky et al., 1991; von Hecker et al., 2016), such that in the latter cases, the origin of the constructed order is anchored to the *right*. The semantics of the ordering in all cases, however, is presumably based on *primacy*, as derived either from dimensional magnitude (von Hecker et al., 2016) or from an action schema (Suitner & Maass, 2016). That is, whatever “comes first” has more primacy than what “comes later”. This is trivially evident for events or actions ordered along the mental time line, implying that what “happens first” is mentally placed at the origin. But action-based primacy is also evident for the number line when assuming that in the activity of counting, 1 comes prior to 2, and so on, such that 1 has more primacy and is placed closer to the origin than 2, and so on. In the case of abstract orderings (see von Hecker et al., 2016) the primacy argument rests on *metaphoric blending* as discussed in Casasanto (2009) who introduces the term with an example: “Linguistic expressions like ‘the prime example’ conflate primacy with goodness (i.e., this phrase can mean the first example, the best example, or both)” (Casasanto, 2009, p. 362). As we have argued in the same vein (von Hecker et al., 2016), dominance in magnitude, that is, the “oldest”, the “richest”, etc., is *blended* with primacy as derived from the learned R/W habit; such that, as the result of such a metaphorical blend, the highest level of dimensional magnitude is anchored at the R/W origin, with the order being subsequently constructed in R/W direction.

In the present research, which takes place in a population with right-to-left R/W background, we focus on a *right-anchoring effect*: Assuming participants construct a *spatial* mental model of a linear order, if they are used to read and write from right to left, they are predicted to be faster to respond and, perhaps, more accurately, when the dominant element of an ordered pair (e.g., the oldest, fastest etc.) appears on the *right* side, compared to the left side, as part of the order hierarchy (right-anchoring).

**The present hypothesis**

On this basis, and as the main hypothesis of the present paper, we predict that whilst in a nondepressed control group, right-anchoring should be evident when constructing a mental order model in a LOC-type experiment, in a depressed group this effect should be significantly reduced under the assumption that mental order construction is less reliant on spatial processes in the depressed, or that spatial processes are less effective in states of depression.

There are two reasons for this prediction. First, as described above, depressed individuals in an earlier experiment using a linear order construction paradigm (Sedek & von Hecker, 2004, Exp. 1 and 3) showed a pattern of accuracies that was more in accordance with an explanation based on propositional reasoning as opposed to integration of the learned piecemeal stimuli into a mental model. Whilst that study could not conclusively address the involvement of spatial processes, the present project does aim at providing such evidence with regards to degrees of spatial involvement being detectable in the response patterns of depressives and controls, via the anchoring assumption. Reduced spatial processing in the depressed is also principally in line with earlier research concluding that there be differences in processing strategies between depressed and nondepressed individuals (J. D. Smith, Tracy, & Murray, 1993; Hertel, 1997; Hertel & Hardin, 1990; Hertel & Rude, 1991; Kofta & Sedek, 1998; Sedek & Kofta, 1990).

A second reason for our main prediction is found in Hinton, Wise, Singh, & von Hecker (2015) who studied depressed and nondepressed individuals using an fMRI-adapted LOC paradigm (see above), using a chain of four ordered elements, that is, using learning pairs A>B, B>C, C>D. To make this task amenable for brain scanning, participants had to be trained up to a criterion in order to achieve reliable readings. As a result, depressed and nondepressed groups did perform at equal levels for accuracy and response latency. Crucially, depressed individuals showed higher levels of activation in parts of the parietal cortex, associated with their task-related performance level, as compared to the nondepressed group, when responding to test queries, immediately after the three individual relations had been learned. This outcome appears plausible assuming that the spatial mental model representing the rank order between the four people was less accessible or needed more activation in order to be retrieved and processed, in the depressed. In other words, depressed individuals would still have to activate parietal regions more than the nondepressed in order to arrive at the same level of performance; that is, those regions that are known to be involved in processing spatial aspects of mental models (Goel, 2007; Hinton, Dymond, Von Hecker, & Evans, 2010; Knauff, Mulack, Kassubek, Salih, & Greenlee, 2002). This interpretation is again in line with our general hypothesis (Sedek & von Hecker, 2004) which is that depressed individuals experience more difficulty than nondepressed when attempting to integrate a linear mental model from piecemeal stimuli, but now making the more specific assumption that such integration might be based on spatial processing.

**Depression versus episodic sadness**

The literature on cognitive symptoms in depression shows cognitive dysfunctions such as functional alterations in executive functions, inhibition and attention (Joormann, 2005; for overviews see Kofta & Sedek, 1998; von Hecker & Meiser, 2005; Williams, Watts, MacLeod, & Mathews, 1988; for a recent meta-analysis see Rock, Roiser, Riedel, & Blackwell, 2014). At the same time, studies on episodic (or, experimentally induced) mood states do not show a similarly pervasive pattern for normal sadness. Whereas biases towards negative content in sad participants have been reported for memory tasks (Gilboa-Schechtman, Revelle, & Gotlib, 2000; Bower & Forgas, 2001; Williams et al., 1988), results concerning other cognitive functions are mixed and often show null results in comparison between experimental sad and non-sad participants (e.g., Pérez, Rivera, Fuster, & Rodríguez, 1999; for an overview see Chepenik, Cornew, & Farah, 2007). On the other hand, episodic sadness may well share cognitive markers with states of depression (Flett et al., 1997). The unclear empirical situation may have methodological reasons. For example, the short-lived nature of experimentally induced mood states makes it difficult to study the effect of episodic sadness in more than one task at a time. At any rate, a second aim of the present research is to test the specificity of our hypothesis as pertaining to depression. Alternatively, experimentally induced sad mood may parallel the results in the depressed if the emotion of sadness is associated with reduced spatial processes in linear order construction; that is, if induced sad mood makes one less reliant on spatial processes, or that spatial processes are less effective in states of induced sadness. We therefore include a sample of experimentally induced sad participants with an open hypothesis: Either the LOC paradigm will reflect an underlying difference between normal (situationally induced or situationally limited) sad mood and a state of depression in terms of the right-anchoring effect, such that using materials with no sadness-related content in the linear order task, sad participants will show a significant anchoring effect, not different to the one expected for controls. Alternatively, an absence of right-anchoring in induced sadness will be indicative of a parallel significance of the cognitive marker “sad mood” in episodic sadness and in states of depression.

Method

The present study has obtained ethics approval from the Ethics committee of the Psychology Department of Shahid Bahonar University. As there is a possibility that perceptual factors during the learning phase may enhance or counteract the emergence of an anchoring effect (see von Hecker et al., 2016, Experiment 2) it was decided to present all learning pairs with the dominant element on the right side. These conditions would facilitate right-anchoring and as such would constitute a conservative test environment for the hypotheses of no such anchoring tendencies in the depressed group.

**Participants**

300 students from Shahid Bahonar University of Kerman (non-Psychology departments) completed the Farsi version of BDI-II (Ghassemzadeh, Mojtabai, Karamghadiri, & Ebrahimkhani, 2005). These students were unfamiliar with psychological experimentation. One-hundred and fourteen participants with scores between 0 and 10, or 14 and above (Dozois, Dobson, & Ahnberg, 1998), were classified as extreme groups of non-depressed and depressed respectively, and were invited to participate in the main study. At the beginning of the main study (7 to 21 days later), a second BDI-II was administered to assure the stability of the above classification. Fifteen participants who changed categories across the two mood assessments were dismissed. Participants who had stable scores within the range of 0 to 10 were randomly assigned to the sad mood induction group (31 participants: 19 females, mean age = 21) or to the control group (31 participants: 23 females, mean age = 22). Those with stable scores of 14 and above were assigned to the depressed group (36 participants: 21 females, mean age = 21). Participation in this study was voluntary and no course credits or payments were given on behalf of their participation.

**Materials**

*Linear order construction (LOC) task.*  Two difficulty levels of a five-term linear order task were used. Each difficulty level was presented twice for each participant, all four orders in a random sequence, to yield four experimental blocks. Four sets of 4-letter Farsi names (two female and two male) were used and randomly assigned to the four experimental blocks. The name sets were chosen from the Farsi name pools used in (von Hecker et al., 2016). Two Farsi adjectives, namely, smart (r1) and fast (r2), were used for comparisons and were counterbalanced with difficulty level. Thus, two versions of the linear order task were created such that male and female name sets were counterbalanced for the two adjectives and difficulty levels; in the first version adjective r1 was applied to a female name set at the easy level, as well as to a male name set at the difficult level; in the second version r1 was assigned to a male name set at the easy level, and to a female name set at the difficult level; with r2 assigned to all not mentioned combinations. Each experimental block had a learning stage and a test stage. In the learning stage, only adjacent pairs (on the hypothetical rank order) were presented as stimuli. For a designed rank order of A > B > C > D > E, the adjacent pairs were AB, BC, CD and DE, with the sequence CD-BC-AB-DE being presented at the easy level, and BC-DE-CD-AB at the difficult level. The difficulty level depended on the number of pairs that participants had to keep activated in memory, during processing, in order to rearrange the sequence appropriately (see K. H. Smith & Foos, 1975). In the first sequence, each subsequent pair could be directly connected with the precedent one. In the second sequence however, the first and second pair had to be stored in memory as unconnected and be kept activated as such until the third pair was encountered which allowed an integration into a chain “B-C-D-E-”, and so on. Each pair was presented as a sentence (e.g., “A is faster than B”) in the middle of the screen with font size 14. In each pair, the dominant element (person) was shown on the right, to perceptually support a right-anchoring bias. In the test stage, all ten possible pairs (combinations out of five persons) were presented in the format A [gap] B, in the middle of the screen and with a 160 mm wide gap (see Figure 1). Each pair appeared twice, one with format AB (dominant person left) and the other time with format BA (dominant person right). The question “Who is [r]er?” (with r replaced by either comparator r1 or r2) was presented 80 mm higher than the screen center. Participants had to indicate their answer by pressing “n” or “b” key on keyboard. Among the stimuli designed for the test stage, pairs AB, BC, CD, and DE represented instances for a 1-step distance and, respectively, pairs AC, BD, and CE for a 2-step distance, pairs AD, BE for a 3-step distance and the pair AE for the maximal 4-step distance.

**Procedure**

The main experimental session was initiated on the second appointment, directly after the participants had completed the Beck-II. First, participants who were assigned to the mood-induced group, were shown a clip of 38 sad pictures from the Geneva Affective Pictures Database [GAPED] (Dan-Glauser & Scherer, 2011) accompanied by sad music, for 3 minutes on a 14 inch screen. After that, the experimenter asked them to write down a sad event from their past in details on an A4 paper (Westermann, Spies, Stahl, & Hesse, 1996)2. The Positive and Negative Affect Scale (PANAS, Watson, Clark, & Tellegen, 1988) was completed by a pilot sample of eight participants before and after the mood manipulation. These pilot results using dependent t-test showed that participants who had undergone the mood manipulation were experiencing significantly more sadness after the manipulation than before (*p* < 0.05).

All participants were informed that the study was about mood and learning. The experiment consisted of four blocks, each block corresponding to a different set of names (two male, two female) and a different comparator (see Materials section above for the counterbalancing). The blocks (two with easy and two with difficult pair arrangements, see above) were presented in a random order. At the beginning of the main task (linear orders), participants were asked to study the name pairs at their own pace. During the learning stage of each block, participants were presented with a predetermined sequence of four name pairs (according to the condition: easy or difficult, see above), representing fictitious people standing in an ordered relation. All pair stimuli were phrased as sentences, for example, “Christine is taller than Katharina” (in the real study, Farsi names were used) in bold “B Koodak” font in the center of the screen. In order to clear participants’ short term memory from any recent material, an arbitrary math question was then asked in which participants had to write down the correct answer on a sheet of paper. In the immediately following test stage, participants were asked twice about each of the 10 possible relations between the five persons, one time with the more dominant person presented on the left and one time on the right side of the screen. This made for a total of 20 test pairs, presented in a random sequence. All participants were asked to respond as quickly and accurately as possible. The overall procedures involved four blocks of the main task (i.e., learning and test stages). To ensure that participants understood the instructions, they were asked to perform one full practice block, including learning stage and test stage before administration of the main task. Sessions were conducted in small groups of 1 or 2 participants in the lab, and lasted approximately 40 minutes (55 minutes for the sad mood group), including instructions and debriefing.

Results

The trimmed response times and accuracies were analyzed in three steps. First, all the data for the three groups were fitted linear mixed models (generalized linear mixed models for accuracies) with *participants* as random factor (for the details in selecting the appropriate random structure see Appendix A). The fixed effects were evaluated based on the selected random structure. Then we investigated the group-related effects (which were only seen in response times) by fitting linear mixed models with the same random structure to each experimental group separately.

**Response Times**

For correct responses, response times were trimmed in three steps. At first, response times below 200 milliseconds were removed (see Whelan, 2008), as being related to pressing keys unintentionally (twice instead of once), system failure, or, presumably, lack of interest in answering. 23 of such short-time responses were detected, 16 of them coming from one participant from the control group who was then removed from further analyses of both accuracy and response times. The remaining 7 short-time responses came from 5 different participants.

In the second step, average latencies of participants were trimmed according to Tukey’s criterion. Participants with average latencies higher (lower) than average latencies plus (minus) 3 times the interquartile range were excluded. Six participants were thus removed from further latency analysis3. In the third step, the data were trimmed according to the median absolute deviation criterion (MAD) based on removing outliers with values lower (higher) than the median minus (plus) 2.5 times of the median absolute deviation of individual distributions (see Leys, Ley, Klein, Bernard, & Licata, 2013).

The data were transformed to log scale and linear mixed models were fitted (Jaeger, 2008; Judd, Westfall, & Kenny, 2012). The main hypothesis for data analysis concerned the existence of a right-anchoring effect overall (main effect), or just in some of the groups under investigation (interaction). In addition, in order to confirm the overall results from the linear mixed models as parts of the argumentation relate to the *absence* of effects, we used a Bayesian approach. For each group, we compared the Bayes factor of the best model (in terms of Bayes factors) incorporating (or not) the factor side of the dominant element and its interactions4.

The final model for the pooled data had fixed effects for group (control vs. depressed vs. sad mood), pair distance (1-step to 4-step), block type (easy vs. difficult), side of the presentation of the dominant element (left-dominant vs. right dominant) and all their interactions. Results showed a significant effect of group, = 9.09; *p* = .01. Post-hoc analyses revealed that participants in the depressed group ( responded significantly slower than those in the sad mood group (). The mean response time for the control group () was not significantly different from either of the two other groups. We also found significant overall main effects for pair distance, = 141.35; *p* < .001, replicating the SDE and showing that responses became faster the wider the pair distance (for mean latencies broken down by group see Tables 1-3). In the overall analysis, side of dominant element was also significant, = 7.07; *p* < .01. Among all other effects, only the interaction between group and side of dominant element was significant, = 6.09; *p* = .05 (see Figure 2).

Analysing each group separately, the same fixed effect structure without the *group* effect and its interactions was used. Analysing the control group separately, the final model showed a significant main effect of pair distance, = 69.71; *p* < .001, showing that responses were faster at wider as compared to narrower distances between the elements in a pair on the hypothetical mental model, . Secondly, side of dominant element yielded a significant main effect, = 11.44; *p* < .001, Cohen’s *dz* , indicating that test pairs presenting the dominant element on the right were responded faster than test pairs presenting it on the left, No further significant effect was found. For the mean latencies in the three groups see Tables 1-3. The Bayes factor in favor of the model accounting for side of the dominant element and its interactions against the best model without the effect of dominant side and its interactions was 7.05, showing moderate evidence (Jeffreys, 1961) in favor of the presence of right-anchoring.

In the depressed group, the final model showed only one significant main effect of pair distance, = 32.88; *p* < .001, showing that responses got faster as the distance between queried pairs were wider, . Side of dominant element however did not yield a significant effect, = .08; *p* = .77, Cohen’s *dz* . The Bayes factor in favor of the model accounting for side of dominant element and its interactions against the best model without this effect and its interactions was .05, indicating strong evidence against the presence of an effect originating from the side of the dominant element (Jeffreys, 1961).

For the sad group, the final model showed significant main effects of distance between the queried pairs, = 46.65; *p* < .001, showing that responses were faster as the distance between queried pairs became wider, . No further significant effect was found. Notably, the effect of side of dominant element was not significant, = .82; *p* = .36, Cohen’s *dz* . The Bayes factor in favor of the model accounting for the effects of side of the dominant element plus its interactions against the best model without those effects was .08, reflecting strong evidence against side of dominant element having an effect (Jeffreys, 1961).

**Accuracies:**

The final model of the pooled data had fixed effects for group (control vs. depressed vs. sad mood), pair distance (1-step to 4-step), block type (easy vs. difficult), side of the presentation of the dominant element (left-dominant vs. right dominant) and all the two-way interactions. There was a significant main effect of block type, = 15.05; *p* < .001, showing that easy blocks yielded on average higher accuracy levels than difficult ones, . There was also a significant main effect of pair distance, replicating the SDE, = 35.46; *p* < .001, showing that responses got more accurate the wider the pair distance (for mean accuracies as broken down by groups see Tables 1-3). Side of dominant element was insignificant, as neither the main effect of *group* nor its interaction effectswere significant in the pooled accuracy model.

Analysing each group separately, the same fixed effect structure without the *group* effect and its interactions was used. Block type was significant in the depressed group, = 12.84; *p* < .001, and in the sad group, = 4.10; *p* < .05, , but not in the control group, *p* = .27, Side of dominant element was insignificant in each group. Pair distance yielded significant main effects, replicating the SDE, in the control group, = 10.57; *p* < .01, the depressed group, = 9.03; *p* = .03, and the sad group, = 13.50; *p* = .003. For mean accuracies in the three groups see Tables 1-3.

**Study times:**

To analyse study times in the learning stage, an ANOVA test was used to examine possible differences between the groups and interactions with difficulty levels. It significantly took more time to study difficult blocks than easy ones (F(1, 1242) = 17.08, *p* < .001). There were no significant differences between the three groups (*p* = .13). The interaction between group and difficulty was also non-significant (*p* = .69). The results remained the same even after removing outliers higher (lower) than mean plus (minus) 3 times the interquartile range. For the study times in three groups see Table 4.

**Post hoc power analysis**

In the series of experiments reported in von Hecker et al. (2019) we obtained medium-sized effects between Cohen’s *dz* = .40 and .48 for the anchoring effect, replicating earlier results with slightly smaller effects (*dz* around .31, von Hecker et al., 2016). Since the present methodology is close to the (2019) study we conducted a power analysis using *dz* = .48 as target effect size. We conceptualized the critical interaction as a main effect of a between-participants (group) factor with regards to the dependent variable “amount of right-anchoring”, using the GPower menu “ANOVA: Fixed effects, omnibus, one-way”, stipulating the used total *N* of 98 and an alpha-level of .05 (GPower 3.1.3., Faul, Erdfelder, Buchner, & Lang, 2009), yielding an achieved power of 1-*β* = .51.

Discussion

In terms of group main effects, the present data are consistent with extant literature. For response latencies, we found on average slower responding in the depressed group (as compared to the sad group) which is in line with many accounts of emotional disorders that have confirmed a general psychomotor and cognitive slowing in the depressed (see Hart & Kwentus, 1987; Van Hoof, Jogems-Kosterman, Sabbe, Zitman, & Hulstijn, W., 1998; Williams et al., 1997). However, such slowing, as is equally well documented for depression, often does not occur at the expense of task accuracy which is found to be at the same level as for nondepressed controls (Harvey et al., 2005; Wagner et al., 2006; Hinton et al., 2015). This was the case in the present study as well. Although, numerically still in line with the idea of general slowing in depression, the comparison between the depressed group and controls was not significant.

As a main result of the present study, depressed and sad participants demonstrated no right-anchoring in a linear order construction task (LOC), in contrast to a control group of participants who were neither depressed or sad and who did exhibit right-anchoring. These results were found using an experimental procedure that, if anything, would facilitate the emergence of right-anchoring because during the learning phase, the dominant name was always shown on the right side of the display. Presentational factors such as this one had been found likely to interact with the LOC task by providing directional influences (see von Hecker et al., 2016, Experiment 2). The result is also unlikely to be due to a general motivation loss in depression or sad mood, because if such a loss had been present, we should have seen shorter study times in any less motivated group, compared to the control group, during the learning stage, which was not the case.

In terms of internal validity, the achieved power of 1-*β* = .51 appears low. Generally, the situation of finding a significant effect with low power, given a particular effect size, is unproblematic because it shows that the observed effect is in fact larger than the effect size that the power analysis was based on (see Mayo & Morey, 2017).

This pattern of results supports our central hypothesis and gives rise to a number of conclusions. Our argument is two-fold (for the moment not distinguishing between mild depression and induced sadness). First, as a general assumption, we suggest that asymmetries such as the anchoring effect may be taken as valid indicators of the involvement of spatial processes in a given cognitive task. More specifically, in this part of the argument we assume that anchoring effects as observed in a LOC task are indicative of the contribution of spatial processes in the construction of a linear mental model of rank orders (see von Hecker et al., 2016, 2019). Secondly, we argue that the deficit in mental model construction (integration of piecemeal information) that has been observed in depressed individuals (Sedek & von Hecker, 2004) might be associated with individuals’ relying less on spatial processes, or, individuals’ deployment of spatial processes being less effective in states of depression or induced sadness. In turn, problems with mental model construction, as we believe, may have negative downstream consequences showing up as depression-related deficits in cognitive functioning, for example, the often-reported loss of creativity and inferior ability to solve problems in the social domain (Gotlib and Hammen, 1992; Lee et al., 2012; Marx et al., 1992; von Hecker et al., 2000, 2013).

The present findings support our central hypothesis in two ways. First, as argued above, the absence of right-anchoring in the depressed sample is in line with previous results (Sedek & von Hecker, 2004, Experiments 1 and 3) showing that depressed individuals’ accuracy patterns were more indicative of propositional reasoning than of mental model integration, but now assuming more specifically that mental model construction entails a *spatial component* (Kaup & Zwaan, 2003; Ragni & Knauff, 2013; Kosslyn, 1994; Tversky, 1993). The lack of right-anchoring in the depressed group gives support to the idea that the underuse, or unsuccessful use, of spatial processes in depressed states is connected with, or lies at the heart of, the impairment in depressed people when it comes to reliably construct mental representations from piecemeal information and flexibly reason on the basis of them (see also Brzezicka, 2013; Hertel, 1997; Hertel & Rude, 1991, Kofta & Sedek, 1998; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008; Sedek & Kofta, 1990; Smith et al., 1993; von Hecker & Sedek, 1999).

Secondly, the present, behavioural, results give support to some interpretations of neurophysiological data on mild depression. We found that depressed individuals did not show evidence for spatial asymmetry in the LOC paradigm which usually does yield such asymmetries in nondepressed individuals (von Hecker et al., 2016, and *in press*). Spatial processes in reasoning have been linked to brain structures in the parietal brain (Pinel, Dehaene, Riviere, & LeBihan, 2001; Diwadkar, Carpenter, & Just, 2000). The Inferior Parietal Lobule, for example, has been identified as important for spatial processing and behaviour in space, with recordings of single neurons in this area, as obtained from monkey models, responding in ways corresponding to spatial stimulation (Andersen, Essick, & Siegel, 1985). On the other hand, activations in the parietal brain in turn have also been linked to transitive reasoning as pertinent to the LOC task ((Acuna, Eliassen, Donoghue, & Sanes, 2002; Goel & Dolan, 2001; Dehaene, Piazza, Pinel, & Cohen, 2003). In this light it is significant that Hinton et al. (2015) found mildly depressed participants to exhibit greater activation (as compared to nondepressed controls) in their parietal cortices in both learning and testing stages of a LOC paradigm. The authors argued that this hyper-activation was presumably due to “a compensatory mechanism in order to reach the same behavioral performance as the non-depressed group, or evidence for a different reasoning strategy in the depressed group” (p. 6).

Furthermore, Brzezicka (2013) argues that in states of clinical and mild depression, dysfunctions in parietal brain areas, specifically, ineffective transmissions of information between prefrontal and parietal regions, are associated with cognitive impairments. Vasic, Walter, Sambataro and Wolf (2009) showed abnormalities within the Dorsolateral Prefrontal Cortex - Parietal network in participants with major depression (compared to controls) during working memory task completion, specifically, a decreased functional connectivity between inferior parietal and superior prefrontal and frontopolar regions in depressed patients when compared to control subjects. This may also mean that some parts of the cortex that are known to be crucially involved in spatial processing, predominantly parietal areas, are, in depressed individuals, less spontaneously involved, or would need more effort to be involved, in reasoning processes as compared to normal controls. Therefore, as we argue here, the absence of right-anchoring in the depressed group may be seen as a behavioural signature of an altered, or less efficient, use of spatial processes as implied by some of the neurophysiological literature for the depressed population, here in the context of executing an LOC task.

The depressed sample in Sedek and von Hecker (2004) showed a reversed symbolic distance effect (SDE) in accuracies, which was indicative of propositional reasoning as opposed to integration in terms of a linear mental model. In the present research, we find replications of the SDE in accuracies and latencies for all groups. It is crucial to realise, however, that the difficulty depressed people might have with integration can show in different ways. As mentioned above, Hinton et al. (2015) found equal accuracy levels as compared to controls in a LOC task, but these were associated with stronger BOLD responses in the parietal lobe, indicating that depressed had to activate their parietal regions more than the nondepressed in order to arrive at the same level of performance. They presumably managed to integrate the piecemeal information, but with more mental effort expended. This pattern therefore supports the assumption of a net integration deficit in depression, even in the presence of indistinguishable accuracy performance levels between depressed and nondepressed participants, if we assume a connection between BOLD activation and performance level. Note also that in the Hinton et al. (2015) study, participants had received extensive pre-training in the LOC task prior to be admitted to the scanner. Longer exposure to the crucial types of materials is likely to level accuracy performance and move it towards ceiling. In relation to this, we observe longer average self-paced study times in the present experiment (see Table 4) as compared to Sedek and von Hecker (2004, Figure 2, p. 243). One likely reason for this is the fact that the sample used here was one of university students at Shiraz who were not familiar with psychological experimentation at all, whereas in Sedek & von Hecker (2004) we used university student samples from a Psychology department who were likely to have gained more such experience. Thus, participants in the present samples might have applied comparatively more diligence in perusing and learning the materials in the first place, thereby leading to accuracy performance levels indistinguishable from the control group. As we may presume, the tendency towards similar accuracy performance levels between depressed and controls included the exhibition of an SDE even in the depressed group and analogous to the control group as we see here. This leads to the speculation that failure to exhibit an SDE in depressed groups might be associated with shorter times of exposure to the learning stimuli. Whilst we must leave this question unsolved, this is indeed only a sidetrack to the present research question because as explained above, the SDE by itself cannot be seen as a valid signature of the involvement of spatial processes in linear order construction (Leth-Steensen & Marley, 2000; von Hecker et al., 2016, 2019). Rather, our argument rests on the absence of *right-anchoring* in the depressed and the sad group, with significant anchoring effects more validly indicating the use of spatial processes in LOC tasks.

**Sadness versus depression**

In the present study, the sad group showed similar results to the depressed group, because neither in the sad group was any right-anchoring observed. There are a number of reasons why one should expect an influence of sad mood on cognition. First, some brain structures that play crucial roles in executive function, attention or perception, are influenced by mood, in particular as their activation tends to vary with sad mood (Chepenik et al., 2007). Second, with sadness being one hallmark of depression, the literature on cognition in depressed states documents a wide range of dysfunctions and changes, compared to nondepressed states (Gotlib & Hammen, 1992; Marx, Williams, & Claridge, 1992; von Hecker, Sedek, & McIntosh, 2000). On the other hand, sadness in healthy participants without depression has not been reported as uniquely associated with cognitive dysfunction (Chepenik, 2007). In contrast, episodic sadness has been associated with performance advantages, such as diligence, systematic as opposed to heuristic processing (Bodenhausen, Sheppard, & Kramer, 1994; Edwards & Weary, 1993, but see Bodenhausen, Gabriel, & Lineberger, 2000, for conflicting results), judgment accuracy (Bless, Bohner, Schwarz, & Strack, 1990), or artistic creativity (Akinola & Mendes, 2008). As Bower (1983) has argued early on, with more recent authors agreeing (e.g., Chepenik et al., 2007), there is ample evidence for cognitive symptoms in episodic sadness to be limited to mood-congruent memory biases, with little or no other effects otherwise (see also Williams et al., 1997). It appears therefore from the general picture that cognition might be relatively encapsulated from episodic sadness, but not so encapsulated from depression. In contrast, the present results, if confirmed in the future by ongoing research, raise the possibility that the support of abstract reasoning by spatial processes might be an exception to this. Linear order construction, as realised here within the LOC paradigm, appears to be less supported by spatial processes in depressed *and* in episodically sad participants likewise, compared to normal (i.e., nondepressed and non-sad) controls.

**Conclusion**

We argue that right-anchoring (in populations with right-to-left R/W background) is the signature of the involvement of spatial processes during the construction of a mental model about linear rank orders. We propose that the representation of such orders is laid out in mental space from the maximum (right) onwards to the left (for reversal of this direction in populations with left-to-right R/W background see von Hecker et al., 2016). We show that in a depressed state, as well as in an episodically induced state of sad mood, linear order construction is less reliant on spatial processes since for these two groups in our study, we do not find the typical anchoring phenomenon of quicker responding to stimuli displaying two elements of the learned order in a spatial orientation on the screen that matches the hypothetical orientation in mental space, as compared to stimuli with an orientation mismatch. The absence of this phenomenon, as far as the present results go, is not linked to a decline in accuracy; it rather reflects an alternative route to performance levels equal to normal controls who do positively show the phenomenon.

Without answering it conclusively, the present research links with the long-standing question to what extent cognitive symptoms of depressed states are connected with the disorder’s hallmark, sad mood (see Chepenik, 2007). The present behavioural data should be followed up by neurophysiological data. Future research, including imaging paradigms that can help address brain activation patterns, will have to show to what extent sad mood *per se* is linked to the known alterations of brain function in depressed states, or indeed to some of the more downstream cognitive problems as seen in mild and clinical states of depression.

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Footnotes

1.

Lack of integrating incoming piecemeal information may also lie at the root of the often documented deficits of depressed individuals in creative thinking; the argument being that in many cases, incoming propositions, rather than being integrated with each other, will serve as associative kernels for negative, ruminative thoughts (MacCabe et al., 2018; Miller, Perich, & Meade, 2019; Slaby, 1992).

2.

The sad group was exposed to a mood manipulation whereas the other two groups were not, which needs justification. A seemingly straightforward alternative would have been to expose both depressed and nondepressed control participants to a neutral mood induction. In the depressed group, however, this could have possibly interfered with their preexisting mood, and so would have likely influenced the comparison between control and depressed groups, which concerned our first and foremost research question in this study. For the same reason (comparability between control and depressed) we also decided against the second alternative, that is, exposing the nondepressed control group to a neutral mood manipulation but not the depressed group. In the light of these considerations, the chosen alternative, i.e., exposing the sad group to a mood manipulation but not the remaining two groups, appeared least problematic.

3.

One of the removed participants was from control group, one from depressed group and 4 from sad mood group. The actual N’s available for the subsequent steps of data analysis were therefore N(control) = 30; N(depressed) = 35; N(sad) = 27.

4.

We measured the Bayes factor for all available models (with 3 predictors and their interaction: 18 models) compared to an intercept only model. Then, the models with highest Bayes factors which contained side of the dominant element and without that effect were selected. The Bayes factors reported in the rest of the article are the ones in favor of the best model *with* the side of the dominant element effect against the model *without* it, in order to assess the significance of the effects connected with Side of dominant element, *per se*.

Appendix A.

Modeling effects:

We used linear mixed models for the logarithm of response times and generalized linear mixed model for accuracies. To find the appropriate random effect structure, three steps were done. In the first step, we fitted three models for each data type (response times and accuracies for pooled data of all experimental groups). These models had indexes from 1 to 3 plus a minimal model with *min* index. All models had the same fixed effect structure which was *group*, distance between the queried pairs (*distance*)*,* side of presentation of dominant element (*DomSide*), difficulty of the block (*BlockType*), and their interactions[[1]](#footnote-1). All models had a random intercept for participant (1 | *pno*). The minimal models had only this random intercept; models 1 to 3 had random slope for *BlockType* as a function of *pno*, *distance* as a function of *pno* and *DomSide* as a function of *pno*, respectively. In the second step, models 1 to 3 were compared with corresponding minimal model using difference statistics, . If there was a significant difference between the model and corresponding minimal model, the random slope for that model retained for the final model. In the third step, the final models were run to evaluate fixed effect structure (see: Jaeger, 2008). If there were any significant group-related effect, we ran the model for each experimental group with the same fixed (without *group* and its interactions, though) and random structure (of the final model), separately. We used R statistics programming language (R Core Team, 2013), using packages *lme4* (Bates et al., 2015) and *car* (Fox et al., 2007) to do the analysis.

Response times:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Model** | ***df*** | **AIC** | **BIC** | **Loglik** | **Deviance** | **∆χ2** | **∆*df*** | ***p*** |
| **tmin** | 50 | 6427.1 | 6758.9 | -3163.6 | 6327.1 |  |  |  |
| **t1** | 52 | 6401.4 | 6746.5 | -3148.7 | 6297.4 | 29.7016 | 2 | 3.551e-07 \*\*\* |
| **t3** | 52 | 6428.8 | 6773.8 | -3162.4 | 6324.8 | 2.3245 | 2 | 0.3128 |
| **t2** | 59 | 6438.1 | 6829.5 | -3160.0 | 6320.1 | 7.063 | 9 | 0.6306 |

tfinal had random slopes for *BlockType* as a function of *pno*.

Accuracies:

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Model** | ***df*** | **AIC** | **BIC** | **Loglik** | **Deviance** | **∆χ2** | **∆*df*** | ***p*** |
| **amin** | 26 | 4697.0 | 4877.5 | -2322.5 | 4645.0 |  |  |  |
| **a1** | 28 | 4662.3 | 4856.7 | -2322.5 | 4606.3 | 38.661 | 2 | 4.026e-09 \*\*\* |
| **a3** | 28 | 4701 | 4895.4 | -2322.5 | 4645 | 0.0162 | 2 | 0.9919 |
| **a2** | 35 | 4673.3 | 4916.3 | -2301.7 | 4603.3 | 7.063 | 9 | 3.811e-06 \*\*\* |

tfinal had random slopes for *BlockType* and *distance* as a function of *pno*.

Figure 1.

The stimulus presentation in Learning, Math and Test phase (examples). Translation to English from Farsi: Learning phase: “A is taller than B”. Math phase: “What is two times 15 minus 7?”. Test phase: “Which one is taller? A B”. A and B stand for Farsi first names, as were printed on the screen displays.

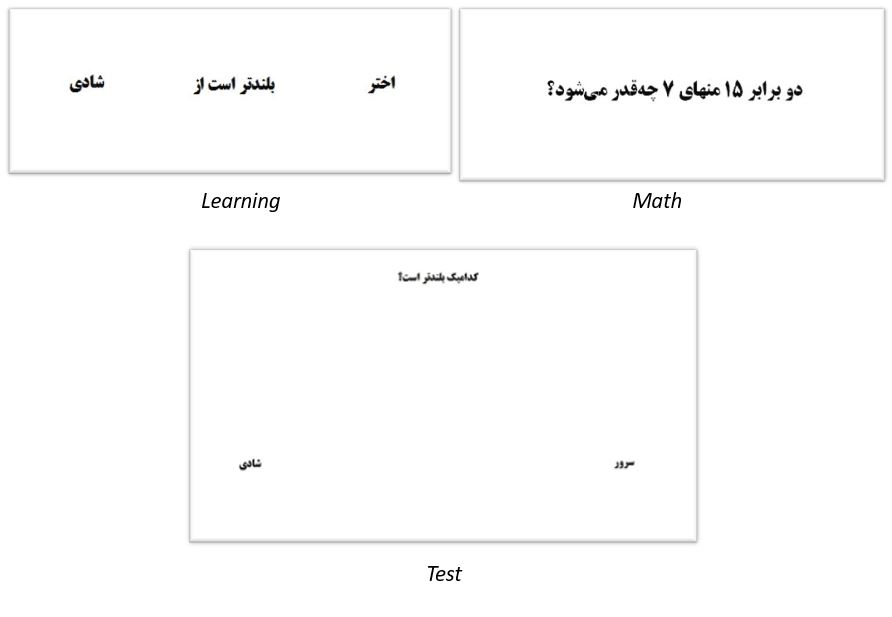
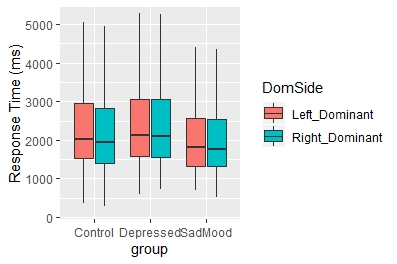


Figure 2.

Response times (ms) as a function of side of the presentation of the dominant element and group



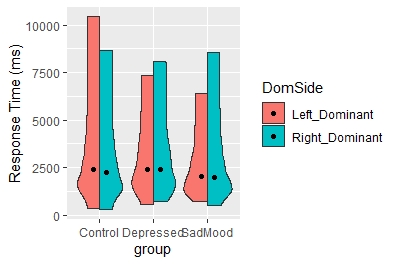


Table 1.

Response times (ms) and accuracies as a function of side of the presentation of the dominant element and pair distance in the control group.

Table 2.

Response times (ms) and accuracies as a function of side of the presentation of the dominant element and pair distance in the depressed group.

Table 3.

Response times (ms) and accuracies as a function of side of the presentation of the dominant element and pair distance in the sad group.

Table 4.

Average study times (ms) per relation pair in the learning stage, as a function of group and difficulty.

Table 1.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Control | Dominant | Pair distance | | | | | | |
| group | person | 1-step | | 2-step | | 3-step | | 4-step | | |
|  |  |  |  |  |  |  |  |  | |  |
| Response | left | 2591 | (1274) | 2454 | (1166) | 2331 | (1455) | 1827 | | (1026) |
| time | right | 2391 | (1142) | 2267 | (1166) | 2098 | (1151) | 2021 | | (1290) |
|  |  |  |  |  |  |  |  |  | |  |
|  |  |  |  |  |  |  |  |  | |  |
| Accuracy | left | .835 | (.372) | .864 | (.343) | .908 | (.289) | .883 | | (.322) |
|  | right | .867 | (.340) | .875 | (.332) | .896 | (.306) | .924 | | (.266) |
|  |  |  |  |  |  |  |  |  | |  |

Table 2.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Depressed | Dominant | Pair distance | | | | | | |
| group | person | 1-step | | 2-step | | 3-step | | 4-step | | |
|  |  |  |  |  |  |  |  |  | |  |
| Response | left | 2508 | (1140) | 2532 | (1218) | 2299 | (1113) | 2112 | | (1177) |
| time | right | 2520 | (1209) | 2444 | (1140) | 2292 | (1161) | 2349 | | (1314) |
|  |  |  |  |  |  |  |  |  | |  |
|  |  |  |  |  |  |  |  |  | |  |
| Accuracy | left | .866 | (.341) | .867 | (.340) | .897 | (.304) | .908 | | (.290) |
|  | right | .860 | (.348) | .889 | (.315) | .887 | (.318) | .900 | | (.301) |
|  |  |  |  |  |  |  |  |  | |  |

Table 3.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sad Mood | Dominant | Pair distance | | | | | | |
| group | person | 1-step | | 2-step | | 3-step | | 4-step | | |
|  |  |  |  |  |  |  |  |  | |  |
| Response | left | 2146 | (941) | 2074 | (935) | 1983 | (985) | 1662 | | (719) |
| time | right | 2146 | (996) | 2012 | (998) | 1924 | (869) | 1778 | | (877) |
|  |  |  |  |  |  |  |  |  | |  |
|  |  |  |  |  |  |  |  |  | |  |
| Accuracy | left | .854 | (.353) | .880 | (.326) | .877 | (.330) | .918 | | (.275) |
|  | right | .857 | (.351) | .879 | (.326) | .894 | (.309) | .902 | | (.299) |
|  |  |  |  |  |  |  |  |  | |  |

Table 4.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Difficult | | Easy | |
| Control group | 12082 | (10068) | 10252 | (7984) |
| Depressed group | 13597 | (11447) | 11559 | (9531) |
| Sad Mood group | 13648 | (11280) | 10689 | (7465) |

1. For response times, we used all the interactions up to the four-way. However, for accuracies only the two-way interactions were used, so that the models could be run in reasonable amount of time. [↑](#footnote-ref-1)