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Negation as conflict: Conflict adaptation following negating vertical spatial words

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ABSTRACT

In this study, we investigated whether the processing of negated directional terms such as “not up” or “not down” poses a conflict for participants and results in similar processing adjustments as non-linguistic conflicts do (Dudschig & Kaup, 2019). In each trial, participants read one of the following four phrases “now up”, “not up”, “now down” or “not down” and responded with a button press on a response key mounted in the upper versus lower vertical space. Behavioral data indicated that processing negated phrases leads to considerable processing difficulties for participants even after extensive practice. Interestingly, in line with standard conflict adaptation effects reported in the Simon, the Flanker and the Stroop task, negation processing was facilitated when preceded by another high conflict trial (i.e. a negated trial) as compared to a low conflict trial (i.e. an affirmative phrase). In addition, electrophysiological data showed that in negated trials first the to-be-negated information was activated (i.e., up in the case of “not up”) and only in a second step, the outcome of the negation process was represented (i.e. down). In line with behavioral data, electrophysiological data was modified by trial sequence, suggesting negation triggering standard conflict adaptation patterns. Taken together, conflict-related processing adjustments can be also observed if the conflict is triggered by linguistic negation of vertical directional words. Implications of these findings are discussed.

1. Introduction

Negation has always fascinated researchers across various disciplines ranging from philosophers, logicians, mathematicians, linguists to psychologists and even animal cognition researchers. Whereby humans can interpret and express negation up to its highest levels such as logical denial, non-human species only seem able to acquire very basic forms of non-linguistic negation, such as rejection or refusal. Children start early on expressing negation behaviorally using rejection and refusal and only later acquire more sophisticated types of negation, probably developing based on basic negation forms (Beaupoil-Hourdel, Morgenstern & Boutet, 2016). From an evolutionary perspective, such findings are specifically interesting, as they point to the possibility that advanced, logical negation expression and comprehension might have developed from early behavioral expressions of denial and refusal. Accordingly, such findings point to a continuity between linguistic and non-linguistic cognition, suggesting that higher-level linguistic processes are potentially based on mechanisms that already play a role for more basic, non-linguistic cognitive processes. Indeed, recent approaches in psychology have shown that negation processing might share mechanisms that are typically involved in action control (Beltrán, Morera, García-Marco, & De Vega, 2019; de Vega et al., 2016; Dudschig & Kaup, 2019; Wirth, Kunde, & Pfister, 2019). Specifically, on the one side, it was shown that sentential negation processing might share neurophysiological mechanisms with action control, such as inhibitory mechanisms (de Vega et al., 2016). On the other side, it was shown that negation processing results in similar information processing adjustments as other types of non-linguistic information processing difficulties (Dudschig & Kaup, 2019), suggesting that negation processing indeed might fall back or recruit mechanisms typically regarded as non-linguistic in nature.

In our previous study mentioned above, we investigated in how far negation processing can be compared to more basic – typically non-linguistic - information processing difficulties, such as incongruent trials in standard conflict tasks (see Botvinick, Braver, Barch, Carter & Cohen, 2001). Such incongruent trials are typically described as high-conflict trials, as a relevant and an irrelevant stimulus dimension compete for selection (e.g., incongruent Flanker trial: ≪ > ≪ where the central and the surrounding stimuli transfer opposing information). Interestingly higher-level negation typically also involves two opposing representations: On the one side, the to-be-negated information (i.e. door closed – for the phrase “the door is not closed”) and on the other

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side the actual information (i.e. door open), that is the outcome following the negation integration. Thus, already on the surface, negation shares defining features with non-linguistic stimuli known to lead to processing difficulties. Our recent study showed that negation implementation recruits mechanisms well known from other types of information processing conflicts (Dudschig & Kaup, 2019). Specifically, negation was applied to the horizontal dimension with the stimuli "not left", "now left", "not right", and "now right" whereby participants had to respond according to phrase meaning using left and right hand-key presses. Participants were substantially slower in responding to negated than to affirmative trials, and this slow-down even persited with extensive preparatory time (Dudschig & Kaup, 2020). Despite negation seemingly being a huge processing challenge for the cognitive system, the results also showed that there are situations where negation is easier to process. Specifically, negation is processed faster if preceded by another negation trial, suggesting that short-term adaptations in the cognitive system determine how we deal with negation (see Botvinick et al., 2001). Botvinick et al. proposed in the *conflict-monitoring model* that experiencing conflict during information processing results in an up-regulation of cognitive control and therefore easing subsequent conflict processing. Interestingly, the findings reported for negation processing were fully in line with studies investigating how humans and non-human primates deal with other types of processing conflicts as typically reported within the Flanker, the Simon or the Stroop literature (see Botvinick et al., 2001). To our knowledge, this was the first demonstration that information processing difficulties introduced via negation result in similar processing adjustments as typically reported for non-linguistic conflict situations.

In addition, this study showed that despite extensive practice participants often seem to fail in merging the meaning of the negation operator and the to-be-negated directional word (Deutsch, Gawronski, & Strack, 2006; Dudschig & Kaup, 2019). Even towards the end of the experiments, there were remarkable response slow-downs in the negation condition. Electrophysiological data showed that in negated trials, first the to-be-negated information was activated (e.g., left in the case of "not left") and only in a second step, the outcome of the negation process was represented (i.e. right) (Dudschig & Kaup, 2019). Many prominent models of negation comprehension and integration would suggest the opposite, that is that a negated phrase – especially in binary cases – is directly translated into its counterpart, without any additional processing step required. For example, the fusion model of negation would suggest that negation can be directly integrated and would result in the correct representation of the meaning (Horn, 1989; for a review see Mayo, Schul, & Burnstein, 2004). However, our previous results showed that negation effects persisted across the duration of the experiments. This is specifically remarkable, as it shows that comprehenders take into account the to-be-negated information even after extensive practice, and that negation cannot be automatically integrated (see also Deutsch et al., 2006; Dudschig, Mackenzie, Leuthold, & Kaup, 2018).

The findings above, when taken together, are particularly interesting for two reasons. First, prominent models of negation comprehension would not suggest that negation in binary cases leads to such long-lasting effortful integration processes that can only be overcome by high cognitive effort. Second, these contrasting models of negation processing – for example, the fusion model (Horn, 1989) or the schema-plus-tag model (Clark & Chase, 1972) of negation comprehension (for a review see Mayo et al., 2004) – would typically also not predict any dynamic changes in the way negation is dealt with depending on trial history. Thus, the reported influence of the current cognitive state in the way negation is handled is unique. Given the novelty of these findings, it needs to be questioned whether these might be a special case, potentially due to the use of the horizontal linguistic dimension (Dudschig & Kaup, 2019). Indeed, within the literature, there are various reasons why the horizontal dimension is processed differently from other spatial dimensions (e.g., vertical, front-back). First, the horizontal dimension is harder to discriminate, potentially due to our body symmetry along this dimension (Maki, 1979; Maki, Maki & Marsh, 1977; Sholl & Egeth, 1981). Second, previous studies have shown that some effects – for example the Simon effect – differentiate largely with regard to whether it occurs in the horizontal or vertical dimension (Vallesi et al., 2005). In the following paragraphs we will introduce these processing differences in more detail, first the general difference between the horizontal dimension and other spatial dimensions and second the role of dimension within the Simon task.

To date, there is converging evidence that adult humans have inferior discrimination performance in the horizontal spatial dimension compared to the vertical dimension when directional words (*left* vs. *right* or *up* vs. *down*) are involved (Maki, 1979; Maki, Maki & Marsh, 1977; Sholl & Egeth, 1981). For children, the easier processing of the vertical compared to the horizontal dimension seems to hold even in tasks that do not involve verbal coding (e.g., Wohlwill & Wiener, 1964) and even animals, for example, cats and octopuses show this performance benefit for the vertical dimension (e.g., Sutherland, 1960; Warren, 1969). Research in visual perception on symmetry processing also suggests a disadvantage of processing horizontal symmetry over vertical symmetry (e.g., Wenderoth, 1994; Rossi-Arnaud, Pieroni, Spataro, & Baddeley, 2012), with the development of symmetry discrimination following the same trajectory (Bornstein & Stiles-Davis, 1984). Studies from comprehension of short narratives have also shown that the horizontal left–right axis is the most difficult axis to subsequently access, followed by the front-back axis and the easiest to process vertical axis (Franklin & Tversky, 1990). Additionally, recent research has suggested that the vertical axis is dominant over the horizontal axis with regard to grounding abstract concepts, such as valence (Damjanovic & Santiago, 2016). In summary, when comparing the two – or even three - major dimensional axes we humans live by, the horizontal, the vertical and the front-back axis, the horizontal dimension is particularly difficult to process.

The second reason for assuming that previous findings relating to the processing of negated dimensional terms might be specific to the horizontal axis are studies showing rather large processing differences between the vertical and horizontal Simon effect (Simon & Rudell, 1967; Stürmer, Leuthold, Soetens, Schröter, & Sommer, 2002; Többel, Hübner, & Stürmer, 2014; Vallesi, Mapelli, Schiff, Amodio, & Umilta, 2005; for a review see: Proctor, Miles, & Baroni, 2011). These findings are of particular relevance for the current study as they follow the same rational. In the visual Simon task, participants respond to a feature (e.g., color) of a stimulus by pressing a left or a right response key. The stimulus is either displayed on the left or right side of the screen, and the results typically show that participants' responses are strongly influenced by the irrelevant task-dimension (i.e., stimulus location). Specifically, responses are slower if the presentation side of the stimulus is incongruent with the response side (e.g., right side stimulus presentation that requires a left response). The Simon effect is typically explained by a dual-route model (e.g., De Jong, Liang, & Lauber, 1994; Kornblum, Hasbroucq & Osman, 1990) suggesting that the unconditional route results in automatic response activation on the side the stimulus is presented and the second conditional route results in response activation according to task instruction. However, follow-up studies suggested that the automatic response activation seems to differ between the vertical and the horizontal Simon task setup, whereby only in the horizontal setup automatic response activation could be observed (e.g., Vallesi et al., 2005). Most interestingly, Vallesi et al. used an identical paradigm as in our previous study investigating negation comprehension and showed that only for the horizontal dimension incongruent trials activate the incorrect motor cortex. Therefore, it seems even more important to question whether – also for higher-level operations such as negation - there exists such a processing specificity for the horizontal dimension. Maybe the observed difficulty to integrate the negation with the dimensional term only applies for rather hard to differentiate horizontal dimensions, whereas other dimensions do not show such difficulties.

The question whether negation works differently depending on the to-be-negated information has previously only been applied to valence words. Here, it has been shown that active emotion down-regulation can be triggered by a negated verbal cue (e.g., "no fear" followed by a face expression fear) but that this does not apply to positive emotions (e.g., Herbert, Deutsch, Sütterlin, Kübler, & Pauli, 2011; Herbert, Deutsch, Platte, & Pauli, 2012). In these studies, negation application had a differential influence on the endpoints of the same dimension (i.e., valence). However, these studies cannot answer the question whether negation application is easier if the underlying dimension is processed more automatically. In the current study, we therefore addressed two research questions: (1) Does negation also result in activation of the to-be-negated information if applied to the vertical dimension? (2) Does this type of negation show similar dynamic processing adjustments as reported in non-linguistic conflict tasks?

In order to address the first question we will use electrophysiological measurements – specifically the lateralized readiness potential (LRP; Coles, 1989). This allows us to investigate whether using the vertical dimension triggers automatic activation of the to-be-inhibited response (e.g., up-response becomes activated following "not up"). The LRP can be used to measure online activation of the motor cortex (see method section for details on LRP calculation). Specifically, for a trial involving a right-hand response, the activation over the left motor cortex should be more pronounced as right-hand responses are controlled via the left motor cortex. In the Simon task, such LRP activations for the wrong response in incompatible trials (i.e. motor cortex activation triggered by the irrelevant stimulus location and not by the relevant stimulus color) could only be observed if the stimuli and responses were aligned in the horizontal dimension, suggesting that only horizontal stimuli result in automatic activation of the irrelevant response (e.g., Vallesi et al., 2005). If also linguistic terms show processing specificity of the horizontal dimension, we would not expect to find incorrect LRP activation. In contrast, if negation rather generally takes place in a two-step fashion – with first the to-be-negated information being activated – we would expect to find incorrect LRP activation also when applying negation to the vertical axis. In order to address the second research question, whether negation integration indeed changes dynamically depending on the current cognitive state, we predict that for the vertical axis there should be observable influences of trial sequence on the way negation is dealt with. Specifically, negation should be easier to process if preceded by another negation trial. In contrast, if previous findings are merely due to the specificity of the way the horizontal axis is processed, no such conflict adaptation effects should be observed when applying negation to vertical spatial terms.

2. Method

2.1. Participants

Thirty-four German native speaking, right-handed participants were tested in this experiment (M_{age} = 23.09, SD_{age} = 3.23, 28 females). One participant had to be excluded from the subsequent analysis due to a removal of a large number of trials (> 50%) following EEG artifact rejection.

2.2. Stimuli & apparatus

The four German phrases "nicht oben" (not up), "jetzt oben" (now up), "nicht unten" (not down) and "jetzt unten" (now down) were the stimuli used in this experiment. Stimuli were presented on a 19-inch CRT monitor at 100 Hz in black on a light grey background with a size of 0.8 cm × 2.4 cm. Viewing distance was approximately 80 cm to the screen. Participants responded with their left and right hand using an upper or lower external key (connected via a USB DAQ device, approx. key distance 30 cm) fixated on a vertically mounted platform (see Fig. 1).

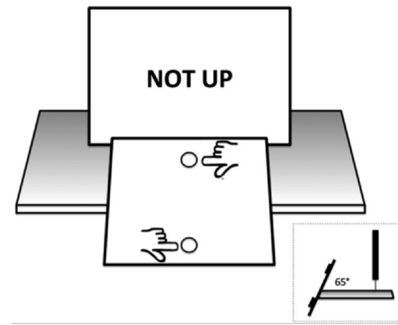

Fig. 1. Experimental setup from the participants' view and the sideview.

2.3. Procedure

The experiment was programmed in Matlab R2015a with the Psychtoolbox extensions (Psychtoolbox 3.0.12; Kleiner, Brainard, Pelli, Ingling, Murray, & Broussard, 2007). Each trial started with a central fixation cross (500 ms, 0.5 cm × 0.5 cm) followed by one of the four phrases displayed on the screen until response (max. 2000 ms). The experiment consisted of 10 blocks, with each block consisting of 128 randomized trials. The experiment started with eight practice trials in a short practice block. Participants rested their response hands on the keys and had to respond according to phrase meaning (e.g., "not up" respond by down-keypress; "now up" respond by up-keypress). The assignment of response hands to the response keys was counterbalanced between participants.

2.4. EEG recording and analysis

EEG was recorded from 70 electrodes at 512 Hz using BioSemi. For the ERP analysis MATLAB toolboxes (EEGLAB: Delorme & Makeig, 2004; FieldTrip: Oostenveld et al., 2011) and custom scripts (for details see: Dudschig, Mackenzie, Maienborn, Kaup, & Leuthold, 2019; Dudschig, Mackenzie, Strozyk, Kaup, & Leuthold, 2016; Dudschig, Maienborn, & Kaup, 2016a, 2016b) were used. The 3.5 s analysis epoch for the LRP started 1000 ms prior to word onset. Off-line an average reference and a high-pass filter (Butterworth IIR: 0.1 Hz, 12 dB/oct) was applied. Subsequently, artifacts were removed and EEG data were corrected. First, uncorrectable epochs were removed (extreme values in single electrodes: larger ± 1000 μV; values exceeding ± 75 μV in multiple electrodes unrelated to prototypical eye movement). Secondly, z-scored variance measures were calculated, and noisy EEG electrodes (z-score > ± 3) were removed if uncorrelated to EOG activity. Thirdly, a spatial independent components analysis (ICA) was performed. ICA components representing ocular activity (blinks / horizontal eye movements) were identified via correlation with hEOG and vEOG activity. Fourth, previously removed noisy channels were interpolated using the average EEG activity of adjacent uncontaminated channels (distance: 4 cm, ~ 3–4 neighbors per electrode). Across the 33 participants remaining in the reported analyses, approximately 84% of trials in total remained following the artifact rejection and correction procedure [range 61–96%]. The correction procedure resulted in approximately 1.7 electrodes being interpolated per participant [range 0–8] with an average of approximately 3.4 ICA components removed per participant [range 2–7]. An ANOVA on the percentage of trials remaining did reveal a significant main effect of current type, with fewer trials rejected when the current trial was affirmative compared to negative (86 vs. 82% remaining, respectively), $F(1, 32) = 36.97, p < .001$. This effect was modulated by previous type, $F(1, 32) = 52.45, p < .001$. Descriptively, the number of trials remaining in the conditions of interest are as follows: affirmative/

affirmative (89% remaining), negated/affirmative (83% remaining), affirmative/negated (79% remaining) and negated/negated (85% remaining).

The LRP (Coles, 1989) is a standard temporal marker for the investigation of timing processes and the localization of reaction time effects in pre-response selection (S-LRP) and post-response-selection (LRP-R) stages. The LRP can also indicate whether the incorrect response is activated at any point during between encountering the input stimulus and performing the response. The LRP calculation is performed using centrolateral electrode sides as follows: (1) Symmetric activity is removed via subtracting the ipsilateral activity recorded over the side of the correct response hand from the activity over the contralateral motor cortex – separately for left and right hand responses. (2) The LRP results from averaging these difference potentials across left and right hand responses. As motor responses are controlled via the contralateral motor cortex (i.e. right / left hand responses are controlled by the left / right motor cortex), negative LRPs reflect correct response activation, in contrast, positive LRP activity indicates activation of the incorrect response. For the analysis of initial incorrect S-LRP activation the mean amplitude in the time-interval from 250 ms to 500 ms was used. Following the calculation of the LRP, each waveform was low-pass filtered (Butterworth IIR: 10 Hz, 36 dB/oct).

2.5. Statistical analysis

Trials were analyzed according to trial sequence resulting in a 2(previous trial type: affirmative vs negated) × 2(current trial type: affirmative vs. negated) design. For the behavioral data, reaction time and error rate served as the dependent variables. For the ERP data, mean amplitude within the 250–500 ms S-LRP time interval served as the dependent variable. Statistical analyses were conducted using ANOVAs and paired *t*-tests.

3. Results

3.1. Behavioral data

Trials classified as “Too Fast“ (< 150 ms) or “Too Slow” (> 2000 ms) were excluded from subsequent analysis (< 1% of trials). Mean reaction time and error rates for the behavioral data are displayed in Fig. 2. There was a main effect of trial type with faster responses to affirmative trials (722 ms) than negated trials (868 ms), $F(1, 32) = 325.52$, $p < .001$, $\eta_p^2 = 0.91$), suggesting that negation implementation requires additional time even for binary negations in the vertical dimension. In line with the second hypothesis, this effect of negation was modulated by previous trial type, $F(1, 32) = 149.07$, $p < .001$, $\eta_p^2 = 0.82$. Post-hoc *t*-tests showed that the difference between affirmative and negated trial types was larger following previous affirmative trials (250 ms, 95% CI: 226 to 275 ms, $t(32) = 20.73$, $p < .001$) than following previous negated trials (41 ms, 95% CI: 18 to 64 ms, $t(32) = 3.58$, $p < 0.01$) (see Fig. 2). Thus, negation is easier to process if the previous trial was also a negation trial, suggesting that negation implementation depends on the current cognitive state[1]. A similar pattern was observed for the error data. There was a main effect of current trial type with more errors to negated trials (9.22%) than affirmative trials (4.80%), $F(1, 32) = 51.73$, $p < .001$, $\eta_p^2 = 0.62$. Again, this was further modulated by previous trial type, $F(1, 32) = 60.61$, $p < .001$, $\eta_p^2 = 0.65$. Post-hoc *t*-tests showed that the difference between affirmative and negated trials was significant following affirmative trials (9.62%, 95% CI: 7.46 to 11.78%, $t(32) = 9.06$, $p < 0.001$) but not following negated trials (-0.77%, 95% CI: −2.24 to 0.70%, $t(32) = -1.06$, $p = 0.30$).

3.2. LRP data

The mean LRP waveforms are displayed in Fig. 3. The LRP was analyzed to see whether the reaction time slow-down in negation trials is due to initial activation of the wrong response (i.e. positive LRP activation for negation trials). Indeed, there was a main effect of current trial type with more negative amplitudes to affirmative trials (−0.23 µ*V*) than to negated trials (0.01 µ*V*), $F(1, 32) = 4.36$, $p = 0.04$, $\eta_p^2 = 0.12$. Like the behavioral data, this effect was modulated by previous trial type, $F(1, 32) = 7.10$, $p = .01$, $\eta_p^2 = 0.18$. Post-hoc *t*-tests revealed a significant difference between affirmative and negated trials following affirmative trials (0.61 µ*V*, 95% CI: 0.24 to 0.97, $t(32) = 3.40$, $p < .01$), whereas there was no significant difference between affirmative and negated trials following negated trials (-0.14 µ*V*, 95% CI: −0.51 to 0.22 µ*V*, $t(32) = -0.80$, $p = .43$). Thus, in line with the hypothesis initial activation of the wrong – to be-inhibited response – in negation trials is particularly pronounced if negation follows affirmative trials. If negation follows negation trials, the results suggest, that it is easier to process and implement negation (without early activation of the wrong response).

4. Discussion

Negation is known to be a resource-demanding and effortful process (e.g., Deutsch et al., 2006; Kaup & Dudschig, 2020). Recently it has been suggested that negation implementation is a dynamic process that depends on the current cognitive state, similar to dynamics active when dealing with other types of information processing difficulties, such as the Stroop or the Simon conflict (see Botvinick et al., 2001; Dudschig & Kaup, 2019). However, it remained open whether these findings might be specific to the horizontal dimension. Indeed, previous studies have shown that vertical and horizontal spatial dimensions are processed rather differently both by humans and non-human animals (e.g., Sutherland, 1960; Warren, 1969; Wohlwill & Wiener 1964). For example, differentiations on the vertical dimension seem to be available earlier in life and easier to process. Also, when looking at specific paradigms typically used to study human cognition – for example, the Simon paradigm – is has been shown that incorrect LRP response activation can be observed mainly in the horizontal dimension (Vallesi et al., 2005). Thus, the current study aimed to address whether previous findings regarding negation implementation (i.e., the activation of the incorrect response, and the effects of trial history on negation processing) generalize to the vertical dimension.

With regard to the first research question – whether negating vertical spatial terms also results in the initial activation of the to-be-negated information – the results of the current study are rather clear. In contrast to the automatic activation of the incorrect response in the Simon task being specific to the horizontal dimension (Vallesi et al., 2005), in the current study we also observed evidence for such incorrect response activation for negating vertical linguistic terms. Specifically, the LRP analysis indicated more positive S-LRP deflection for negation trials than for affirmative trials, especially in the case when the negated trials followed affirmative trials. Thus, it seems that the words used in the current study (“up” vs. “down”) are indeed able to initially activate the to-be-inhibited response in the case of negation trials (“not up” / “not down”). One might wonder why words – in contrast to visual stimuli as used in the Simon task – automatically trigger vertical response tendencies. Two explanations should be considered. First, in the current experimental setup, we used a response layout that indeed

[1] We recognize that response sequence from trial n-1 to trial n plays a critical role in calculations of conflict adaptation (see Mayr et al, 2003). Indeed, when response sequence (repetition vs. alternation) was added to the ANOVA model, there was a three-way interaction between current compatibility, previous compatibility and response sequence, $F(1, 32) = 155.45$, $p < .001$. However, the critical current compatibility by previous compatibility interaction was still significant following the removal of response repetition trials from the sequence, $F(1, 32) = 71.31$, $p < .001$.

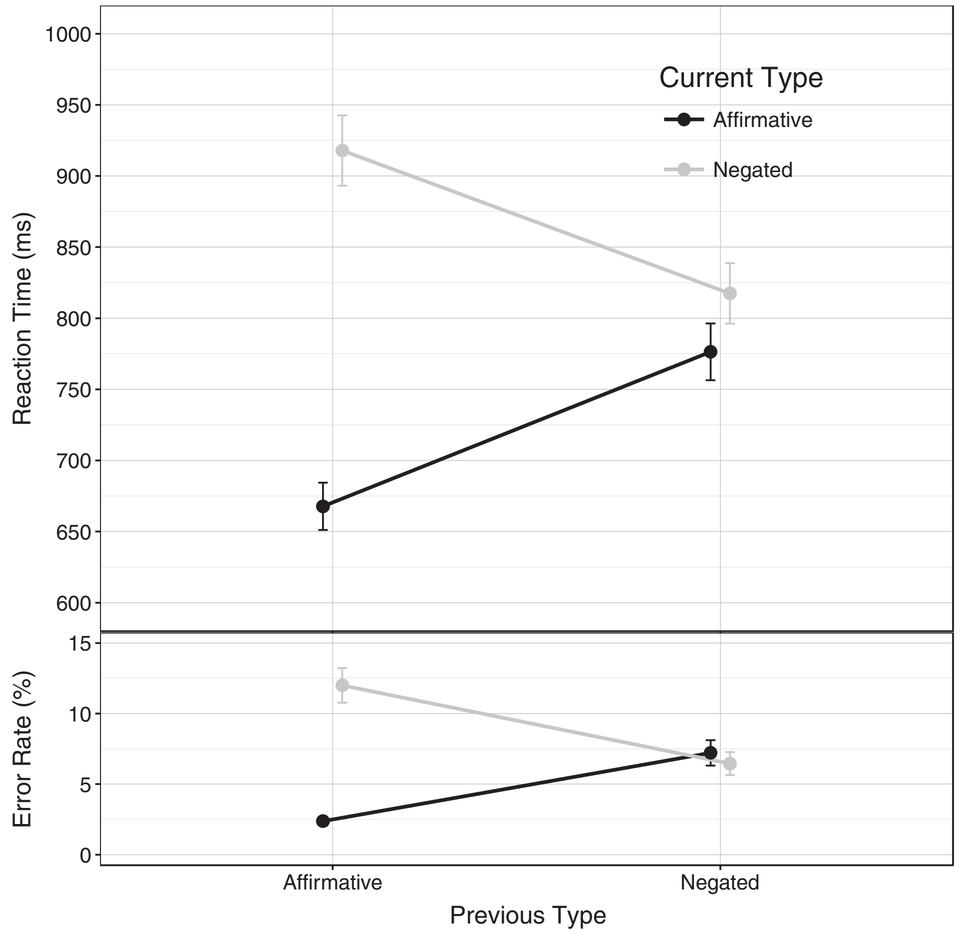

Fig. 2. Mean reaction times (upper plot) and error rates (bottom plot) split for the four experimental conditions resulting from previous trial type (affirmative and negated) and current trial type (affirmative and negated). Error-bars represent +- 1 SEM.

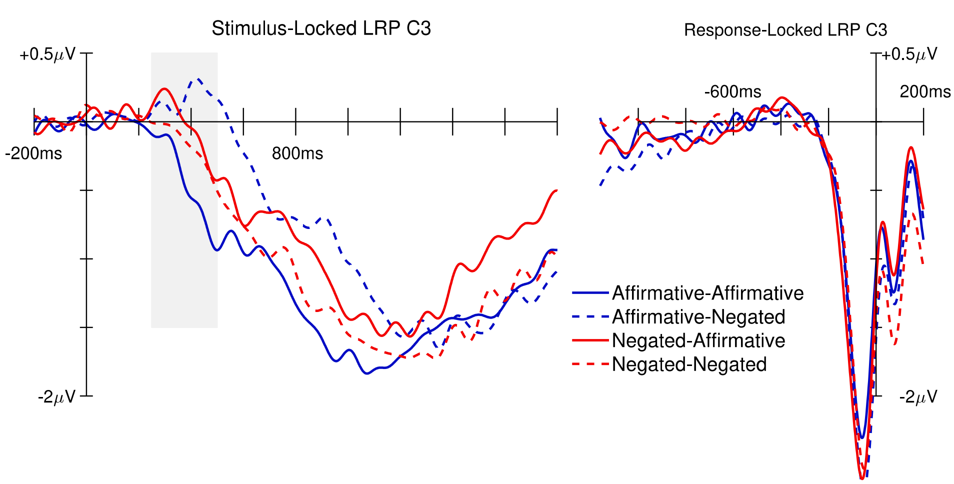

Fig. 3. Mean S-LRP (left plot) and LRP-R (right plot) waveforms for the four experimental conditions resulting from previous trial type (affirmative and negated) and current trial type (affirmative and negated). The grey bar in the S-LRP indicates the analysis window for initial incorrect (i.e. positive) activation in the LRP. The LRP-R shows fully aligned mean amplitudes for the four experimental conditions, indicating that there are no response-related effects after response selection.

placed the up-response at an upper location on a vertically mounted board, and the down-response at a lower response location. In contrast, previous studies have not always pursued such a response setup but sometimes also let participants perform the up-down responses on the horizontal plane, by pressing a button further away (i.e. up response) and a button closer to the participant (i.e. down response) (e.g., Vallesi et al., 2005). Using upper- vs. lower mounted response keys might strengthen the automatic impact of up- vs. down-associated stimuli as no additional translational processes were required. Second, in difference to previous studies, our stimuli were verbal in nature. Indeed, it has been previously reported that for verbal material the vertical dimension is rather automatized compared to the horizontal dimension (e.g., Damjanovic & Santiago, 2016), potentially resulting in automatic activation of the responses if the words “up” and “down” are involved.

The other question addressed in the current study was whether negation implementation indeed follows a dynamic process, whereby it depends on the trial history whether negation integration and implementation are rather time consuming or rather easy (see Dudschig & Kaup, 2019). For other types of effort- and resources demanding cognitive processes, such as the resolution of an incongruent Flanker trial or the response to an incongruent Simon trial, it has been suggested that these processes are easier if they follow another incompatible trial (Botvinick et al., 2001). These dynamic adjustment processes were attributed to the *conflict monitoring system* detecting processing difficulties during incompatible trials and subsequently resulting in an up-regulation of cognitive control – facilitating the processing of subsequent incompatibilities. Indeed, also in the current study such adjustments in the way negation is dealt with were observed both in the RT and the S-LRP data. Negation implementation was faster following another negation, and the initial incorrect activation observed in the S-LRP for negated trials was particularly pronounced if the negation followed an affirmation trial. Thus, the current study suggests that during resolving linguistic processing difficulties – in our case negation – mechanisms are recruited that resemble processing adjustments in non-linguistic tasks.

Models of negation implementation are often concerned with the question whether negation integration first activates the to-be-inhibited information (i.e. up in the case of “not up”) and only in a second step the actual state of affairs (i.e. down), resulting in a two-step process of negation implementation (e.g., Kaup, Lüdtke, & Zwaan, 2006). Also, the schema-plus-tag model (Clark & Chase, 1972) suggests that negation involves dealing with the affirmative counterpart, thus resulting in additional processing costs. Other models – such as the fusion model of negation (Horn, 1989) – proposed that negation directly activates the actual state of affairs, without any additional processing steps. Our results suggest that the answer to this question – whether both the factual and the counterfactual information becomes activated - cannot be generalized. In contrast, how we deal with a current negation highly depends on directly preceding cognitive tasks. If the cognitive system is highly prepared to deal with conflict – it might be successful in directly arriving at the correct representation. In contrast, if the cognitive system previously dealt with non-conflicting affirmative trials, it is rather difficult to directly integrate the negation in following trials.

However, there are certain alternative interpretations of the current study that need to be addressed. The task in the present experiment required participants to execute a particular response after processing the linguistic stimuli. For instance, when reading “now up” they had to press the upper key, and when reading “not up” they had to press the lower key. Thus, strictly speaking, the task was not a purely linguistic task but rather a linguistic task plus an additional response-selection task. From the perspective of language comprehension models one could additionally argue that the linguistic task was rather artificial because negation was not used in a pragmatically felicitous way (for instance for denying a presupposition, or in the case of imperative negations, for stopping an ongoing or anticipated action). Finally, the paradigm implemented binary spatial choices (between up and down) and thus can only be used to investigate negation processing in a rather limited scenario. The question, therefore, arises in how far the current study allows conclusions concerning negation processing in day to day linguistic tasks. However, we would like to mention that there are also everyday situations with a tight coupling between language and action consequences (e.g. sentences such as “Don’t leave the door open”).

Related to the previous point, one might argue that the current study investigated the process of response recoding more than that of negation processing. According to this perspective, the negation in the current paradigm is a cue to reverse the response. Thus, in the presence of a negation, the mapping of the spatial term to the correct response is reversed relative to a trial without a negation. The word “now” thus indicates the response mapping “up” → up response / “down” → down response, whereas the word “no” indicates the response mapping “up” → down response / “down” → up response. In our view, this is not necessarily problematic because negation processing inherently involves some kind of mapping reversal. Hearing that a dress is red or that someone carries a suitcase usually leads to a meaning representation that involves the respective properties (red, suitcase). In the case of negation, this “mapping of linguistic terms to properties of the meaning representation” is altered. Hearing that a dress is not red or that someone is not carrying a suitcase, usually leads to a meaning representation that does not involve the respective properties (red and suitcase are absent). This is even stronger in the case of expressions with binary negation such as “the door is not open” which results in the meaning representation of a closed door (Kaup & Dudschig, 2020).

Thus, we would argue that the current study by investigating in more detail negation induced reversal processes investigates one of the subprocesses inherent to negation processing and is therefore informative for theories concerned with negation processes. However, we would like to point out that regarding the present paradigm in terms of purely investigating response reversal processes might point to a limitation regarding the interpretation of the response time pattern in terms of conflict adaptation processes. As was expected on the basis of the literature on conflict adaptation processes, trial history in our current study affected responses for both, negative and affirmative conditions. Responses to negative phrases were faster after a negative than after an affirmative previous trial whereas responses to affirmative phrases were faster after an affirmative than after a negative previous trial. The question arises whether this indeed reflects conflict adaptation processes (as we interpreted it) or rather the need to change the mapping between spatial terms and responses in the different trial conditions. In other words, it is possible that responses to negative (affirmative) phrases were faster after negative (affirmative) trials because in these trials the mapping between spatial terms and responses was the same in the current and the previous trial whereas a mapping reversal had to be undertaken in the other trial sequences (i.e., negative (affirmative) trials after affirmative (negative) previous trials). However, we would like to point out one problem with the explanation of the whole data pattern in terms of mapping-reversals processes: The idea that following negation trials no mapping reversal takes place for another negation trial does not explain, why there is still a main effect of negation following negation trials (if in that case a reversal needs to take place for the affirmative responses, one would expect affirmative responses following negation trials (mapping reversal needed) to be slower than negation trials following negation trials (no mapping reversal needed). Nevertheless, on the basis of the current experiment, it is impossible to rule out all types of alternative explanations or to fully define the role of the action component in the task. One would for example need to conduct an additional study, in which response reversal is indicated by a different means than negation and investigate the differences to the current results or to further decouple the language and action component.

In summary, the current study provides two main findings: First, with regard to tasks using linguistic stimuli, the vertical dimension seems to result in the automatic activation of response tendencies, as typically observed in the horizontal dimension. Second, the negation implementation using the vertical dimension takes place in a dynamic way, resulting in typical conflict adaptation effects as reported in the Stroop, the Simon and the Flanker literature. Future studies would be required to investigate whether negation integration also follows such dynamic patterns if used in setups that do not require direct responses but resembles a more naturalistic language comprehension situation (see also: Kan et al., 2013). This seems particularly important to rule out explanations based on response rehearsal. Finally, our findings open a new way of investigating control processes across linguistic and non-linguistic tasks and their interplay.

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