Low numbers from a low head? Effects of observed head orientation on numerical cognition

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Abstract

The present research shows effects of observed vertical head orientation of another person on numerical cognition in the observer. Participants saw portrait-like photographs of persons from a frontal view with gaze being directed at the camera and the head being tilted up or down (vs. not tilted). The photograph appeared immediately before each trial in different numerical cognition tasks. In Experiment 1, participants produced smaller numbers in a Random Number Generation (RNG) task after having viewed persons with a down-tilted head orientation relative to up-tilted and non-tilted head orientations. In Experiment 2, numerical estimates in an anchoring-like trivia question task were smaller following presentations of persons with a down-tilted head orientation relative to a non-tilted head orientation. In Experiment 3, a response key that was associated with larger numbers in a numerical magnitude task was pressed less frequently in a randomly intermixed free choice task when the photograph showed a person with a down-tilted relative to an up-tilted head orientation. These findings consistently show that social displays can influence numerical cognition across a variety of task settings.

Keywords: numerical magnitude; number generation; observation of head orientation; social cueing; mental number line; numerical cognition

1. Introduction

Imagine that after a day of sightseeing in Rome, you discuss the height of St. Peter's Basilica with a friend at the hotel bar. Your friend looks down and comes up with an estimate of 180 meters. Now you are starting to ponder about the height of the dome. Will your own estimate be higher or lower depending on your friend's head orientation? Most people will likely doubt such an influence: The size of the dome is, after all, independent of your friend's head posture. However, the present research suggests that the spatial information inherent to body cues could bias numerical estimates due to a spatial grounding of numerical cognition.

Modern research on numerical cognition found that numerical and spatial cognition are intimately linked. To illustrate this bidirectional association between numbers and space, the notion of a 'mental number line' was borrowed from research on numerical comparisons (Moyer & Landauer, 1967; Restle, 1970). This concept describes an imagery analogue system for the cognitive representation of magnitudes and/or their numerical symbols along a vertical (or horizontal) continuum: A small number is represented by a coding of a low (or left) position, while a large number is represented by a coding of a high (or right) position (e.g., Winter & Matlock, 2013; for a review, see Winter, Matlock, Shaki, & Fischer, 2015).

1.1. Bidirectional link between numerical magnitude and spatial attention

Evidence for a spatial coding of numerical magnitude comes from the so-called Spatial-Numerical Association of Response Codes (SNARC) paradigm (Dehaene, Bossini, & Giraux, 1993; for a review see Wood, Willmes, Nuerk, & Fischer, 2008). In the vertical version of the SNARC paradigm, participants solving an unrelated parity judgment task answered to small numbers [0-4] faster with lower manual button responses and to larger numbers [5-9] faster with upper button responses (Ito & Hatta, 2004; Hartmann, Gashaj, Stahnke, & Mast, 2014). In the original horizontal paradigm, this effect of numerical magnitude on response times was found to be independent of the hand performing the response, but dependent on the spatial location of the response keys on a left-to-right axis (Experiment 6; Dehaene et al., 1993). Thus, the underlying mechanism does not depend on the hand performing the response, but on the more abstract mental number line (Schwarz & Keus, 2004) in external space (cf. Brozzoli, Ishihara, Göbel, Salemme, Rossetti, & Farnè, 2008).

Being grounded in spatial codes, numerical cognition affects spatial codes and vice versa. In line with this hypothesis, several studies demonstrated effects of numerical magnitude and/or quantity on spatial attention (attentional SNARC effects; Fischer et al., 2003; Pecher & Boot, 2011). In one study, participants detected a target presented at the bottom of a screen faster after having read pieces of information contextualizing a number as a small quantity (e.g. *The man had two books in his bookcase*) compared to information contextualizing it as a large quantity (e.g. *The man read two books a day*), while the opposite was found for targets presented at the top of the screen (Pecher & Boot, 2011). Furthermore, several studies showed that spatial codes involved in dynamic body movements (head-turning; body turns) on an up-down (or left-to-right) axis (Hartmann Grabherr, & Mast, 2012; Loetscher, Schwarz, Schubiger, & Brugger, 2008; Shaki & Fischer, 2014) influence random number generation (RNG; Evans, 1978). In one study, participants freely generated numbers between 1 and 30 while tilting their head upwards and downwards to the beat of an electronic metronome. Results revealed that participants generated larger numbers when they had their head tilted upwards compared to downwards (Winter & Matlock, 2013). Another study extended this influence of embodied spatial codes to numerical trivia estimation (Eerland, Guadalupe, & Zwaan, 2011). Specifically, participants gave smaller estimates to numerical trivia questions (e.g. *How large is the Eiffel Tower?*) when unknowingly leaning slightly to the left (vs. right) on a Wii Balance Board.

Additional research suggests that observing another person's movements can be sufficient for an effect on numerical cognition. For instance, Grade and colleagues (2013) asked participants to generate numbers between 1 and 10 after having viewed a pair of eyes in close-up view looking to the left or right (Experiment 1), or to the bottom or top (Experiment 2). In control trials, only the color of the eyes was changed. Results showed that participants generated smaller numbers when the eyes looked to the left or downwards relative to the control conditions. Based on gaze cueing research (e.g. Driver, Davis, Ricciardelli, Kidd, Maxwell, & Baron-Cohen, 1999; Friesen, Moore, & Kingstone, 2005), the authors concluded that the spatial cue inherent to the averted eyes not only shifted attention in outer ‘perceptual space’ but also on the mental number line in inner ‘mental space’. However, it should be noted that the observation of upward and rightward eye movements did not result in a production of larger numbers relative to the control condition. Furthermore, the version of the RNG task chosen by Grade and colleagues (2013) was restricted to the fixed number range from one to ten. Finally, Grade and colleagues (2013) did not dissociate the spatial stimuli (gaze cues) and the non-spatial responses (verbal response; cf. Fischer and Shaki, 2016). Thus, their approach allows for alternative, method-related accounts to the mental number line explanation like polarity correspondence between spatial and numerical dimensions (Proctor & Cho, 2006). Specifically, their pattern of results could result from coding correspondence between positive (large) and negative (small) numerical polarity on the one hand and positive (top or right) and negative (bottom or left) spatial polarity on the other hand rather than a spatial representation of numerical magnitude (Proctor & Cho, 2006; see also Gozli, 2017).

1.2. Influence of gaze and head cueing on spatial attention

Grade and colleagues’ (2013) eye movement manipulation of number processing paved the way for bringing together numerical cognition and social cueing research. However, social cueing paradigms typically use portrait-like photographs of faces instead of pictures of eyes as stimuli (Frischen, Bayliss, & Tipper, 2007), even if they investigated the influence of gaze cueing only (e.g., Driver et al., 1999). One reason for this more holistic approach to gaze cueing is the interest of social cueing research in interactions between gaze, head, and body information in triggering orienting responses in observers (Frischen et al., 2007; Hietanen, 1999; Langton & Bruce, 2000; Langton, Watt, & Bruce, 2000).

In the social cueing literature, different models for the discrimination of direction information derived from (incongruent) gaze, head, and body direction were suggested (e.g. Baron-Cohen, 1992, 1995; Perrett, Hietanen, Oram, & Benson, 1992; Perrett & Emery, 1994). For instance, Hietanen (2002) proposed a direction-detection system that references cues from gaze, head, and body orientation to each other in a hierarchical fashion (from body as least and gaze as most informative cue) to infer one overall direction information relevant for spatial response selection. Interestingly, Langton (2000) suggested a similar model, but with a parallel integration of gaze, head, and body cues (see also Pomianowska, Germeys, Verfaillie, & Newell, 2012). He argued that incongruent (vertical and horizontal) head and gaze information equally interfered with each other in cueing spatial attention (see also Langton & Bruce, 1999). Thus, he stressed the significance of head orientation alone in discerning social spatial attention.

In line with Langton's version of the direction-detection system (Langton, 2000; see also Pomianowska et al., 2012), the present study used portrait-like photographs of people with the head oriented up vs. down and gaze directed at the camera (see Figure 1). In a preliminary test of the material, we showed that the identification of vertically presented targets (circle or square) was faster when the direction of the head orientation and the location of target corresponded.[1] This finding indicates that in our head orientation pictures, the direction of head orientation automatically produced congruent orienting responses. Thus, the head orientation stimuli used in this study constitute proper social cues to further elaborate on the link between socially instigated visuospatial attention orienting and numerical cognition.

1.3. Influence of head cueing on the processing of numerical magnitude

The present experiments investigated whether numerical cognition is affected by another person's vertical head orientation. In Experiment 1, participants generated random

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[1] The preliminary test of the material is provided at: https://osf.io/rtkdp/?view_only=9bc2382dd85946fc8cd5f8a86d4a8125

numbers after viewing photographs of people with the head tilted up, down, or not tilted (RNG; Evans, 1978). In Experiment 2, participants answered numerical trivia questions with more complex number ranges (from one- to five-digit numbers) after having seen photographs with heads tilted down or not tilted. Note that in both experiments the head orientation pictures were no longer present during the numerical cognition task. In Experiment 3, participants used two response keys to judge if a given number was smaller or larger than 5 in number trials and could freely decide between the same two keys in picture trials. In these trials, participants viewed a person with her head tilted up or down immediately before the free response decision. We hypothesized that participants respond to persons with heads tilted down (up) with smaller (larger) numerical magnitudes than to persons with head tilted up (down) or not tilted (Experiment 1), typing a multi-digit number (Experiment 2), or freely choosing between two keys that are associated to numerical magnitude due to a parallel numerical cognition task (Experiment 3).

The present experiments aim at extending our understanding of the link between visuospatial cognitive processing and numerical cognition by testing the influence of holistic head cues. Further deviating from the gaze cueing (of numerical magnitude) experiments by Grade and colleagues (2013), the present research took efforts to dissociate the spatial social cueing stimuli from the numerical cognition tasks. The majority of behavioral numerical cognition studies measured spatial-numerical associations with experimental paradigms, in which physical spatial features were present during the numerical cognition task - either at the stimuli, or response level, or both levels (e.g., Fischer & Shaki, 2016; Shaki & Fischer, 2018). As a consequence, response code effects like the SNARC (e.g. Dehaene et al., 1993) could be the result of polarity correspondence (e.g., Proctor & Cho, 2006) rather the spatial nature of numerical cognition on a conceptual level (cf. Fischer & Shaki, 2016). In order to refute such methods-based explanations, the present research employed three different experimental tasks, in which spatial cues and numerical cognition tasks were presented sequentially rather than simultaneously (cf. Fischer & Shaki, 2016). Moreover, Experiment 2 addresses the question whether effects of spatial coding on numerical cognition are limited to the fixed number range typical to RNG tasks or extend to multi-digit number ranges. Finally, Experiment 3 was designed to shed light on the conceptual link between the representation of external space and numbers (Brozzoli et al., 2008) that presumably underlies head-orientation effects on numerical cognition. Specifically, the conceptual association of numerical magnitude and head orientation was measured indirectly in a non-instructed free-choice task that only shared the (counterbalanced) response keys with a forced-choice numerical magnitude task (cf. Fischer & Shaki, 2016). In sum, the present research further establishes the influence of external cues on numerical cognition and brings together holistic social cueing stimuli with a variety of numerical task settings, thus further elaborating on the nature of the link between social cueing and numerical cognition.

2. Experiment 1

Experiment 1 examined the hypothesis that the passive viewing of down- and up-tilted faces primes the generation of smaller and larger numbers, respectively, in a manual RNG task. In each trial, a photograph of a model with the head tilted up, down, or not tilted was presented for a short time immediately before the RNG task. Previous research showed that an ostensive cue like direct eye gaze must communicate to the observer that he is the addressee of the expressive display (Hietanen, 1999, 2002; Sperber & Wilson, 1986). Therefore, each model had a static head postures with a direct line of sight to the camera (cf. Pomianowska et al., 2012). With the models looking directly at the participant, we additionally controlled for spatial priming by the gaze direction of the model (see Grade et al., 2013).

2.1. Methods

2.1.1. Participants

Sixty-one volunteers (44 female, 17 male, M = 26.23 years, range: 19-59) from the Würzburg area participated in the experiment. Participants received a financial compensation for study participation. Due to our uncertainty about the expected effect size, we collected data of n = 61 participants. A sensitivity analysis showed that with this sample size, a medium-sized effect of *f(U)* $\geq$ 0.28 (effect size specification as in SPSS) could be detected with a statistical power of 1-β = .80 in a repeated measures analysis of variance (ANOVA) with three measurement levels and alpha-level = .05 (calculated with G*Power 3.1; Faul, Erdfelder, Lang, & Buchner, 2007).

2.1.2. Apparatus and stimuli

The experiment was run on laptops using Inquisit 3 software. The priming stimuli consisted of 54 portrait-like photographs (1158 x 1158 pixels) of 18 models (nine male, three pictures per person) taken from a set of photographs of 21 models (ten male, three pictures per person; overall 63 portrait-like photographs). Pictures were postprocessed to a white background color and shadows were removed. The color saturation was set to minimum (grey color). Contrast and brightness of the pictures were matched using Adobe Photoshop CS6.

The photographs can be viewed in the supplementary information file to this article (for an example picture see Fig. 1). The models were between 18 and 65 years old. Each model wore a uniform black shirt and was shown from a front view with line of sight towards the camera. From the 54 pictures, one third (18 pictures) showed the model with the head tilted up (henceforth called *up-tilted heads*); a second third with the head tilted down (*down-tilted heads*). In the remaining pictures the head was not tilted (*non-tilted heads* as controls). For a quantitative measure of the head tilt, we measured the distance between the line of the chin and the bottom of the picture. The down-tilted heads had distances ranging between 0.21 and 0.67 cm (M = 0.53, SD = 0.11), the non-tilted heads ranged between 0.75 and 1.05 cm (M = 0.91, SD = 0.08), the up-tilted heads between 1.31 and 1.66 cm (M = 1.45, SD = 0.11).

Figure 1. Example picture of a model with a down-tilted (left), non-tilted (middle) and up-tilted (right) head orientation presented in Experiments 1-3.

An additional set of 36 photographs (18 models, 9 male, two pictures per person) was selected from the Radboud Faces Database (Langner, Dotsch, Bijlstra, Wigboldus, Hawk, & Knippenberg, 2010) for catch trials in which participants should not respond. The pictures were matched in size and color with the tilted head pictures described above. Half of the pictures showed the model with a clear body orientation (including head and gaze) to the left and the other half with a clear body orientation to the right. Please note that in Hietanen's studies (1999, 2002), analogous pictures did not affect the observers' attention orienting, presumably because there were no ostensive cues (like gaze and/or body directed at the observer) that signaled to the observers that they were the addressees of a communicative intent (e.g. Böckler, Knoblich, & Sebanz, 2011; Csibra & Gergely, 2009; based on Sperber & Wilson, 1986).

2.1.3. Procedure

A trial started with the picture of a person that was replaced by a fixation cross after 1,500 ms. Thus, the head orientation picture was not visible while the participants responded. The fixation cross was displayed until response registration or until 3,000 ms (2,000 ms in the catch trials) had elapsed (see Fig. 2). In case of an incorrect or omitted response, an error message appeared for 2,500 ms. The next trial started after 700 ms.

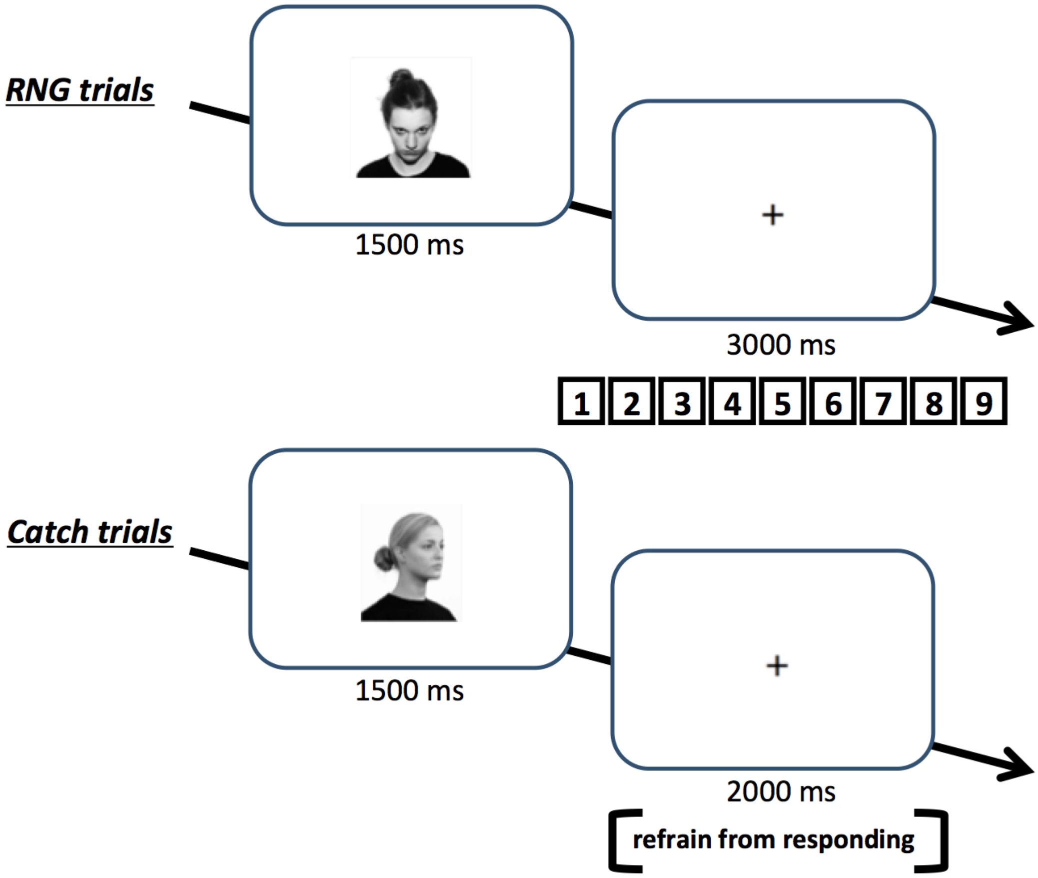

Figure 2. Sequence of events in experimental (RNG; top) and catch (bottom) trials of Experiment 1. Participants were instructed to press one of the numerical keys on the top row of the keyboard only if the displayed model looked directly at the participant (eye contact).

Instructions for the RNG task were to generate a one-digit number when the model in the photograph is shown from the front (experimental trials) and to not respond when the model is oriented to the left or right (catch trials). Thus, the photographs were relevant to identify experimental trials. Catch trials were randomly intermixed to discourage participants from strategic number generation before the picture presentation. Participants were explicitly instructed to spontaneously generate a random number and to avoid a systematic sequence or pattern. The metaphor of an urn containing the 9 numbers was used to illustrate the selection of a random number (cf. Baddeley, 1966; Grade et al., 2013; Loetscher & Brugger, 2007). The one-digit number was entered with the numerical keys (1-9) on the top row of the keyboard. Instructions for the catch trials were to wait until the trial had ended.

The experiment had one practice block with 6 trials and three experimental blocks with 36 trials each. Half of the trials in a block were catch trials. In the 18 experimental trials of a block, the three types of tilted-head pictures (up-, down-, non-tilted) were presented in random order, showing one photograph of each of the 18 models in every block. In the 18 catch trials of a block, each model was shown once with either a left or a right body orientation. Participants had a short rest period after each block with a reminder of the task instructions.

2.1.4. Data Analysis

The mean of the self-generated numbers was computed for each head orientation (down-tilted, non-tilted, up-tilted). These mean numbers were submitted to a one-factorial repeated-measures analysis of variance (ANOVA) with observed head orientation (down-tilted, non-tilted, up-tilted) as within-subject factor. In case of significant main effects and in accordance with our a priori hypotheses, the data was subsequently submitted to one-sided paired-samples t-tests.

2.2. Results

The ANOVA showed a significant main effect of head orientation, $F(2, 59) = 4.57$, $p = .012$ $\eta_p^2 = .071$. Subsequent t-tests showed that numbers generated after a down-tilted head ($M = 4.86 \pm SD = 0.89$) were significantly lower compared to those generated after non-tilted heads ($M = 5.25 \pm SD = 0.62$), $t(60) = -2.86$, $p = .006$, $d_z = 0.37$, and up-tilted heads ($M = 5.16 \pm SD = 0.79$), $t(60) = -2.07$, $p = .043$, $d_z = 0.27$ (see Fig. 3). Numbers generated after up-tilted heads did not differ from the control condition with non-tilted heads ($t < 1$).

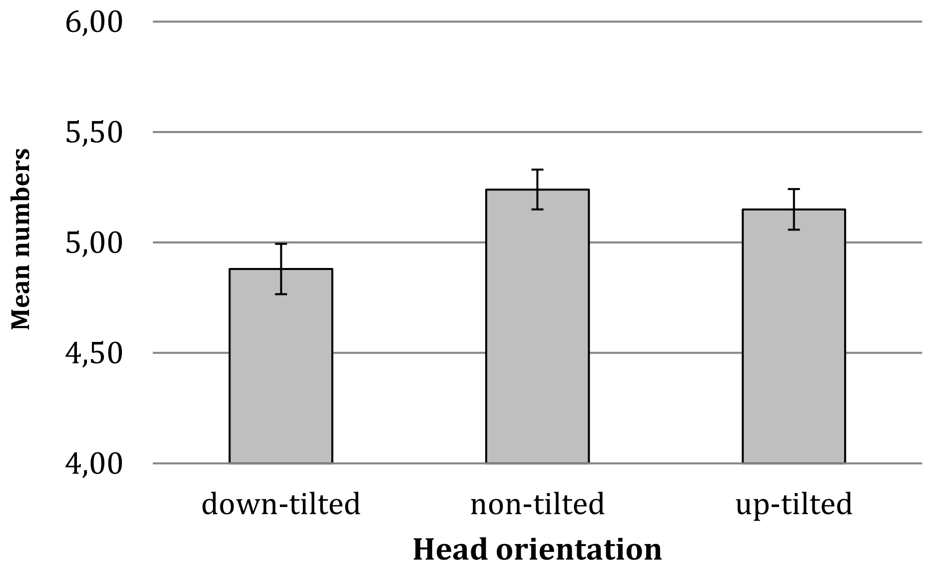

Figure 3. Mean numbers produced in Experiment 1 as a function of the model's head orientation. Error bars indicate the standard error.

2.3. Discussion

Observing a model with her head tilted down influenced number generation in accordance with the hypothesis, with smaller numbers being produced relative to a control condition with non-tilted head orientations. Following the interpretation of Grade and colleagues (2013), this effect can be explained with a transfer of the attention shift that is induced by the head-orientation in perceptual space to the mental number line. As a consequence, smaller numbers were more accessible in memory following the perception of a down-tilted head picture. By contrast, observing the same models with the head tilted up did not significantly affect random number generation relative to the control condition. This finding is in line with the findings of Grade and colleagues (2013) and other researchers (e.g. Hartmann et al., 2012; Loetscher et al., 2008) and could be explained with a logarithmic-like distribution of numbers along the mental number line (e.g. Dehaene & Changeux, 1993; Dehaene et al., 1993). According to this framework, the mental number line allocates more space to smaller numbers and less to larger numbers (and/or numerosities), which allows for a more precise processing of the former relative to the latter (resulting in a small number bias, e.g. Banks & Hill, 1974; Loetscher & Brugger, 2007).

Challenging the attention shift account, an alternative polarity correspondence explanation (Proctor & Cho, 2006) is possible due to the fixed spatial arrangement of the numerical response keys on the keyboard with smaller numbers to the left and larger ones to the right. Specifically, a match between the polar dimensions ‘downward tilt’ and ‘left-sided response location’ could have facilitated corresponding response sets on the left side (see also Roettger & Domahs, 2015). For a test of this alternative account, we used an anchoring-like numerical estimation task with multi-digit number ranges in Experiment 2 to de-confound quantity estimates from particular response locations a-priori. After all, participants have to press keys on different locations of the keyboard to type a multi-digit number, which renders a polarity correspondence relation between vertical head orientations and left-right response locations unlikely.

3. Experiment 2

Experiment 2 examined effects of vertical head orientations on estimates of quantities in a modified anchoring paradigm. Many studies showed that the presentation of a numerical value (the anchor) before a difficult numerical trivia question affects judgments under uncertainty, with larger estimates following large values and smaller estimates following small values (Tversky & Kahneman, 1974; for a review see Furnham & Boo, 2011). In our personalized variant of the anchoring paradigm, the picture of a person was presented before the trivia question who supposedly provided a mean numerical value (for a similar procedure see Erle & Topolinski, 2017). Importantly, the person supposedly providing the numerical value was presented either with the head tilted down or with the head in a straight position. This procedure allowed us to present pictures of persons in a meaningful social context whilst manipulating their vertical head orientation. We hypothesized that the model’s head orientation operates like an anchor value for the subsequent numerical judgment. Accordingly, numerical answers to the trivia questions should be smaller after having viewed a model with a down-tilted head. Note that the numerical estimate provided by the model was only used to center the participants' numerical judgments around a fixed value to restrict the variance of their quantity estimates (cf. Eerland et al., 2011). In addition, the numerical estimate provided by the model was varied between questions, but not across participants as in classical anchoring studies (e.g. Strack & Mussweiler, 1997). Models with an up-tilted head were not included in this experiment for two reasons. First, due to the absence of an effect in Experiment 1 and the presumably logarithmic-shaped distribution of numbers along the mental number line, we assumed the detection of an association between upper space and larger numerical magnitude much more difficult than that between lower space and small numerical magnitude (e.g. Dehaene & Changeux, 1993; Dehaene et al., 1993). Second, focusing on the down-tilted head pictures allowed us to reduce the overall number of trials.

3.1. Methods

3.1.1. Participants

Eighty-five persons (48 female, 35 male, 2 indicated no gender, M = 25.64 years, range: 16-79) participated for compensation with a chocolate bar. In Experiment 1, the effect size of the effect of down- vs. non-tilted head on number generation was $d_z = 0.37$ (one-tailed paired-samples t-test). An a-priori power analysis (calculated with G*Power 3.1) showed that a minimum of $n = 81$ must be collected for the detection of an analogous effect with a statistical power of $1\text{-}\beta = .95$ (alpha-level = .05; matched-pairs t-test). We therefore collected data of n = 85.

3.1.2. Apparatus, stimuli, and procedure

Apparatus and stimuli were identical to those in Experiment 1. Only pictures with down-tilted and non-tilted head orientations (20 pictures each) were taken from the set of 21 photographs. For the anchoring-like paradigm, 20 numerical trivia questions (e.g. *How many* *popes have there been?*) were developed and pretested in a short pre-study with 40 participants. The numerical values provided for the 20 questions were the mean estimations given by the participants in the pre-study. Note that these numbers were not varied across participants, i.e. each of the 20 questions was always presented with its respective mean numerical value.

In addition to a task and questions unrelated to the present hypothesis, the experiment consisted of a single block with 20 trials. Each model was displayed only once in a session. Half of the models had a down-tilted head orientation and the other half were presented with a non-tilted head position. The selection of models showing a down-tilted versus non-tilted head orientation and the assignment of the trivia questions were randomized. A trial started with the presentation of a photograph that was replaced after 1,500 ms by one of the trivia questions next to its respective mean numerical value. This number was presented as the numerical estimate supposedly given by the person shown in the preceding photograph. Note that each question was always presented with the same number, and only the head position varied. Participants were asked to enter their own numerical estimate into a field box that was positioned at the center of the screen. The question and the model's numerical estimate were present on the screen until the participant entered her numerical judgment (see Fig. 4). Similar to Experiment 1, the head orientation picture was not visible while the participants responded and the head picture presentation time was 1,500ms.

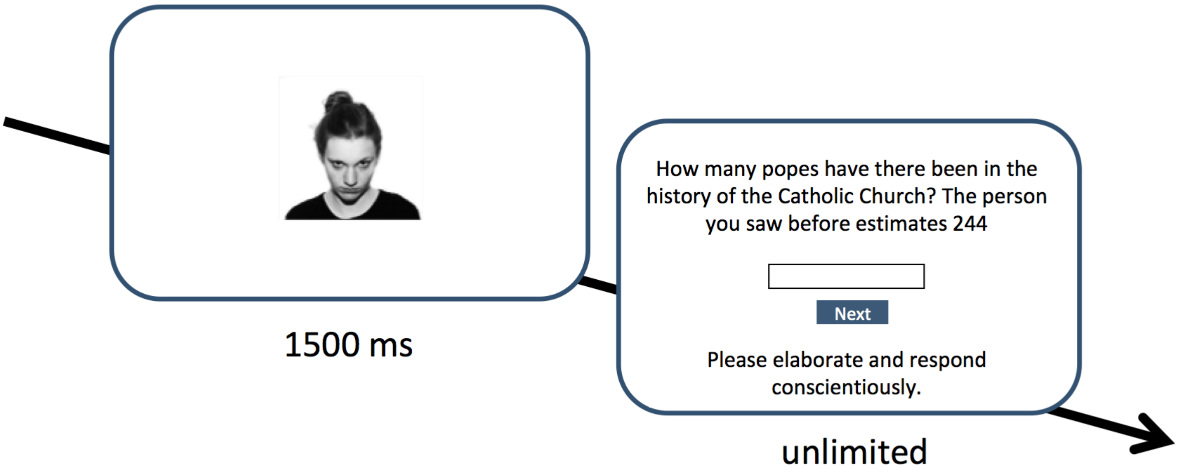

Figure 4. Events in a trial of Experiment 2. A model with her head tilted down or not tilted was presented first who supposedly provided an estimate for a subsequent numerical trivia question.

Instructions for the trivia question task additionally varied in terms of how conscientiously participants should think about their answers to the trivia questions. Several authors (Bahnik & Strack, 2016; Simmons, LeBoeuf, & Nelson, 2010) posit that the classical anchoring effect is the result of different processes working in parallel. However, little is known about the circumstances that favor numerical over semantic processes (e.g. Bahnik & Strack, 2016). As many questions presented in anchoring studies are difficult, participants must guess a numerical value in the end. Nonetheless, this guess may involve different degrees of elaboration. Thus, the extent of semantic knowledge involved in the numerical estimate should depend on the degree of conscientiousness that participants invest in seeking for an appropriate answer (e.g. by searching for knowledge about similar or analogue facts). In Experiment 2, participants were randomly assigned to either a conscientious or a spontaneous processing condition (between-subjects design) to investigate the influence of conscientiousness on the influence of head cueing on numerical estimates. A spontaneous or conscientious search mode for the quantity estimate was highlighted in the task instructions and at the bottom of every trivia question slide (“*Please respond as spontaneously as possible”* vs. “*Please elaborate and respond conscientiously”*).

3.1.3. Data Analysis

The numerical estimates for each trivia question were z-transformed. Mean z-scores were computed for each head orientation (down-tilted, non-tilted) and submitted to a two-factorial mixed ANOVA with head orientation (down-tilted, non-tilted) as within-subject factor and level of elaboration (spontaneous vs. conscientious) as between-subject factor.

3.2. Results

Data of three participants were lost due to computer crashes. The ANOVA showed a significant main effect of head orientation, $F(1, 81) = 4.61$, $p = .035$ $\eta_p^2 = .054$**,** with mean estimates following down-tilted heads ($M = -.06 \pm SD = 0.32$) being significantly smaller relative to those made after presentations of a non-tilted head ($M = .06 \pm SD = 0.36$; see Fig. 5). Task instructions to respond conscientiously versus spontaneously had no effect, $F(1,81) = 1.05$, $p = .308$. There was no interaction effect ($F < 1$).[2]

[2] As a manipulation check for the level of elaboration the mean response latencies for all participants were calculated and submitted to an independent-samples t-test. Participants instructed to respond conscientiously (M = 17,949ms ± SD = 7,696ms) took significantly more time to come up with an estimate than participants instructed to respond spontaneously (M = 13,996ms ± SD = 4,638ms), $t(81) = -2.789$, $p = .007$, $d_s = 0.62$. Thus, the instructions significantly affected response latencies.

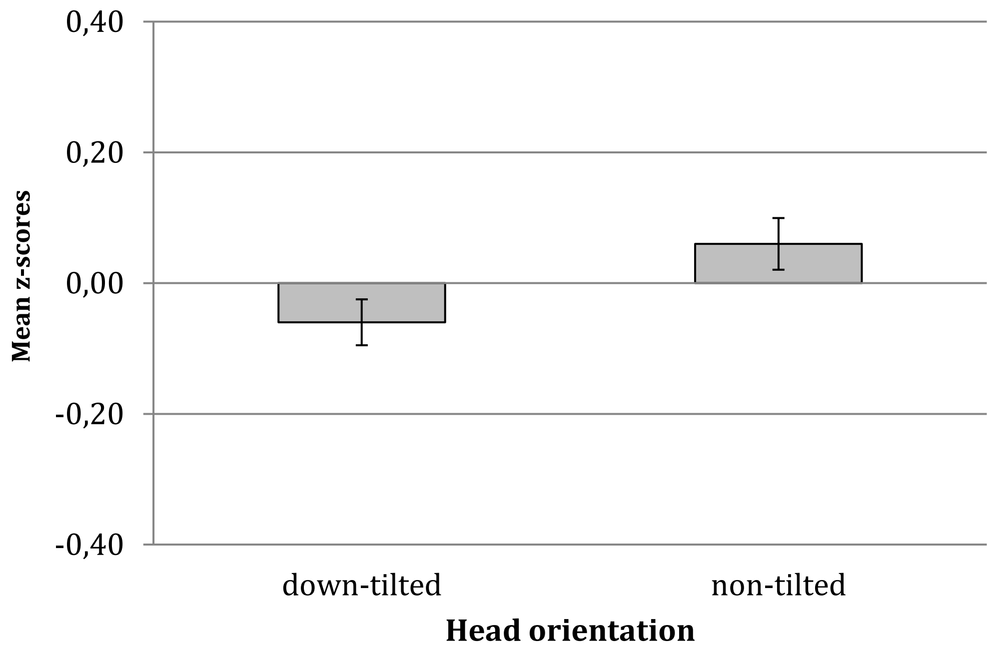

Figure 5. Mean z-scores of the numerical estimates in Experiment 2 as a function of the model's head orientation. Error bars show the standard error.

3.3. Discussion

Viewing a down-tilted head orientation influenced participants' quantity estimations to the numerical trivia questions: Estimates were smaller after having viewed a model with a lowered head position. It should be noted that the range of the produced numbers was larger and more variable in this experiment (ranging between one-digit to five-digit numbers) in comparison to the previous experiment with the RNG task. Typing multi-digit numbers involved key presses on different locations of the keyboard. Therefore, a polarity correspondence relation (Proctor & Cho, 2006) between vertical head orientations and left-right response locations on the keyboard is not a plausible account of the head-orientation effect observed in this Experiment. Nonetheless, employing the numerical keys on the top row of the keyboard for multi-digit numbers still affords a horizontal hand movement. Hence, an additional experiment was conducted without explicit (and with counterbalanced implicit) mapping of numerical magnitude categories onto left-right responses in relevant priming trials.

4. Experiment 3

Experiments 1 and 2 suggest an intimate link between perceived spatial head orientation of another person and one's own numerical cognition. However, the nature of this link is less clear, as the response keys were spatially distributed from left to right in both experiments. Accordingly, it is possible that the effects observed in Experiments 1 and 2 were - at least partially - the result of a methodological artifact (Fischer & Shaki, 2016). In order to refute this methods-based alternative explanation, Fischer and Shaki (2016) introduced a double classification go-nogo task with separate (1) numerical magnitude (1, 2, 8, and 9) and (2) object orientation trials (several cartoon images). In their study, participants had to press (or had to refrain from pressing) a single response key depending on a double response rule that combined numerical magnitude (presented number is smaller vs. larger than 5) and object orientation (presented object is facing to the left vs. right). In consequence, participants had to keep in mind one response rule combining instructions for both types of trials. Results showed that participants responded faster (in the go-trials) when the response rule combined either cartoon image orientation to the left and the judgment "smaller than 5", or cartoon image orientation to the right and the judgment "larger than 5" (relative to incongruent response rule combinations).

Inspired by this approach, Experiment 3 measured the effect of head orientation on numerical magnitude with a more indirect measurement task that dissociated the cueing stimuli from the numerical task. For a better control of the influence of response key, we additionally manipulated the association between response key location and its meaning in terms of magnitude judgment (compare the critique of Fischer & Shaki, 2016). Moreover, while Fischer and Shaki (2016) measured the processing efficiency of different types of spatial-numerical associations, Experiment 3 aimed at mapping the spatial features of numerical magnitude representation more explicitly via free key choice in response to the head orientation pictures.

Participants worked on two tasks that were intermixed in random order: (1) a reaction time task with speeded categorizations of digits into smaller and larger than five and (2) a free choice task in which participants could freely select a response key. Importantly, the same response keys were used for both tasks. The number categorization task was used to create short-term associations between particular keypresses and small and large numbers, which are transferred to the intermixed free-choice task (for a related setup, see De Houwer, Beckers, Vandorpe, & Custers, 2005). We expected that participants would select the response key associated with large numbers less frequently following presentations of down-tilted head pictures relative to up-tilted head pictures (and vice versa with presses of the response key associated with small numbers). Note that the task instructions for the free-choice task had no explicit mapping of numbers (or categories of numbers) to the response keys. Consequently, for a systematic effect of vertical head orientation on the response choices in the free choice task, participants must have inadvertently applied the number-response associations established in the number categorization task to the response choice in the free choice task.

4.1. Methods

4.1.1. Participants

Forty-three volunteers (30 female, 13 male, age = 24.63, range 18-47) participated and received financial compensation for study participation. Due to the absence of reliable a-priori knowledge on the expected effect size, we collected data of n = 43 participants. A sensitivity analysis showed that with this sample size, a medium-sized effect of $d_z \geq 0.38$ could be detected with a statistical power of 1-β = .80 in a matched-samples t-test with the alpha-level set to .05 (calculated with G*Power 3.1).

4.1.2. Apparatus, stimuli, and procedure

Apparatus and pictures were the same as in Experiment 1. In the number categorization task, a digit (1-9 excluding 5) appeared in Tahoma font at the center of the screen for 2,500 ms or until response registration. Half of the participants were instructed to categorize the digit as quickly and as accurately as possible into smaller or larger than five by pressing the “F” and “J” keys of the keyboard, while the assignment was reversed for the other half of the participants. In the trials of the free-choice task, a picture showing a model with a down-tilted or up-tilted head was shown for 2,500 ms or until one of the two response keys was pressed (see Fig. 6). Instructions for this task highlighted that there was no correct response for this task and that participants could freely decide which response key they wanted to press. After an incorrect response (in the number categorization task) or no keypress, a corresponding error message appeared for 2,500 ms. The next trial was initiated after a variable inter-trial interval (400-800 in steps of 100 ms).

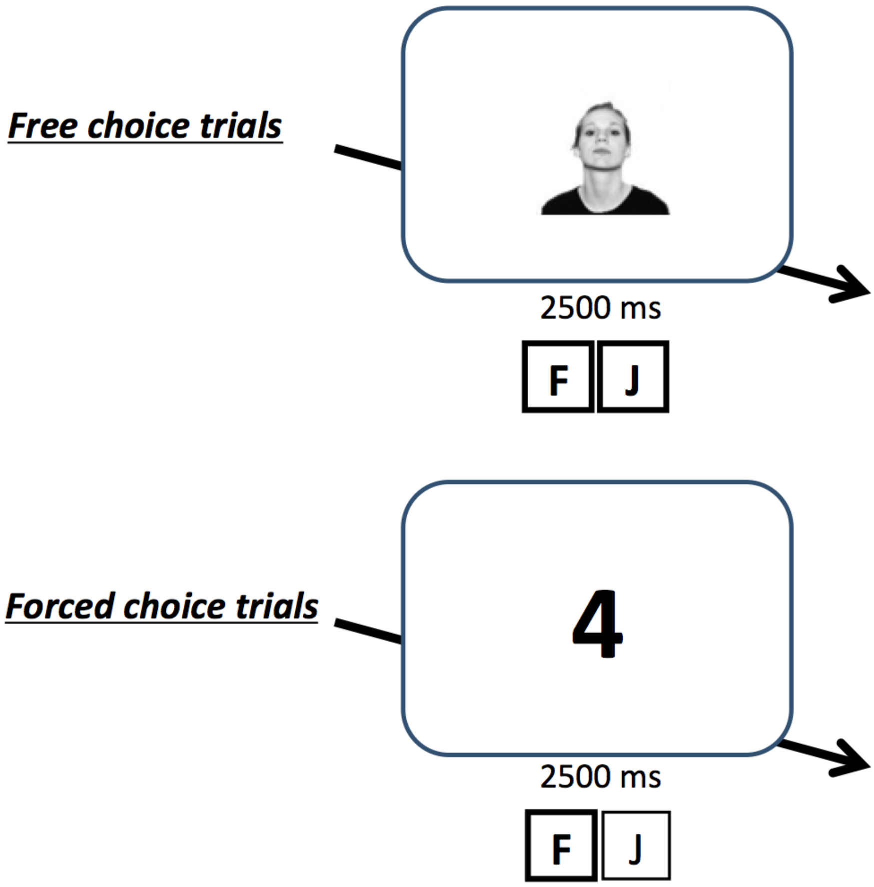

Figure 6. Free choice (top) and forced choice (bottom) trials that were randomly intermixed in Experiment 3.

The experiment consisted of 8 practice trials and three experimental blocks with 36 trials each (total of 108 trials). Within each block, half of the trials were free-choice trials (with picture presentations) and the other half were number categorization trials (with digit presentations). Pictures with straight head positions were not included in this experiment to maximize effect size. Trials and stimuli were presented in random order. Only one of the two pictures of a model was presented in a block. A short resting period with a reminder of the task instructions was allowed between blocks.

4.1.3. Data Analysis

For the free choice trials, the proportion of 'larger'-key presses was computed and submitted to a two-factorial mixed-factor ANOVA with head orientation (tilted downwards vs. tilted upwards) as within-subjects factor and number association (small-left/large-right key association vs. small-right/large-left key association) as between-subjects factor.

4.2. Results

4.2.1. Number categorization task.

The proportion of correct numerical magnitude categorizations per participant ranged from 76% to 100% (*M* = 94.83 % ± *SD* = 4.48%).

4.2.2. Free-choice task.

A response was omitted in 0.3% of the trials because the 2,500ms deadline elapsed before the participant provided a response. The ANOVA showed a significant main effect of head orientation, $F(1,41) = 7.33$, $p = .010$ $\eta_p^2 = .152$. The key associated with larger numbers was selected less frequently following presentations of down-tilted heads (*M* = 0.45 ± *SD* = 0.24) relative to up-tilted heads (*M* = 0.54 ± *SD* = 0.24; see Fig. 7). The exploratively analyzed main effect of number-response association was also below the statistical significance level, $F(1,41) = 5.68$, $p = .022$**,** $\eta_p^2 = .122$. The key associated with larger numbers was chosen less frequently when located to the left (*M* = 0.42 ± *SD* = 0.26) relative to the right (*M* = 0.57 ± *SD* = 0.12). The exploratively analyzed interaction between both factors was not below the statistical significance level, $F(1,41) = 1.87$, $p = .179$.

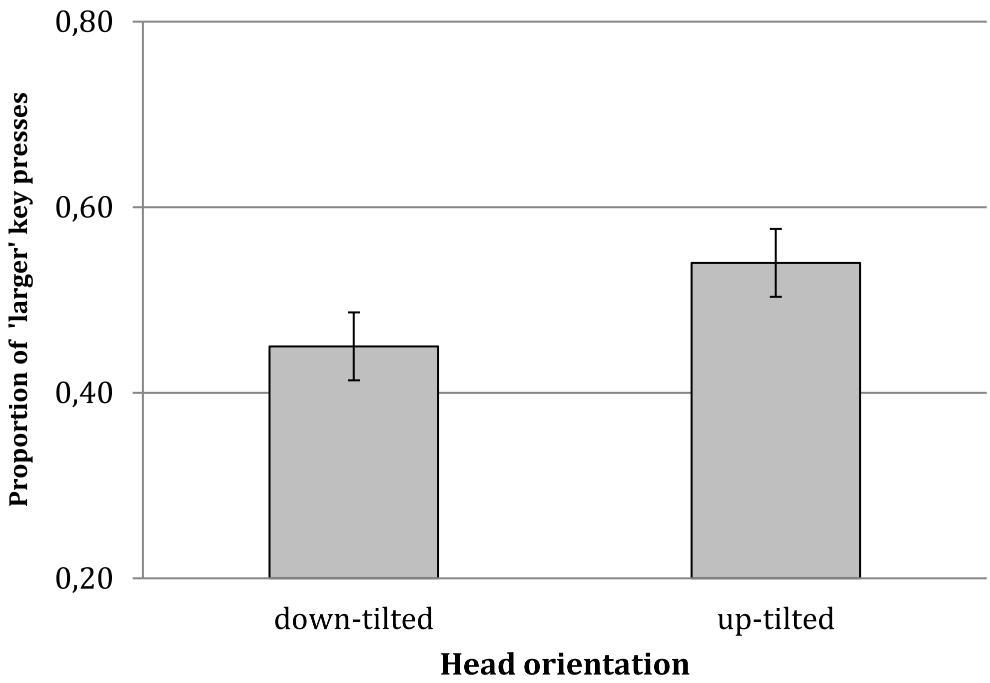

Figure 7. Proportion of ‘larger’ key presses (in %) in Experiment 3 as a function of the model’s head orientation. Error bars indicate standard errors.

4.3. Discussion

The models’ head position influenced response choice in accordance with the hypothesis: The response key associated with larger numbers was pressed more frequently after observing a person with an up-tilted head relative to a down-tilted head. Importantly, this effect was obtained although number processing was irrelevant for the task at hand. Moreover, the head-orientation effect was not mediated by the spatial arrangement of the two response keys on the horizontal axis, arguing against an explanation with a polarity correspondence (Proctor & Cho, 2006). Instead, we propose that the effect of head orientation on the response choice resulted from the activation of spatial codes in a shared cognitive system that is accessed by both person perception and representations of magnitudes (Walsh, 2003).

Notwithstanding this explanation, it should be noted that the explorative analysis of the number-response key mapping data also showed an effect the statistical significance level: The right (left) key was pressed more frequently when the response key was mapped onto the larger (smaller) number category in the number classification task. This SNARC-like effect points at a congruency relation between left responses and small and right responses and large magnitude (see Wood, Nuerk, & Willmes, 2006), which could be explained with an anatomical (i.e. hand-based) association between numbers and (internal) space (e.g. Wiemer, Bekkering, & Lindemann, 2017) or correspondence between numerical and spatial polarity (Proctor & Cho, 2006). Crucially, however, the mapping effect did not interact with the head orientation effect, which means that both effects were unrelated. Consequently, the results show conceptual spatial-numerical associations that can be explained with a transfer of numerical magnitude coding maintained in working memory from the number categorization to the tilted head trials (cf. Fischer & Shaki, 2016; Van Dijck, Abrahamse, Acar, Ketels & Fias, 2014).

5. General Discussion

The present research investigated effects of observed vertical head orientation on numerical cognition. Three experiments showed that participants produced smaller numbers in an RNG task (Experiment 1), estimated smaller quantities in an anchoring-like estimation task (Experiment 2), and chose keys associated with smaller numbers more frequently in a free choice task (Experiment 3) after they had observed a person with a head tilted down relative to a not tilted head and/or up-tilted head. This head-orientation effect was independent of the model's gaze direction, which was always directed towards the camera and, hence, oriented towards the observer. The effect was obtained with different types of numerical judgment tasks, and thus seems to be a robust phenomenon. Furthermore, head orientation influenced response choice when responses became extrinsically associated with large and small numbers through task procedures (Experiment 3), suggesting that the effect is independent of a particular response arrangement. In short, the observation of another person with her head tilted down seems to increase the accessibility of small numerical magnitudes across a broad range of tasks and situations.

5.1. Effects of head cueing on numerical cognition

The present findings are in line with a growing body of behavioral and neuropsychological studies showing that spatial cognition and numerical cognition interact with each other and have overlapping representations and neural substrates (for reviews see Bueti & Walsh, 2009; Hubbard, Piazza, Pinel & Dehaene, 2005; Walsh, 2003). Research suggests that spatial perceptions and spatial attention affect numerical cognition, and vice versa, because numbers and quantities are cognitively arranged on a mental number line: On a vertical axis from low (small numbers) to high (large numbers) and/or on a horizontal axis from the left (small magnitude) to the right (high magnitude) (e.g., Grade, Badets, & Pesenti, 20017; Grade et al., 2013; Sixtus, Lonnemann, Fischer, & Werner, 2019). Importantly, the influence of spatial perception on numerical cognition can also be based on social perceptions such as the perceived (dynamic) gaze shifts of another person to the bottom (left) or to the top (right) (Grade et al., 2013). The present study extends this line of research to social perceptions of another person's (static) vertical head posture, demonstrating that social effects on numerical cognitions are not exclusive to perceptions of gaze direction in close-up view. Moreover, the present research extends previous findings of social number cueing to flexible number ranges typical to anchoring and anchoring-like estimation tasks (see also Eerland et al., 2011). Finally, the present research took efforts to substantiate that the effects of head orientation on numerical cognition are the result of a conceptual link between numbers and space and not of spatial task demands (see Fischer & Shaki, 2016).

A critical question is what process was causally responsible for the head-orientation effect. In our opinion, several possibilities exist. One possibility is that spatial concepts are automatically applied to another's nonverbal cues (gaze, head, body, gestures) during encoding (Langton & Bruce, 2000). Thus, observed behavior can become a prime to numerical cognition through the conceptual link between space and numbers. This explanation would imply that every nonverbal signal that is encoded in a spatial reference frame can bias numerical cognition

(Hietanen; 2002; Langton & Bruce, 2000; Langton, Watt, & Bruce, 2000). An alternative account would explain the effect with a preferential fixation of eyes during interpersonal contact, especially when eye contact is established by the interaction partner (see Senju & Johnson, 2009). As lowered and elevated head postures correspond with a slightly lower and higher positioning of the eyes, participants' attention could have shifted towards lower and higher parts of the display in a corresponding way. As a consequence, these attention shifts could be responsible for the effect.

A completely different third explanation is that the position of the head changed the general appearance of the person, creating particular emotional or communicative impressions. For instance, a person with a lowered head could have been perceived as "angry" or "depressed". Holmes and Lourenco (2011) showed that the perceived intensity of another's emotional facial expression ranging from mild to extreme can affect the speed of left- and right-sided responses in a SNARC-like paradigm, suggesting that magnitude information is also extracted from emotional expressions. According to this line of reasoning, however, the perception of *more* anger (depression, etc.) in displays of a lowered head should have led to *higher* numbers and estimates of magnitudes, while exactly the opposite pattern was observed in the present research. Thus, a lowered head position would have lowered the intensity of a perceived emotional expression relative to the neutral (non-tilted) head posture, which is not very plausible. Future studies could measure eye movements during person viewing to decide between these possibilities.

Independent of its spatial vs. emotional nature, all three explanations explain the results of Experiments 1 to 3 with an automatic process in terms of a common sensory-motoric metric in generalized magnitude codes (Walsh, 2003; Hommel, Müsseler, Aschersleben, & Prinz, 2001) rather than strategic behavior based on propositional inferences (Strack & Deutsch, 2004). Specifically, both the social cueing and the eye fixation explanations rely on sensorimotor simulation of spatial features of the head orientation pictures (cf. Grade et al., 2016; Sixtus, Fischer, & Lindemann, 2017; Hommel et al., 2001). Moreover, Holmes and Lourenco (2011) also identified the level of intensity (rather than the valence) as the relevant dimension underlying speeded right-side responses to emotional expressions in their study. Finally, the separation of the head orientation stimuli and the numerical estimation task in Experiments 2 as well as the numerical judgment task in Experiment 3 renders a strategic response behavior unlikely. In consequence, the observed tilted head pictures presumably prime numerical cognition via a conceptual link between different dimensions of magnitude codes (Walsh, 2003). Taking into account the results of Experiments 1 and 3, the underlying mechanism might best be described as spatial attention-orienting responses to an observed person's visual field orientation (Langton, 2000) that extend to the observer's processing of 'numerical space' (see also Grade et al., 2013).

5.2. Limitations and future research

The present experiments have some limitations. Firstly, only down-tilted head orientation had an effect on number processing. Presentations of up-tilted head orientation in Experiment 1 did not produce larger numbers in the RNG task. This finding indicates that magnitude information is exclusive to or more easily extracted from lowered head orientation, which is in line with demonstrations of a small number bias (e.g. Banks & Hill, 1974; Loetscher & Brugger, 2007) and the compressed shape of the mental number line (e.g. Dehaene & Changeux, 1993; Dehaene et al., 1993). Future research should use larger number ranges that extend the distance between large magnitudes. A second limitation is that only static displays of head postures were used in the present research. Social cueing researchers argue that when gaze and head are not congruent, observers implicitly infer motion (e.g. Pomianowska, Germeys, Verfaillie, & Newell, 2012). Thus, the downward motion implied in the lowered head orientation could have influenced the observers' attention orienting, which in turn affected numerical magnitude operations (be it generated and/or estimated numbers or judgments).

Preliminary results of an unpublished experiment in our laboratory indicate that dynamic displays of head postures have stronger effects on spatial attention orientation. Therefore, future studies might employ head movement instead of static posture stimuli to further elaborate on attention orienting as possible underlying mechanism of numerical magnitude operations (also suggested by neuroimaging studies, e.g. Hubbard, Piazza, Pinel, & Dehaene, 2005; Knops, Thirion, Hubbard, Michel, & Dehaene, 2009).

A third limitation of the present work concern the spatially distributed response keys that participants had to employ across all three Experiments. The present work took efforts to dissociate spatial stimuli (head cues) and spatial responses (response keys) by (1) presenting them sequentially (rather than simultaneously) and (2) by employing horizontally aligned response keys to vertical spatial cues across all three Experiments. Moreover, the results of Experiment 3 can be interpreted preliminarily as indicators of separate congruency effects between external head orientation (down vs. up) vs. anatomical hand location (left vs. right) and numerical magnitude (smaller vs. larger). However, to strip the experimental setup completely from a spatial coding of hand movements, future studies should combine the present sequential approach with a verbal response format.

Fourthly, it should be highlighted that the head postures were not explained to the participants and thus presented without meaningful context. It is likely that a spatial encoding of head postures is conditional and influenced by the social context in which they appear. For instance, a lowered head has a different social meaning when the person is looking down at an object at the floor compared to when she is staring at another person (as in the present studies). Effects of perceived head postures on numerical cognitions may consequently change depending on the social context in which they occur. Future studies may therefore study effects of head orientation as parts of a more complex body orientation in social situations. However, it should be also noted that social stimuli are not necessary for a spatial priming of numerical magnitude operations, as many numerical cognition studies showed (Hartmann et al., 2012;

Hartmann et al., 2014; Holmes & Lourenco, 2012; Woodin & Winter, 2018; for a review, see Winter et al., 2015).

Fifthly, the participants in all three Experiments were German native speakers, even though only the trivia questions in Experiment 2 required proficiency in German language. In line with the suggested grounding of the association between numbers and spatial verticality in the objective organization of the physical world (in accordance with universal laws of gravity; Myachykov, Scheepers, Fischer, & Kessler, 2014; Fischer, 2012), the results of the present research should also be found with other language groups. By contrast, numerical association to spatial horizontality supposedly reflects culture-specific experience like reading direction (an *embodied* representational feature; Myachykov et al., 2014), which is why horizontal cueing effects should be limited to cultures writing from left to right (e.g., based on Latin, Greek, or Cyrillic letters; or vice versa like in Arabic). Future research should empirically test these predictions across samples of participants with other (and/or opposing) writing traditions and language backgrounds.

Finally, most behavioral studies of numerical cognition confounded spatial stimuli and non-spatial responses - or vice versa (see critique of Fischer & Shaki, 2016 and Shaki & Fischer, 2018). Consequently, response priming processes underlying SNARC effects could have resulted from correspondence relations between numerical positive (large) and negative (small) as well as spatial positive (top) and negative (bottom) polarities, respectively (Proctor & Cho, 2006; Roettger & Domahs, 2015). The present experiments aimed at eliminating polarity correspondence relations by presenting the spatial cues and the numerical tasks sequentially rather than simultaneously. Additionally, the number generation and estimation tasks in Experiment 1 and 2 are less prone to spatial confound, because numerical magnitude was not unambiguously mapped onto two spatially arranged keys (and key locations were at right angles with the head orientation manipulation). Most importantly, Experiment 3 used a similar strategy as Fischer and Shaki (2016) to systematically disentangle the spatial arrangement of the response keys and its numerical meaning and found an effect of vertical head orientations on numerical decisions in the absence of a polarity correspondence. Therefore, a conceptual link between numbers and space is an explanation better suited for the present results than the polarity correspondence principle.

5.3. Conclusion

To conclude, social displays such as the vertical orientation of the head can influence numerical cognition based on spatial-numerical associations on a cognitive level. The present experiments integrate findings of social cueing and numerical cognition research. Social cognition research might be interested in the application of the head-orientation effect to social interactions with numerical content like price negotiations. Embodied cognition research might be interested in the situational features of the head-orientation effect (Myachykov et al., 2014) and its potential applicability to other forms of abstract knowledge that are grounded in space (e.g. musical pitch representation, see Loudwin & Bannert, 2017). Finally, let us go back to the person estimating the height of the dome of St Peter's Cathedral in Rome. According to the present research, her estimate might indeed be lower when the friend has a downward oriented head posture. Thus, it might be closer to the correct response of 136.6 meters than the other person's estimate.

Compliance with Ethical Standards

Conflict of Interest: All authors declare that they have no conflict of interest.

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Informed consent: Informed consent was obtained from all individual participants included in the study.

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Data availability

All pictures used in Experiments 1-3, the trivia questions employed in Experiment 2, as well as all the datasets generated and analyzed during the current study are available in the Open Science Framework repository: https://doi.org/10.17605/OSF.IO/RTKDP