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Manipulating number generation: Loud + long = large?

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ABSTRACT

Humans make numerous choices every day and tend to perceive these choices as free. The present study shows how simple free choices are biased by experiencing unrelated auditory information. In two experiments, participants categorized tones according to their intensity on the dimensions *volume* and *duration* on the majority of trials. On some trials, however, they were to randomly generate a number, and we found these choices to be influenced by tone intensity. Particularly, if participants were cued toward volume, loud tones clearly biased participants to generate larger numbers. For tone duration, a similar effect only emerged if spatial information was reinforced by the motor context of the task. The findings extend previous findings relating to the ATOM framework (A Theory of Magnitude) by an explicit focus on auditory magnitude processing. As such, they also constrain ATOM by showing that the connections between different magnitude dimensions vary to a considerable degree.

1. Introduction

Humans make numerous choices every day and many of these choices are made with great ease. Still, the circumstances leading to a particular decision are not obvious at times. Here, we focus on how the concurrent processing of information regarding space, magnitude, quantity, or intensity influences such (putative) free choices. Such information is processed constantly: We have to estimate how many cookies we can take from a plate so that our partner can have a similar amount, we have to use more or less force to lift different objects, and we may listen to quiet or loud music while meandering through the corridors of a shopping-mall. Importantly, such different physical dimensions are not processed independently but several interactions have been reported.

1.1. Common processing of magnitude dimensions

The common processing of different dimensions is evident in both, neurological cases such as synesthesia (e.g. Gertner, Henik, & Cohen Kadosh, 2009; Mann, Korzenko, Carriere, & Dixon, 2009) and in more mundane experimental effects. A famous example for these latter effects is the spatial–numerical association of response codes (the *SNARC effect*; Dehaene, Bossini, & Giraux, 1993; for reviews see Fias & Fischer, 2004; Gevers & Lammertyn, 2005). The SNARC effect describes the observation that smaller numbers are responded to more easily with responses toward a left location whereas larger numbers are responded to more easily with responses toward a right location. This connection of number magnitude and response side suggests that numbers are represented spatially (e.g., Dehaene et al., 1993; Kaan, 2005; Schwarz & Keus, 2004), and even gaze direction was found to be affected by number magnitude, with smaller numbers promoting a left-oriented gaze-direction whereas the opposite is true for higher numbers (Ruiz Fernández, Rahona, Hervás, Vázques, & Ulrich,

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2011). In broader terms, these results are in line with ATOM (“A Theory Of Magnitude”; Walsh, 2003), which suggests a common magnitude system underlying processing of time/duration, space, and quantity.[1]

The ATOM framework has stimulated investigations which suggested the system to process additional information such as intensity in terms of response force (cf. Vierck & Kiesel, 2010), with many results being well in line with the hypothesized common magnitude system. On the other hand, there are also studies arguing for (at least partially) dissociated processing of the mentioned dimensions (cf. Bonato, Zorzi, & Umiltà, 2012). For example, in one study, reliable effects of numerosity on duration processing of visual stimuli emerged, but not vice versa (Dormal, Seron, & Pesenti, 2006). Some further dissociations have been reported from patients with dyscalculia, showing that at least to some degree the dimensions are processed separately (Cappelletti, Freeman, & Butterworth, 2011; Cappelletti, Freeman, & Cipolotti, 2011). Furthermore, there are also reports arguing against a mutual influence of numerosity and duration of *auditory* stimuli in either direction (Agrillo, Ranpura, & Butterworth, 2010).

1.2. Effects on random number generation

Several recent studies that aimed at investigating influences on number processing employed a random number generation task. In such a task, participants are instructed to (verbally) produce random numbers within given limits whilst avoiding any systematic strategies. The concept of randomness is sometimes explained by using metaphors, e.g., to imagine drawing a ball from an urn, saying the number written on it, and putting the ball back. Particularly relevant to the present concern are studies showing that such random number generation interacts with concurrent activities which draw on a spatial component. In one study (Loetscher, Schwarz, Schubiger, & Brugger, 2008), participants performed a random number generation task whilst having their head turned to the left or the right side. They tended to generate more small numbers when turning the head to the left compared to when turning the head to the right, hence an influence of a spatial left/right component on number processing. Converging evidence was later reported in a study showing that spatial changes of eye positions predict differences between successively generated random numbers (Loetscher, Bockisch, Nicholls, & Brugger, 2010). In sum then, spatial features of bodily movements appear to be capable of affecting number processing when operationalized by means of a random number generation task. This effect is consistent with the ATOM framework described above (Walsh, 2003). Whether such effects on number generation generalize to other dimensions is an open question that will be explored in the present study.

1.3. The present experiments

Interestingly, the current formulation of the ATOM framework does not address auditory information, such as the volume or duration of tones, even though this information seems to be processed in the same brain areas that ATOM is ascribed to (Bueti & Walsh, 2009; von Kriegstein, Smith, Paterson, Ives, & Griffiths, 2007). Consequently, one aim of the present study was to test whether earlier findings related to ATOM extend to such auditory information. Building on previous work, we employed a random number generation task to address this question (cf. Loetscher et al., 2008, 2010). Of interest was the influence of auditory stimulation on the generated numbers. Importantly, we used stimuli that varied on two dimensions – volume and duration – and our predictions were as follows:

- If auditory magnitude information is processed within the same system, *volume* should exert an influence as it can be construed as a variation of intensity. Thus, this variation serves as a benchmark test whether or not our auditory stimuli can influence random number generation in principle. In light of earlier studies (e.g., Vierck & Kiesel, 2010) we predicted intense, loud auditory stimulation to bias participants toward generating larger numbers.
- For the *duration* component opposing predictions can be derived from the literature. On the one hand, based on a common magnitude system an influence appears likely (Bueti & Walsh, 2009). On the other hand, however, the available evidence for partial dissociations and a lacking influence from duration on number processing, suggests that tone duration may not have any influence on number processing (Agrillo et al., 2010; Dormal et al., 2006).
- In any case, we further expected influences from the volume or the duration dimension of the tones to occur only if participants attended the respective dimension. This prediction was based on the fact that similar attentional modulations were already reported for the SNARC effect. For instance, the SNARC effect occurs reliably if participants have to categorize numbers according to their parity (e.g., Dehaene et al., 1993). It vanishes, however, if the task does not require participants to process number identity but a number’s ink color instead (Fias, Lauwereyns, & Lammertyn, 2001).

We report two experiments in which participants performed a categorization of tones as to whether they are quiet vs. loud (volume) or short vs. long (duration). The relevant dimension was cued immediately before tone onset. Crucially, on

[1] For a comprehensive overview on research on interactions between space, time, and number processing we refer the reader also to chapters in a recent book edited by Dehaene and Brannon (2011). It should also be noted that “number processing“ in this context may refer to different aspects such as quantities, numerical magnitude, or numerosity. Throughout this manuscript, we use the most precise concept possible to describe each finding, even though all concepts ultimately relate to number processing as a whole.

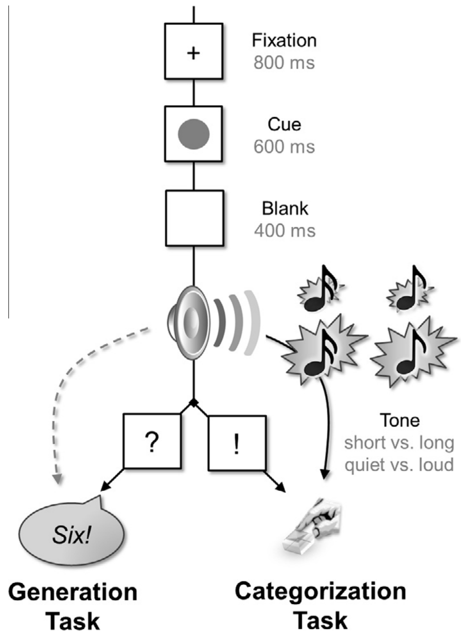

Fig. 1. Trial procedure in Experiment 1. A cue indicated the to-be-attended dimension (volume or duration) of a following tone. After tone offset, participants either were (1) to press a response key depending on the cued characteristic of the tone ("categorization task") or (2) to generate and speak out a random number from 1 to 9 ("generation task").

some trials participants were to randomly generate a number instead of performing the categorization task, allowing us to address the impact of the now-irrelevant tone on number generation.

2. Experiment 1

Experiment 1 was run to test the hypothesis that auditory stimulus intensity can bias random number generation. On each trial, participants heard a tone that varied on the two dimensions *volume* (quiet vs. loud) and *duration* (short vs. long). They then performed one of two tasks: The *categorization task* demanded for categorizing the just-heard tone on one of these dimensions according to a preceding cue. This task was employed to force participants to attend the tones, especially with regard to the cued dimension. In the *number generation task*, participants had to randomly generate a number from 1 to 9. Specifically, we expected high-intensities of the cued dimension (loud/long) to bias participants toward generating larger numbers, whereas we expected a reduced and possibly absent effect for the uncued dimension.

2.1. Method

2.1.1. Participants, apparatus, and stimuli

Twenty-two undergraduate students were recruited (16 female, mean age: 23.2 years) and reported normal or corrected-to-normal vision and hearing. Dimension cues were a square and a circle, about 1.5 cm in diameter, presented in white against a black background. Target stimuli were four tones (440 Hz; presented via headphones) that varied in duration (200 ms vs. 800 ms) and volume. The tones were generated with Audacity (http://audacity.sourceforge.net); loud tones were generated with amplitude ten times higher than of the quiet tones. Responses were made with both index fingers on two external response keys in front of the participants.

2.1.2. Procedure

Fig. 1 illustrates the trial procedure. Each trial started with a fixation cross (800 ms), followed by a cue (600 ms) indicating whether the subsequent tone was to be categorized regarding its volume or its duration. We assume that participants attended the cued dimension, whilst the other dimension was likely unattended. After a blank screen (400 ms), one of the four possible tones was presented (volume: quiet vs. loud; duration: short vs. long), followed by a centrally presented exclamation mark (in 384 of the 504 trials) or question mark (in 120 of the 504 trials). An exclamation mark indicated the *categorization task*, and participants responded to a high-intensity tone (loud/long, depending on the cue) by pressing the right response key and to a low-intensity tone (quiet/short) by pressing the left response key as quickly as possible. A question mark indicated the *number generation task*, and participants were to choose and speak out a digit (1–9) as fast as possible. Participants were instructed to generate this digit as spontaneously and randomly as possible without relying on any type of strategy. The digit was registered by the experimenter (who sat behind a screen and was not visible to the participants).

Both tasks were randomly intermixed and, obviously, only the generation task was directly relevant for the present hypotheses. The categorization task was only applied to ensure that participants (a) attended to the cued dimension of the tone in each trial and (b) did not prepare a number to report in advance. After the experiment, participants answered a questionnaire asking whether they had participated in similar studies, whether they used a certain strategy, and what they thought the purpose of the experiment was. On this basis we excluded from further analyses participants who correctly inferred the purpose of the study or reported a strategy that would support the current hypotheses (five participants in total). This seems necessary to us in order to preclude an artificially inflated effect. Note that inclusion of these participants did not change the pattern of results, but rather increased the observed effects.

2.2. Results

The analyses focused on the number generation task. Prior to analyses, we excluded trials with response times (RTs) of the generation response deviating from the corresponding cell mean by more than 2.5 standard deviations (2.1% of all trials). We then computed means of the generated numbers for each of four cells resulting from crossing the factors 'dimension' (volume vs. duration), and 'intensity of dimension' (high vs. low), separately for when a respective dimension was cued or not. These data were then submitted to separate 2×2 repeated-measures Analyses of Variance (ANOVA) for each cue condition (i.e., whether the analyzed condition was cued and thus presumably attended or not). The detailed means (and standard deviations) on which the ANOVAs were run are given in Table 1. First, the ANOVA for the uncued condition revealed no significant effect ($ps > .239$). In contrast, the ANOVA for the attended condition revealed a significant main effect of intensity: Digits named after high-intensity tones were significantly larger than those named after low-intensity tones, $F(1,16) = 7.10$, $p = .017$, $\eta_p^2 = .31$. Neither the main effect of dimension nor the interaction was significant ($ps > .239$).

To follow up on these results, we calculated planned comparisons on intensity effects (high-intensity tones–low-intensity tones) which are illustrated in Fig. 2 (left panel). The one-sample t-tests against zero were significant for both dimensions if they were cued, volume, $t(16) = 2.49$, $p = .024$, d = 0.60, and duration, $t(16) = 2.37$, $p = .031$, d = 0.57.

To support the above analyses, we re-analyzed the data by only considering whether a high- or low-intensity tone made participants generate a small number (1–4) or a large number (6–9; cf. Badets, Bouquet, Ric, & Pesenti, 2012; Loetscher et al., 2008).[2] Accordingly, we repeated the above ANOVAs on the mean percentage of large numbers generated by the participants for each combination of experimental factors (see Table 1). The results mirror those reported above. When analyses were run on the uncued dimension, no effect approached significance in the corresponding ANOVA ($Fs < 1$). In contrast, when the dimensions were cued, the ANOVA again yielded a significant main effect of intensity: Participants named more large numbers after high-intensity tones than after low-intensity tones, $F(1,16) = 7.85$, $p = .013$, $\eta_p^2 = .33$. Neither the main effect of dimension nor the interaction was significant ($Fs < 1$). Considered separately, the intensity effect (high-intensity tones–low-intensity tones) was again significant for both dimensions if cued, volume, $t(16) = 2.81$, $p = .013$, d = 0.68, and duration, $t(16) = 2.25$, $p = .038$, d = 0.55.

To test whether the uncued dimension of each tone did have any impact at all (even though it did not influence number generation), we analyzed mean RTs of the categorization task with a 2×2 repeated-measures ANOVA with the factors cued dimension (volume vs. duration) and congruency of cued and uncued dimension (congruent vs. incongruent). This analysis was run on correct trials only (92.9%) and we corrected for outliers by removing trials in which the RT deviated more than 2.5 standard deviations from the corresponding cell mean (2.6%). Descriptively, participants responded faster when both dimensions were congruent[3] than when they were incongruent, both when attending to volume (576 ms vs. 610 ms) and when attending to duration (582 ms vs. 620 ms). These observations were supported by a significant main effect of congruency, $F(1,16) = 10.31$, $p = .005$, $\eta_p^2 = .39$, whereas neither the main effect of (cued) dimension nor the interaction approached significance ($Fs < 1$).

2.3. Discussion

Experiment 1 investigated whether the processing of irrelevant tone intensity (volume and duration) affects free number generation. Consistent with ATOM (Walsh, 2003), tone intensity influenced choice of digits, and larger digits were generated after high-intensity tones (long and/or loud). This influence was further confined to the attended dimension: Tone volume affected digit choice only when participants were cued to attend to volume, and tone duration only yielded an influence when participants were cued to attend to duration. This influence was present although participants were not aware of the purpose of the experiment. In line with recent other findings (Loetscher & Brugger, 2007; Loetscher et al., 2008), there is a tendency in the data of this experiment to generate more small than large numbers and the grand mean across the analyzed conditions was 4.54. However, this bias does not undermine our conclusions as it conceivably is present for all analyzed conditions and thus does not create a confound.

Note that even duration exerted an influence, a finding apparently contrasting findings from other studies (e.g., Agrillo et al., 2010). One might, however, suspect a causal role of the spatial left/right dimension for our findings: Although participants never performed a left/right button press in number generation trials, they might well have planned such a button

[2] We thank an anonymous reviewer for this suggestion.

[3] Congruent means that both dimensions would afford the same response.

Table 1
Descriptive statistics of the digits generated in Experiments 1 and 2, as a function of cued dimension, tone volume, and tone duration. The upper half of the table shows condition means and standard deviations whereas the lower half shows the mean percentage of large numbers (6–9) as compared to small numbers (1–4) and the corresponding standard deviation.

Dependent variable	Tone duration	Tone volume	Experiment 1 Cued dimension		Experiment 2 Cued dimension	
			Volume	Duration	Volume	Duration
Mean number	Short	Quiet	4.22 (1.32)	4.01 (1.24)	5.13 (0.96)	4.98 (0.85)
		Loud	4.78 (0.73)	4.01 (1.06)	5.10 (1.12)	5.12 (1.09)
	Long	Quiet	4.12 (0.99)	4.84 (1.19)	4.53 (1.08)	5.19 (0.89)
		Loud	5.26 (1.22)	5.06 (1.31)	5.34 (1.26)	4.89 (1.21)
Percentage of large numbers	Short	Quiet	36 (19)	30 (21)	49 (22)	47 (20)
		Loud	45 (19)	31 (21)	51 (25)	52 (24)
	Long	Quiet	29 (16)	47 (24)	38 (25)	51 (22)
		Loud	54 (24)	50 (25)	54 (29)	45 (26)

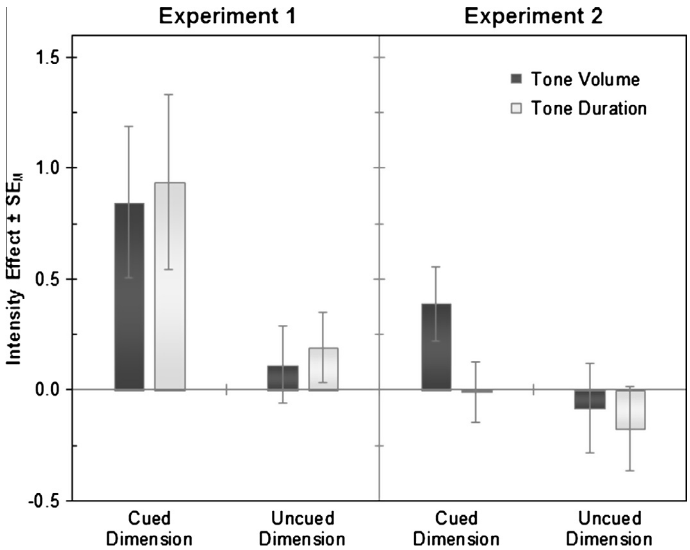

Fig. 2. Intensity effects in both experiments, calculated as the mean difference of generated numbers after high-intensity and low-intensity tones. Error bars represent the standard error of each intensity effect (cf. Pfister & Janczyk, 2013).

press in expectation of an upcoming cue for the categorization task. Accordingly, the spatial left/right dimension may have mediated the effects of stimulus intensity and our findings might not be due to tone intensity (volume/duration) directly. In addition, the mere presence of the spatial left/right dimension may have increased the sensitivity of the magnitude system (which includes a spatial component; Walsh, 2003), and could thus be a necessary precondition for other dimensions to exert an influence as we have observed here. This issue was addressed in Experiment 2.

3. Experiment 2

Experiment 2 explored the influence of tone intensity on number generation while controlling for the spatial dimension of the categorization task. In the categorization task, participants now responded by mouse-clicking on a response field above or below fixation; the position of the correct answer was randomly chosen in each trial and could thus not be anticipated. Accordingly, any remaining influence on number choice has to be driven by auditory stimulus intensity directly.

3.1. Method

3.1.1. Participants, apparatus, and stimuli

Nineteen undergraduate students (17 female, mean age: 20.6 years) were recruited and fulfilled the same criteria as in Experiment 1. Stimuli were identical to Experiment 1 with one exception: Two white boxes (4 cm × 3 cm) served as response fields and were presented above or below fixation.

3.1.2. Procedure

Trials were similar to Experiment 1 with one critical modification. Following the tone, the white boxes appeared 2.5 cm above or below the center of the screen. These boxes contained the words QUIET/SHORT and LOUD/LONG, respectively (in German language). The mapping of these word-pairs to the boxes was randomly chosen on each trial. In 512 of the 672 trials, a centrally presented exclamation mark prompted participants to click as quickly as possible on the box that correctly described the tone. In the remaining 160 trials, a question mark appeared instead of the exclamation mark, prompting participants to generate a digit as fast as possible. After the experiment, participants were asked the same questions as in Experiment 1. One participant correctly guessed the purpose of the study and was excluded from the analyses.

3.2. Results and discussion

The same analyses as in Experiment 1 were conducted and we excluded 2.2% of the trials as outliers due to the same criterion as in Experiment 1. First, and as in Experiment 1, the ANOVA (see Table 1 for detailed descriptive statistics) on the data when the dimensions were uncued revealed no significant effects (*ps* > .298). Secondly, considering the data from the cued dimensions, the ANOVA revealed no significant main effects (*ps* > .150). Importantly, however, the interaction was significant, $F(1,17) = 5.10$, $p = .037$, $\eta_p^2 = .23$. Follow-up *t*-tests on the intensity effects (see Fig. 2, right panel) showed that this interaction was driven by a significant intensity effect for volume, $t(17) = 2.31$, $p = .034$, d = 0.54, and a non-significant intensity effect for duration, $t(17) = -0.07$, $p = .946$, d = −0.02.

We also analyzed the data by only considering whether a high- or low-intensity tone made participants generate a small number (1–4) or a large number (6–9; see Table 1). The corresponding ANOVA for the cued dimensions yielded no significant main effects (*ps* > .161) but a marginally significant interaction, $F(1,17) = 4.28$, $p = .054$, $\eta_p^2 = .20$. Considered separately, the intensity effect was significant for volume, $t(17) = 2.54$, $p = .021$, d = 0.60, but not for duration, $t(17) = -0.39$, $p = .700$, d = −0.09. No effect approached significance in the ANOVA for the uncued dimensions (*Fs* < 1).

Finally the RT data of the categorization task fully replicated the results of Experiment 1 (percentage correct: 90.8%; removed outliers: 2.6%). Participants were again faster when cued and uncued dimensions were congruent as compared to incongruent both, when attending to volume (1071 vs. 1095 ms) and when attending to duration (1045 vs. 1085 ms). These differences gave rise to significant main effect of congruency, $F(1,17) = 5.81$, $p = .028$, $\eta_p^2 = .25$, whereas the main effect of the (cued) dimension and the interaction failed to reach significance (*ps* > 286).

In sum, participants again generated larger numbers following loud tones than following quiet tones, when tone volume was cued and thus the attended information. Notably, this was the case even in the absence of spatial left/right features of the responses. In contrast, no influence on number generation was observed for the tone duration dimension.

4. General discussion

The present study examined the impact of auditory stimulus intensity on random number generation. From the viewpoint of a common magnitude system processing space, time, and magnitude (Walsh, 2003), stimulation of one of the dimensions should also activate its other dimensions. Regarding these collateral activations, response intensity was previously shown to interact with other dimensions as well (Vierck & Kiesel, 2010), but a similar impact of auditory stimulation has not been addressed by previous research (see also Bueti & Walsh, 2009). To this end we based our experiments on previous findings by Loetscher et al. (2008, 2010), who showed that spatial (left/right) body orientations and eye-movements influence random number generation. For example, and in line with what can be expected from the ATOM framework (Walsh, 2003), leftward body orientations resulted in a bias towards producing more small numbers than rightward body orientations did. In contrast to body movements or orientations, stimuli of the present study were either quiet vs. loud (volume dimension) and short vs. long (duration dimension) tones. If auditory stimuli have a similar impact as previous results suggest (e.g., Vierck & Kiesel, 2010), one can assume loud and/or long stimuli leading toward the generation of larger numbers.

In Experiment 1, long tones biased the participants to generate larger numbers, if participants attended to tone duration. Likewise, larger numbers were named after loud tones when participants attended to volume. In Experiment 2, we removed the spatial left/right dimension prevalent in the design of Experiment 1. Still, an influence of stimulus intensity on number choice emerged for volume, not though for duration. This finding suggests that indeed stimulus intensity alone can activate the number magnitude dimension and thus influence number generation. The lack of an effect of tone duration in Experiment 2 might reflect a stronger connection between the magnitude representation and tone volume as compared to tone duration. This interpretation fits with the notion that duration-dependent interactions of time and numbers (so-called TiN-ARC effects) are usually less stable than those between other dimensions (e.g., Fabbri, Cancellieri, & Natale, 2012). A recent study also casts doubt on the interpretation of previous findings related to duration (Yates, Loetscher, & Nicholls, 2012), further supporting the weaker connection of tone *duration* and other information represented in the ATOM framework, even though this information seems to be processed in the same brain areas that ATOM is ascribed to. As such the results are quite compatible with studies showing no influence from duration on number processing, either with visual (Dormal et al., 2006) or auditory stimuli (Agrillo et al., 2010). Admittedly, our data does not allow assessing whether or not an influence of the reversed direction would emerge. As has been suggested by others (e.g., Cappelletti, Freeman, & Butterworth, 2011; Cappelletti, Freeman, & Cipolotti, 2011), our results indicate a substantial overlap between various magnitude dimension (Walsh, 2003), yet at the same time this overlap is not overarching but some dimension-specific processing must be assumed. Otherwise duration should have left more reliable traces in number processing as well.

In any case, a direct comparison of both experiments reveals a considerably stronger effect in Experiment 1 where the impact of tone volume and tone duration could have been mediated by the spatial dimension of the intermixed categorization task. In other words, processing a spatial dimension might have increased the general sensitivity of the magnitude system (Walsh, 2003). Interactions of different aspects of the magnitude system thus seem to depend on how information can be used to guide own motor actions. Converging evidence for this claim comes from a recent experiment on the impact of observed motor actions on number generation (Badets et al., 2012). More precisely, this study found that observing closing grips biased participants towards generating smaller numbers as compared to an opening grip. Furthermore, this bias was only present for biologically plausible hand stimuli but not for similar non-biological stimuli. Thus, the number representation within the magnitude system seems to be closely tied to own motor actions (see also Badets & Pesenti, 2010, 2011), and number choices are especially influenced if this choice can be mapped onto current actions.

On a different note, our findings also relate to the idea that heuristics are used when decisions have to be made in situations of uncertainty (Mussweiler, Englich, & Strack, 2004; Strack & Mussweiler, 2003; Tversky & Kahneman, 1974). For instance, the anchoring and adjustment heuristic is recruited in situations in which participants have to make a best guess on a quantity such as the result of a rather complex mathematical operation (e.g., Mussweiler et al., 2004). Here, any preceding or concurrent activation of another quantity biases the generated numbers. From a perspective of the ATOM framework, this effect can be seen as a direct interplay of two representations relating to numerical magnitude. The present setup might similarly be construed as a highly uncertain setting because none of the nine possible responses in the number generation task was any more correct/incorrect than the others, so one can expect participants to feel some uncertainty about the most appropriate response. In this situation, experiencing activation in one dimension of the magnitude processing system (e.g., tone volume or spatial features) may be construed as a heuristic that biases choices regarding another dimension (number magnitude).

Even though some heuristics imply a conscious component (such as the fluency heuristic, Volz, Schooler, & von Cramon, 2010), the present mechanism is rather implicit than explicit. Suggestive in this regard is the fact that the participants whose data was analyzed did not report awareness of purpose of the study or the application of a strategy in favor of our hypotheses. Of course, however, a definite conclusion regarding this point needs a different experimental approach to ensure that the irrelevant information is indeed processed unconsciously (cf. Kiesel et al., 2006; O'Connor and Neill, 2010). In any case, our data shows that random number generation can be biased by encountering auditory stimuli assumed to activate a common magnitude system. The present results and their implied constraints regarding mutual interactions between dimensions of a magnitude system can be summarized as follows: First, if stimuli have more than one dimension, only the attended one biases random number generation. Secondly, duration processing seems not to affect number processing (see also Agrillo et al., 2010; Dormal et al., 2006). Finally, volume – in contrast – reliably biases number generation in the predicted way, thus extending the ATOM framework (Walsh, 2003) to auditory stimulation.

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