



Judging risk magnitude: walking to the left and base jumping to the right

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Abstract

When thinking about quantifiable domains such as numbers, pitch, and size, they are implicitly mapped on to representational space with small/low/less and large/high/more of the respective domain represented on the left and right sides of representational space, respectively. Recent research has also demonstrated that more abstract domains (colours, language, political party names) are also mapped in the same way. This study investigated a new abstract domain, risk, to examine if this same pattern of effects is apparent (left = low risk/right = high risk) to get a better understanding of how risk magnitudes are processed. Experiment 1 ($n = 26$) presented objective, statistically calculated risk stimuli (micromorts) to participants, who indicated if the stimuli had lower or higher risks than a referent, with their left and right hands. Experiment 2 ($n = 25$) utilised the same task, but the risk stimuli were generated by the participants themselves. Both experiments found the expected association of risk with space—indicated by faster left-hand responses to low-risk stimuli and faster right-hand responses to high-risk stimuli. Risks appear to fit onto a standard left–right spatial association; however, the effect sizes for all analyses were small. The results of this study are not only in line with the idea of a generalised magnitude processing system, but might also inform best practices in effective communications of risks.

Keywords Spatial associations · SNARC · Distance effect · Risk communication

Introduction

The organisation of numbers in representational space typically occurs in an intrinsic and implicit manner. For example, if asked to judge number parity, people from Western cultures, on average, will respond faster to smaller numbers with their left hands and faster to larger numbers with their right hands. This phenomenon is called the spatial numerical association of response codes (SNARC; Dehaene et al. 1993). The mapping of small and large numbers onto the left and right sides of representational space, respectively, has been replicated in various experiments (see Wood et al.

2008 for a review); demonstrating that a higher order spatial categorisation is taking place within the mind.

There is strong evidence that this spatial mapping is not just restricted to numbers, but rather is apparent for many domains with a difference in magnitude (i.e. small/large, low/high, short/long, etc.; see Macnamara et al. 2017 for a review). Numerous studies (e.g. Fabbri et al. 2013; Santiago et al. 2007; Sellaro et al. 2015) have demonstrated that non-number constructs, such as pitch and time, can also be spatially mapped in a left–right manner. For example, an experiment on musical elements has found that low-pitch tones (e.g. C3/G3) are responded to faster with participants' left hands and high-pitch tones (e.g. E5/B5) are faster with the right—hence a SNARC-like effect (Lidji et al. 2007). Likewise, past (e.g. yesterday morning) and future (e.g. tomorrow afternoon) stimulus words are explicitly mapped onto space, indicating that time is also conceptualised on a horizontal line (Ding et al. 2015).

As there is already overwhelming evidence validating the SNARC and SNARC-like effects, newer research is moving beyond the traditionally quantified areas (numbers, time) and attempting to investigate more abstract spatial concepts,

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domains where the distinction in stimuli is not easily measurable (Macnamara et al. 2017). Colours are one example of a successful spatial mapping where the categorisation of stimuli is related to ordinal information rather than from a continuum (Zhang et al. 2016). The colours such as red, orange, yellow, green, blue, indigo and violet were organised from left to right in representational space based on the participants' awareness of the order of the rainbow (Zhang et al. 2016). Relational reasoning statements ($A > B > C > D$) can also generate horizontal spatial associations (Prado et al. 2008), as well as left-wing and right-wing political party names (van Elk et al. 2010). Thus, why is it that a theoretical concept that is fundamentally based on discrete categorisations so easily adapts to metaphorical constructs?

A potential answer may lay with one of the most researched non-quantifiable spatial domains: letters of the alphabet. The substantial evidence showing spatial mappings for letters has typically been attributed to the spatial processing of ordinal sequences (Gevers et al. 2003; Shaki and Gevers 2011). Just like with colours, in the absence of quantitative information to spatially organise the domain, people may instead categorise and place the data in a horizontally ordered manner. On reflection, this is not all that different from how numbers would be processed in space. For example, the number 8 would be judged as a large number in an experiment on the numbers 1–9 (Dehaene et al. 1993). Yet if the experiment included numbers from 1 to 100, then the number 8 would clearly be judged as small. Hence, spatial associations of numbers are also relative to where a stimulus is in an ordered sequence (Dehaene et al. 1993).

Another consequence of unconscious spatial processing, which is heavily reliant on ordered sequences, is the distance effect. If asked to identify the larger of two numbers, it takes less time to complete as the numerical distance between the numbers increases. That is, it is quicker to identify '9' as being larger if the alternative option is '2' than if the alternative is '7' (Moyer and Landauer 1967). In a SNARC comparison judgement task (e.g. number lower/higher than a referent number), the distance effect is evidenced by increasingly faster judgments as the numerical distance between the number and the referent increases (Dehaene 1997; Viarouge et al. 2014). For example, in relation to the referent 5, the numbers 1 and 9 are judged significantly faster than the numbers 4 and 6. An important feature of the SNARC and distance effect phenomena is that people typically are not aware that these spatial associations are taking place.

The purpose of this study is to examine a new abstract domain that has yet to be examined using a SNARC or distance effect framework: risk. It is hypothesised that because other abstract constructs have been conceptualised into orders, we will be able to assimilate risk into a similar magnitude scale: low to left and high to right. Thankfully, a measure of risk already exists: micromorts. Micromorts

(μmt) index the acute risk of death, whereby one micromort equals a one-in-a-million chance of dying from a sudden event, per day (Fry et al. 2016; Spiegelhalter 2014). The term micromort was originally coined in the medical field to assist in communicating risk levels to the patients (Gompertz 1825; Spiegelhalter 2014). For example, giving birth via caesarean section has 170 μmt , which means that 170 women out of one million die from a caesarean (Ahmad et al. 2015).

In contrast to prior research on spatial mappings, investigating risk in this manner is truly unique because even micromorts are on a continuous scale, not (directly) ordinal. Micromort activities vary from 10 μmt , 66 μmt , 92 μmt to 297 μmt , and so on, depending on the activity (Fry et al. 2016). Therefore, unlike numbers where it is common knowledge that 1 precedes 2, which precedes 3, and onwards, the participants may be unaware that rock climbing has a lower risk than skydiving, which in turn has a lower risk than base jumping. There will be a great reliance on the participants' own understanding of risky activities. Indeed, if the participants cannot understand the difference between low-risk and high-risk activities, then the spatial associations may not be able to manifest at all.

As such, we will also be able to examine how well people can make accurate judgments about risk (Keage and Loetscher 2018). In terms of broader implications, in the field of medicine in particular, being able to effectively communicate the risk of a medical procedure is central to informed consent (Ahmad et al. 2015; Fry et al. 2016). Patients who do not comprehend the risks for which they are providing consent for may put their lives in danger without realising it. Therefore, this experiment will not only attempt to demonstrate the commonalities between spatially processing quantifiable and non-quantifiable magnitudes, but may also provide insights into how people conceptualise risk.

Already, research suggests that a better understanding of risk perception may help to improve the communication of risks to the public. Both Spiegelhalter (2017), and Garcia-Retamero and Galesic (2010) report that the visual formats (e.g. percentages, frequency, graphics) used when presenting risk information can significantly affect how the message is comprehended; and further, that it is critical to develop optimal risk communication visual aids, for individuals to understand potential risks such as health and medicine (Galesic et al. 2009). To accomplish this, those who are in charge of promoting risk and safety, need to first understand how people conceptualise and respond to risk information (Slovic 1987). In this study, if we can provide evidence for the spatial organisation of risk being on a left-to-right framework, this knowledge could be integrated into our current understanding of risk, to facilitate the creation of more beneficial visual communication aids that utilise visuospatial elements.

Finally, in addition to the implications for risk communication, the expansion of the SNARC framework into yet another abstract domain could also provide evidential support for A Theory of Magnitude (ATOM). ATOM purports the existence of a generalised magnitude system, whereby all types of spatial associations share a common processing mechanism within the brain (Buetti and Walsh 2009; Walsh 2003). For every domain (e.g. numbers, time, colours, etc.) which can be successfully mapped onto space, more support is given for this theory. The intention of this study is to demonstrate that low-risk activities and high-risk activities are yet another abstract domain which can be spatially represented in the same left-to-right manner, respectively.

Experiment 1: objective risk

A comparison judgement task was employed to investigate whether risk can be mapped on space. Using objective, statistically standardised risk stimuli (micromorts), it was expected that low risks would be mapped on the left and high risks on the right. In reference to the distance effect, it was expected that extremely low-risk and extremely high-risk activities would be easier (i.e. faster and more accurate) to judge than activities only slightly lower or higher in risk than the referent.

Methods

Participants

Twenty-eight adults participated. Six men and 22 women were between the ages of 18–33 ($M = 23.52$, $SD = 4.14$), native English speakers, right handed (as determined by the Flinders Handedness Survey, Nicholls et al. 2013), and had corrected-to-normal vision. Participants were recruited at University of South Australia campuses and through an online research participation system. They were compensated for their time with a \$10 honorarium. All participants gave informed consent and the study was approved by the Human Research Ethics Committee at the University of South Australia.

Materials

The stimuli (see Table 1) were words indicating activities extracted from micromort research (Blastland and Spiegelhalter 2013; Fry et al. 2016; Irwin and Kong 2014; Soreide et al. 2007). Four low-risk, four high-risk and two referent micromort activities were selected. The low- and high-risk stimuli were the same for all participants, while the referent activity was counterbalanced across participants. Participants were not informed of the specific micromort values nor the low- or high-risk categorisations. The text was black, on a white background, with size 22, Courier New font. The text was 5 mm tall, aligned in the centre and had a vertical visual angle of 0.57° . As the stimuli words were of different lengths, the horizontal visual angle alternated between 2.86° and 7.67° . There were no visual angle differences between the stimuli representing low and high risks ($p > 0.05$).

The experiment was conducted using EPrime (Psychology Software Tools, Inc. [E-Prime 2.0] 2012). Stimuli were presented on a 580-mm (width), LCD (Model: DELL P2314Ht), 1920×1080 resolution computer monitor. The risk judgements and reactions times were recorded on an E-Prime response box (model 200A), with the left and right buttons 65 mm apart. Participants were seated 500 mm from the screen, at a desk 720 mm tall.

A Risk Perception Form was developed by the authors to capture the participants’ subjective beliefs of the risk level for each stimulus. The activities, including the referents, were presented in a vertical list and the participants were asked to rank them from low risk to high risk (1–10, respectively) in terms of how risky they believed the activities were.

Procedure

Participants completed four trial blocks, where each of the eight stimuli were randomly presented ten times per block (4×80 trials). Trials began with a fixation point in the centre of the screen for 500 ms. A target word then replaced the fixation. During this time, participants were instructed to judge as quickly as possible whether the presented stimulus had a lower or higher risk than the assigned referent. Judgements were made on the response box with the index fingers of the left and right hands. The assignment of risk magnitude (low/high) to response hand (left/right) was counterbalanced by block and by participants (ABBA or BAAB). For example, (A) left

Table 1 Micromort (μmt) activities

Low-risk activities	Referent activities	High-risk activities
Walking (44 km): 1 μmt	Skydiving: 10 μmt	Giving birth: 120 μmt
Commercial aircraft (12,070 km): 1 μmt	Anaesthesia: 10 μmt	Coal mining: 430 μmt
Cycling (90 km): 2 μmt		Base jumping: 430 μmt
Rock climbing: 3 μmt		Climb Mt. Everest: 12,000 μmt

hand=low risk/right hand=high risk vs. (B) left hand=high risk/right hand=low risk.

Following a response, or if no response was detected within 2000 ms, the stimulus would disappear. A 250-ms inter-trial break, with a blank screen, ended each trial (see Fig. 1 for trial sequence). A ten-trial practice block preceded each side of response change (3×10 trials), providing participants with the chance to adapt to the new response mappings. These practice trials were excluded from data analysis. Participants were offered a minute break between blocks. The testing session finished with the Risk Perception Form. Each session was approximately 15 min.

Statistical analysis

The raw reaction time (RT) data were screened and RTs greater than 2000 ms or less than 100 ms (invalid responses) were excluded from further analyses. All inaccurate response trials were removed as well, based on the three categorisations: objective risk, subjective response and subjective rank.

Three linear mixed-effects regression models with individual trial data and ID set as a random intercept were conducted in STATA v15.1, at 0.05 alpha level, to test for a SNARC-like effect. All models had RT as the outcome. The first model had three predictor (fixed effects) variables: side of response (right 1, left 2), magnitude (low 1, high 2), and an interaction between side of response and magnitude. The second model analysed the same three predictors; however, the low- and high-risk magnitudes were based upon the participants' actual responses during the experimental task—i.e. whether they judged a stimulus as low or high risk—instead of objectively categorising magnitude according to the micromorts. The low- and high-risk magnitudes in the third model were defined by how the participants ranked the activities relative to the referent on the Risk Perception Form.

As the first analysis focused on objectively categorised risk and the latter two models were structured to suit the participants' individual perspectives, the models were named objective risk, subjective response, and the subjective rank,

respectively. Preliminary analyses revealed that the variables such as age, gender, referent, and counterbalanced order did not affect RT, thus they were not included in the final models.

A final mixed-effects model was conducted to examine the distance effect, only on the objective risk RT data, again using individual trial data and with ID as a random intercept. There were three predictor (fixed effects) variables: magnitude (low, high), distance position (1, 2, 3, 4) and the interaction between magnitude and distance position. Distance position was defined as the increasing distance between the referent and each stimulus risk level position, e.g. position 1: rock climbing/giving birth; position 2: cycling/coal mining; position 3: commercial aircraft/base jumping; position 4: walking/climb Mt. Everest. The two subjective models were not run because some participants had unequal categorisations for low- and high-risk activities (e.g. six low-risk and two high-risk activities).

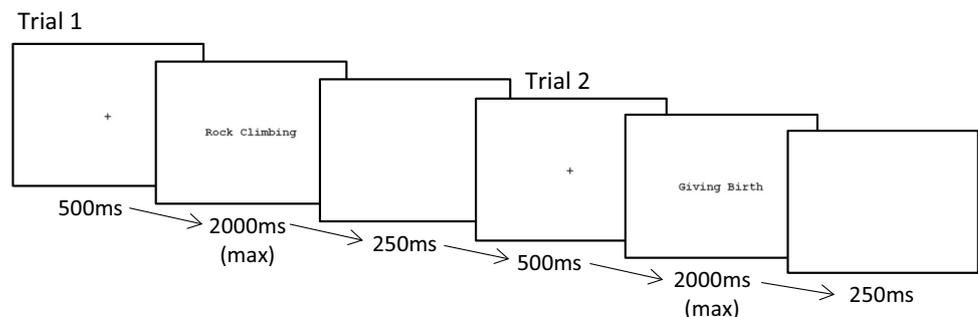
Cohen's f^2 was calculated for the effect sizes for all models (Selya et al. 2012) with f^2 values > 0.02 , > 0.15 , and > 0.35 representing small, medium, and large effect sizes, respectively.

Results

Two participants were excluded from the analyses due to more than 50% invalid responses (RTs greater than 2000 ms/less than 100 ms). The average error rate (inaccurate response judgements) was 30.11% for the remaining 26 participants ($M = 23.33$ years, $SD = 4.23$; male: 5, female: 21). See Online Appendix A for the mean RTs for each predictor variable in the analyses.

The mixed-effects model revealed a significant interaction ($p = 0.029$) between magnitude and side of response for the objective risk analysis, which is evidence of a SNARC-like effect for risk. Left-hand responses were faster to low-risk stimuli (mean = 653.05 ms, $SD = 257.27$ ms) than high-risk stimuli (mean = 665.26 ms, $SD = 258.43$ ms); and right-hand responses were faster to high-risk stimuli (mean = 639.83 ms, $SD = 240.68$ ms) than low-risk stimuli

Fig. 1 Example of two trial sequences



(mean = 662.71 ms, SD = 252.29 ms). There was also a significant main effect for magnitude ($p = 0.034$), but not for side of response ($p > 0.05$).

For the subjective rank analysis, the SNARC-like interaction effect was significant ($p = 0.002$), whereby left-hand responses were faster to low-risk stimuli (mean = 644.59 ms, SD = 264.59 ms) than high-risk stimuli (mean = 682.46 ms, SD = 265.52 ms); and right-hand responses were faster to high-risk stimuli (mean = 648.11 ms, SD = 236.01 ms) than low-risk stimuli (mean = 661.33 ms, SD = 258.21 ms). There was also significant main effects found for side of response ($p = 0.004$) and magnitude ($p = 0.003$).

Last, the subjective response analysis yielded no significant main effects or an interaction ($p > 0.05$).

As presented in Table 2, the effect sizes for the main effects and interactions across all three analyses, significant or not, were minimal (see Table 2).

The distance effect analysis revealed a significant main effect for distance position ($b = -43.92$, $p < 0.001$, $f^2 = 0.004$). The negative slope indicates that for every one-unit increase in distance position away from the referent (1–2–3–4), participants responded 43.92 ms faster according to the linear mixed model. There was also a main effect of magnitude ($b = -35.92$, $p = 0.043$, $f^2 < 0.001$), but the interaction between the two missed conventional significant levels ($b = 11.25$, $p = 0.057$, $f^2 < 0.001$). See Online Appendix B for the mean RTs for each predictor variable in the distance effect analysis.

Experiment 1 discussion

As predicted by our hypothesis, there was a mapping of low- and high-risk magnitudes to the left and right response buttons, respectively, and the RT patterns were in the expected directions; this was apparent for the objective risk

and subjective rankings of risk. This suggests that risk does have a SNARC-like structure and can be implicitly mapped onto representational space in the same way as more quantifiable domains. However, despite this outcome, the effect sizes across the board were small. For the objective risk and subjective response categories, the main effects and interactions had effect sizes all less than 0.001. In comparison, the subjective rank findings were marginally larger (e.g. the interaction effect was $f^2 = 0.002$)—although still small. As such, the generalisability of the data is limited.

It was deduced that a very likely reason for the small effect sizes was the use of statistically generated, risk stimuli (micromorts). As mentioned previously, an informed understanding of objective risk levels could not be guaranteed in the participants, as knowledge of numbers or time would have been. Furthermore, as evidenced by the high number of errors (30%), participants struggled with accurately classifying risk—particularly low risks which were more inaccurately judged than high risks (see Fig. 2). Accurate perceptions of risk might, therefore, be a prerequisite for producing stronger evidence for a spatial mapping in this domain.

In support of this, the effect size of the interaction slope (indicative of a SNARC-like effect) was largest when RTs were classified on subjective rankings of activities, the most subjective of our categorisations. Even though the activities had standardised risk levels, we underestimated the influence that individual perspectives would have on the data. Our findings unintentionally added to the body of literature (Fischhoff et al. 1978; Fox-Glassman and Weber 2016; Slovic et al. 1979) demonstrating that participants are relatively poor in accurately judging the risks of every day activities. Research has shown that previous experiences with an activity can alter a person’s perceptions about that activity’s risk (Keage and Loetscher 2018; Slovic and Peters 2006; van der Linden 2014). The affect heuristic perspective claims that people rely on their

Table 2 Mixed-effects model slope for the side of response and magnitude variables for experiment 1

Variables	<i>b</i>	SE	<i>p</i>	f^2	95% CI	
					LL	UL
Objective risk RT						
Side of response	−35.00	20.07	0.081	<0.001	−74.34	4.338
Magnitude	−41.67	19.62	0.034	<0.001	−80.12	−3.225
Side of response × magnitude	27.12	12.42	0.029	<0.001	2.775	51.46
Subjective response RT						
Side of response	−18.13	20.73	0.382	<0.001	−58.76	22.50
Magnitude	−19.16	20.26	0.344	<0.001	−58.86	20.54
Side of response × magnitude	19.76	12.79	0.122	<0.001	−5.299	44.82
Subjective rank RT						
Side of response	−55.94	19.52	0.004	0.001	−94.20	−17.68
Magnitude	−58.59	19.54	0.003	0.002	−96.89	−20.28
Side of response × magnitude	43.39	12.32	<0.001	0.002	19.24	67.54

b beta coefficient, *SE* standard error; f^2 effect size, *CI* confidence interval, *LL* lower limit, *UL* upper limit

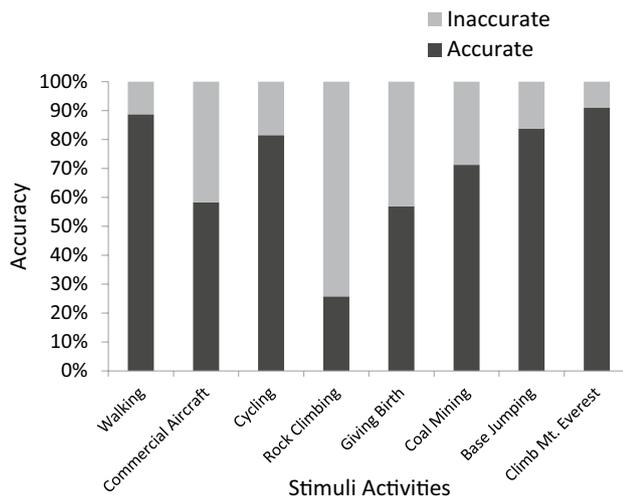


Fig. 2 Percentage of accurate and inaccurate risk judgements per stimulus activity

positive or negative feelings about a potential risk when making judgements (Finucane et al. 2000; Slovic 2016). From this perspective, if you have positive feelings about a base jumping experience, you may end up perceiving base jumping as having a lower risk than it actually does (c.f. Slovic and Peters 2006). In the same way, a frightening plane ride would have the opposite effect of increasing fear and irrationalising the dangers of air travel. Consequently, we decided to take a subjectively driven approach to our research question to increase the robustness of our findings.

Experiment 2: subjective risk

To get a better picture of how we think about risks and the similarities with numerical processing, a second experiment was conducted that attempted to investigate the role of subjectivity and familiarity. Participants were instructed to create their own low- and high-risk stimuli rather than use micromorts. This meant that the stimuli differed per participant. From this perspective, participants would be aware of the accurate risk judgements to be made and understand the order of the increasing content magnitude. The hypothesis was the same as Experiment 1: faster RTs for left hand/low risk and right hand/high risk; in addition to an expected distance effect for extreme low- and high-risk activities.

Methods

Participants

Twenty-eight right-handed adults (8 men and 20 women) between the ages of 18 and 33 ($M=23.9$, $SD=4.25$) were recruited using the same eligibility criteria as Experiment

1. They were compensated for their time with a \$10 honorarium. All participants gave informed consent and the study was approved by the Human Research Ethics Committee at the University of South Australia.

Materials

The apparatus was identical to Experiment 1. However, a Risk Stimuli Form was developed to help participants generate their own stimuli. All participants were assigned skydiving as the referent activity, and then instructed to create and rank four activities with a lower risk and four activities with a higher risk than skydiving. The form was vertical in design, to specifically avoid priming the participants with a horizontal structure. Instructions were counterbalanced between participants in terms of ordering the activities from top to bottom: either low risk to high risk or high risk to low risk. Each risk level was equally presented at either half. Finally, no number ranking was on the form, so that there could be no confounding with the numerical SNARC.

Procedure

The experiment protocol was nearly identical to Experiment 1. However, the Risk Stimuli Form was administered prior to the experiment—to obtain the participant-generated stimuli—instead of the Risk Perception Form afterwards. Additionally, for each participant, the presented stimuli were taken directly from the Risk Stimuli Form and entered into EPrime (Psychology Software Tools, Inc. [E-Prime 2.0] 2012). This process took approximately 5 min, and the experimental task began immediately after entering the stimuli.

Statistical analysis

Similar screening and statistical techniques to Experiment 1 were used for the SNARC-like and distance effect analyses. Although unlike Experiment 1, participants were aware of the low- and high-risk categorisations for each stimulus. As Experiment 2 was purely subjective, no additional analyses were run.

Preliminary analyses on the same extraneous variables as Experiment 1 (see “Statistical analysis”)—as well as the addition of counterbalanced vertical rank order—revealed no influence on RT, thus they were again excluded from the main analysis.

Results

Three participants were excluded due to error rates more than two standard deviations above the mean. The average error rate was 10.18% for the remaining 25 participants

($M = 24$ years, $SD = 4.25$; male: 8, female: 17). The RTs for the predictor variables in the analysis are presented in Online Appendix C.

The mixed-effects model revealed a significant interaction ($p < 0.001$) between side of response and magnitude. Reaction times were elicited in the expected SNARC-like directions: left-hand responses were faster to low-risk stimuli (mean = 673.58 ms, $SD = 270.46$ ms) than high-risk stimuli (mean = 696.25 ms, $SD = 270.46$ ms); and right-hand responses were faster to high-risk stimuli (mean = 661.43 ms, $SD = 256.85$ ms) than low-risk stimuli (mean = 682.67 ms, $SD = 269.19$ ms). The main effects for side of response ($p = 0.001$) and magnitude ($p < 0.001$) were also significant. These findings are again indicative of a SNARC-like effect, but just like Experiment 1, the effect sizes were small (see Table 3).

The distance effect analysis produced a significant main effect for distance position ($b = -47.86$, $p < 0.001$, $f^2 = 0.006$), whereby the participants responded 47.86 ms faster for every one-unit increase in distance position away from the referent. The main effect of magnitude was also significant ($b = -40.85$, $p = 0.001$, $f^2 = 0.001$), as well as the interaction between magnitude and distance position ($b = 15.53$, $p = 0.001$, $f^2 = 0.002$). See Online Appendix D for the mean RTs for each predictor variable in the distance effect analysis.

Experiment 2 discussion

Just like Experiment 1, the results from this experiment did provide evidence that risk judgements are spatially mapped on the left and right sides of space. The data demonstrated that left-hand RTs were significantly faster for low-risk judgements and right-hand RTs were significantly faster for high-risk judgements. By having the participants create their own stimuli rather than use objective stimuli, we speculated that a stronger spatial mapping, in regard to effect size, would be found. However, the data in Experiment 2 produced identical effect sizes for the side of response ($f^2 = 0.001$), magnitude ($f^2 = 0.002$), and interaction ($f^2 = 0.002$) effects, as was found in the Experiment 1 subjective rank analysis. So while the outcome of this experiment

does not provide more robust evidence to our theory, it does at least corroborate the findings regarding risk as a spatial association from Experiment 1.

General discussion

The findings of these experiments provide important insights into the processing system for risk magnitude. We can deduce that risk magnitude can be spatially mapped with low and high risks being associated with the left and right of space, respectively. Our findings thus add a novel domain (risk magnitude) to the growing list of abstract domains eliciting spatial associations (Macnamara et al. 2017). Yet, despite the significance in establishing an association between risk and space, further experimentation on risk is required to illuminate the nuances of spatial risk mappings and strengthen the robustness of the data. As it stands, our effect sizes were small for all variables.

In Experiment 1, the subjective ranking categorisation was the most subjective of the three categorisations. Requiring the participants to order the stimuli from low risk to high risk revealed to us their beliefs and expertise of risk. The analysis based upon the rankings produced a marginally higher effect size than the other two, which led us to developing Experiment 2. Focussed solely on personally generated stimuli, we posited that the participants' familiarity with the risk activities would assist in producing a stronger spatial mapping. Currently, the relationship between the level of expertise with any type of stimuli and the strength of spatial mappings is a complex and not yet fully understood component of SNARC research. While a certain degree of familiarity has been shown to be a prerequisite for a spatial mapping to occur, higher expertise does not necessarily translate to a stronger mapping (e.g. Cipora et al. 2016; Hoffmann et al. 2014; Macnamara et al. 2017). This ended up being reinforced by Experiment 2, in that the stimuli created by the participants themselves (which theoretically should have been more familiar to them) did not produce stronger spatial mappings than the micromorts of Experiment 1. Future research is, therefore,

Table 3 Mixed-effects model slope for the side of response and magnitude variables for experiment 2

Variables	<i>b</i>	SE	<i>p</i>	f^2	95% CI	
					LL	UL
Side of response	-54.24	16.01	0.001	0.001	-85.63	-22.85
Magnitude	-68.83	16.01	<0.001	0.002	-100.2	-37.46
Side of response × magnitude	44.61	10.12	<0.001	0.002	24.78	64.44

b = beta coefficient; SE = standard error; f^2 = effect size; CI = confidence interval; LL = lower limit; UL = upper limit

needed to understand the effects of risk expertise and general risk propensity on the mapping of risks on space.

As of additional importance, an effect of distance position was found for the stimuli in both experiments. In view of that fact that each participant differed in their risk activities in Experiment 2, it is especially promising that the stimuli extremities could still be judged quicker than the other stimuli. This distance effect is thus comparable to the effect found with numerical stimuli (Moyer and Landauer 1967; van Opstal and Verguts 2011), and suggests an analogue representation of risk and numerical magnitudes. The distance effect for risk judgments mirrors a hallmark finding in numerical processing; participants are known to pick the larger of two numbers much faster when the distance between the numbers is also larger—e.g. faster decision for alternatives ‘1 and 5’ than for ‘4 and 5’ (Dehaene 1997; Moyer and Landauer 1967). The dominant explanation for the distance effect in numerical processing is that an analogical representation of quantity meaning is assessed to judge numerical differences. The neural quantity representation of nearby numbers (e.g. 4 and 5) overlap to some degree and are, therefore, more difficult to discriminate than numbers that are more distant to each other (e.g. 1 and 5).

Our study adds to the body of literature demonstrating that the distance effect is not exclusive to numerical processing. The effect has been documented for many tasks involving the comparison of a wide range of magnitudes, including short and long durations, small and large angles, early and late months, and low- and high-pitch sounds (Conson et al. 2008; Fias et al. 2003; Gevers et al. 2003; Lidji et al. 2007). The observation of distance effects across a wide range of domains suggests that potentially all properties, not just quantifiable ones, are mapped on an analogue magnitude representation system for magnitude judgments—irrespective of the type of domain at hand.

Since it seems implausible that the analogue representations of dimensions have their own dedicated neural brain structure involved in the comparisons of their magnitudes (Pinel et al. 2004), the idea of a generalised magnitude processing system—as for example the previously mentioned, ATOM (Walsh 2003)—has been put forward. To substantiate this theory, some studies have focused on which parts of the brain are active during magnitude processing tasks. So far the consensus is that a region within the parietal cortex may be the locus (Cantlon et al. 2009; Cohen Kadosh et al. 2008; Cutini et al. 2014; Fias et al. 2003; Pinel et al. 2004; Sokolowski et al. 2017; Viarouge et al. 2014). Yet, while there seems to be a wide consensus on the existence of a common magnitude system, the specifics of the system are a matter of debate (Buetti and Walsh 2009; Cohen Kadosh et al. 2008; Fias et al. 2003). It is, therefore, important to demonstrate that a wide range of domains share common

behavioural characteristics to refine our understanding of how we process magnitudes.

The findings of this study not only tie in nicely with the idea of a generalised magnitude system and ATOM, but actually share commonalities with alternative theories of spatial organisation. Even though a generalised magnitude system may be the primary theory under investigation in this study, we cannot discount that other underlying mechanisms might be manipulating the outcome. For example, the working memory account denotes order as a factor regulating which side of space stimuli are represented on (see Fias et al. 2011; van Dijck et al. 2013 for more information). The spatial biases within an ordered sequence of stimuli are formed while manipulating quantity in working memory which then determines the speed of the response hand, e.g. faster responses on the left to stimuli that are first in a sequence (van Dijck and Fias 2011).

Any future research into the relationship between risk and space should attempt to address the design limitations within our experiments, and address newly raised questions from our empirical data. First, a replication of the results with a larger sample could provide stronger empirical evidence for our findings. Also, if these two experiments were to be repeated in their current forms, it would have been worthwhile to ask the participants from Experiment 2 to rank the risk levels of all the activities (their own and the stimuli from Experiment 1); this data could have shown us how the participants are placing all stimuli across a risk spectrum.

Finally, this pathway of research into risk communication could open the doors to experiments in countries with right-to-left writing languages. There is already so much evidence for a reversed SNARC effect (right-left horizontal mappings) within Hebrew and Arabic cultures (Dehaene et al. 1993; Fuhrman and Boroditsky 2010; Shaki et al. 2009). If a right-to-left SNARC-like mapping for risk could be replicated using Hebrew or Arabic speakers, this could further signify that there is a spatial categorisation taking place within the mind when people think about risk. Risk education within those cultures could, therefore, benefit from an adaption to right-left visual material.

In summary, in addition to making a contribution to the behavioural commonalities of magnitude processing, this study has also helped to inform best practices in effective communications of risks. Clearly, people are struggling with accurately interpreting information about risk and making adequate decisions based on this information (Cokely et al. 2012; Fox-Glassman and Weber 2016; Garcia-Retamero and Cokely 2013). The unusually high error rate for making risk judgements showcases how the public’s perception of danger contrasts with what statistics have proven are actually dangerous activities (Slovic 2016). For example, Fig. 2 illustrated how on over 40% of trials in Experiment 1 participants incorrectly judged

flying on a commercial aircraft as a high-risk activity. This is despite commercial aircraft flying having only 1 μm t. From a cultural perspective, the impact of terrorism in today's society may be unduly affecting individuals' personal beliefs about flying. Accordingly, communication of accurate risks needs to be targeted at challenging stereotypes of danger.

Since our research suggests that people do tend to intuitively associate low and high risks with the left and right sides of representational space, respectively (in Western cultures), horizontal spatial mappings could be harnessed and applied as a design feature of visual aids to better communicate risks. Future research is warranted to investigate the degree to which risk magnitude processing and the processing of other magnitudes (including numbers) involve the same underlying processes and representations (Walsh 2003). If a significant overlap would be confirmed then this would suggest that methods used to learn and teach about different magnitudes (e.g. numbers) might also be applicable for increasing risk literacy.

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