Experimental Brain Research (2019) 237:2789–2798
https://doi.org/10.1007/s00221-019-05632-w

RESEARCH ARTICLE

The effects of risk magnitude training on mapping risks on space

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Received: 3 April 2019 / Accepted: 16 August 2019 / Published online: 23 August 2019

Abstract

Risk perception has recently been shown to reveal a mental spatial representation, with people responding faster to low-risk items on the left side, and high-risk items on the right side. Subjective risk perception has a stronger spatial representation than objective risk perception; however, both reveal small effect sizes. With risk magnitude being a new domain within spatial mapping literature, we sought to explore its nuances. Following discussion surrounding the relationship between spatial mapping and level of expertise, this study investigated the effect of training an objective risk magnitude sequence on mental spatial representations. Participants ($n = 34$) used their left and right hands to indicate whether eight risk stimuli were lower or higher risk than a referent activity, both before and after training. Training involved repetitively learning the objectively correct order of the same eight risk stimuli for approximately 15 min. Pre-training results demonstrated the expected spatial representations. Contrary to our predictions, the spatial representation did not get stronger post-training, but instead disappeared. Previous research has demonstrated a loss of spatial-numerical mappings with increased task load. An increase in post-training reaction times could reflect an increase in task load due to a lack of adequate knowledge of risk stimulus order; thus revealing no mental spatial representation. However, failure to find training effects highlights the flexibility of weaker spatial representations, and supports research demonstrating spatial representation flexibility.

Keywords Spatial associations · SNARC · Distance effect · Risk communication · Spatial training

Introduction

Risk envelops each and every decision we make in our lives: what to eat, what to do, and how to get there. Risk can be defined as uncertainty of an outcome when presented with several possibilities (Knight 1921; Mohr et al. 2010). With risk being unavoidable and ever-present in our lives, how do we think about and conceptualise risk? One suggestion is that, in line with other magnitude-based sequences such as numbers, size, and time, risk magnitude may be conceptualised spatially (Macnamara et al. 2019). Extensive research has demonstrated an association of low numbers to the left side of space and high numbers to the right side of space, with low and high determined relative to the specified number range (Wood et al. 2008). This effect, evidenced through faster leftward responses to low numbers and faster rightward responses to high numbers, has been termed the Spatial-Numerical Association of Response Codes (SNARC) (Dehaene et al. 1993). The SNARC effect is automatic, arising even when magnitude is irrelevant to the task (Dehaene 1992; Dehaene et al. 1993). Further evidence of an unconscious analogue representation of numbers is the distance effect, which refers to faster response times as numerical distance between the numbers being compared increases (e.g. faster to decide 9 is larger than 5, than 6 is larger than 5) (Moyer and Landauer 1967). While distance effects are indicative of an analogical representation of numerical magnitude along a mental number line, they do not indicate whether or how this representation is mapped onto space (Dehaene 1992; Verguts et al. 2005).

There is strong evidence of a SNARC-like effect extending beyond numbers to non-numerical magnitude and ordinal domains such as letters, months, luminance, pitch, and even more abstract concepts including the level of emotion (e.g. increasing levels of happiness) depicted by emotional expressions (Holmes and Lourenco 2011). A SNARC-like effect is evidenced in ordinal and magnitude-based domains through faster leftward responses to stimuli earlier in a sequence (e.g. earlier months of the year) or smaller

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magnitudes (e.g. lower pitch), and faster rightward responses to stimuli later in a sequence (e.g. later months of the year) or larger magnitudes (e.g. higher pitch) (Gevers et al. 2003; Cho et al. 2012).

Recently, risk magnitude was added to the growing list of abstract domains which reveal a spatial association (Macnamara et al. 2019). Macnamara et al. (2019) demonstrated spatial mapping for risk activities, with faster left-sided responses to lower risks and faster right-sided responses to higher risks as well as a distance effect, in responses to an objectively ordered list of risk activities and to the same stimuli, but subjectively ranked. Risk order in the objectively ordered list was based solely on micromort level, and participants were unaware of the correct order. Micromorts are an objective risk measure, with one micromort representing a one-in-a-million chance of death from an acute risk activity (Spiegelhalter 2014; Fry et al. 2016). Contrastingly, the subjectively ranked list comprised the same risk activities ordered by participants, reflecting their subjective idea of the risk order. Spatial mapping effect sizes for both risk orderings were small, much lower than those typical within SNARC literature. However, Macnamara et al. (2019) demonstrated stronger spatial mapping effect sizes for responses to the subjectively ranked risk activity order ($f^2 = 0.002$) compared to the objectively ranked order ($f^2 < 0.001$). These initial results might indicate that familiarity with the order leads to stronger spatial representations, and prompts the question of whether learning the objective risk magnitude order would create enhanced spatial mappings.

In contrast to the small SNARC-like effect sizes for risk magnitude, pooled effect sizes for the original SNARC effect are large ($d = 1.04$) in similar tasks to those employed by Macnamara et al. (2019), namely magnitude classification tasks with a fixed standard (see Wood et al. 2008 for meta-analysis). In contrast, Macnamara et al. (2018) demonstrated smaller effect sizes for non-numerical spatial mappings ($d = 0.488$, d adjusted $= 0.350$). The strength of the SNARC effect may be due to the close and over-practiced connection of numerical order and magnitude with space in everyday life (e.g. distances represented by numbers). This reasoning is also contentious with higher expertise not always translating to stronger mapping (e.g. Hoffmann et al. 2014; Cipora et al. 2016). However, at least in the early stages of numerical learning, more practice seems to evoke stronger spatial mapping effects (Hoffmann et al. 2013).

Literature on training spatial mappings is limited; however, previous research has demonstrated success in training to create new spatial associations for novel sequences. Spatial representations, where items earlier in the sequence are associated with the left, and vice versa for items later in the sequence, of arbitrary sequences of fruits and vegetables, simple words (e.g. “chair”) and figures have been demonstrated following training phases in which the sequences are learned (Van Opstal et al. 2009; Previtali et al. 2010; Ginsburg et al. 2017). It is possible that if new sequences can be trained to evoke spatial representations, perhaps existing but weak spatial mappings could be enhanced through similar trainings. However, unlike such arbitrary sequences, risk magnitude is implicitly spatially mapped (Macnamara et al. 2019) and people have preconceived ideas about the level of risk involved in certain activities. For spatial representations of objective risk order to be improved through trained, it is essential that such training is also effective on preconceived sequences and existing spatial mappings. In fact, Ginsburg et al. (2014) and Ginsburg and Gevers (2015) successfully created spatial representations for newly learned five-digit number sequences, which were revealed when the new sequence order was retrieved during the classification task. This research indicates that existing spatial mappings, such as number, can be altered through training.

However, in the case of risk magnitude, training would aim to enhance the pre-existing weak spatial representation. Improvements of this kind to spatial representations for risk may also provide benefits to other outcomes. For example, Loudwin and Bannert (2017) were successful in improving non-musicians estimations of pitch differences through spatial training. Kucian et al. (2011) found that not only children’s spatial representation of numbers, but also their arithmetic ability improved following a mental number line training game. Moreover, Fischer et al. (2011) found improvements in children’s spatial estimates and their counting ability after spatial training. These studies provide an indication of the benefits that result from spatial training, and the increased spatial representations produced through training. It is possible that this benefit of training through the formation of spatial representations may extend to risk magnitude.

With risk magnitude being a new domain within spatial mapping literature, and one which demonstrates smaller effect sizes, we sought to explore its nuances. The current study will investigate the effect of training a risk magnitude sequence on SNARC-like responses, extending knowledge regarding the development of spatial mappings through training, as well as understanding of risk conceptualisations. Furthermore, this study will inform the debate surrounding the complex relationship between expertise and spatial mapping strength. Previous studies (e.g. Previtali et al. 2010) provide evidence to believe training will be successful. Thus, it was hypothesised that there will be a larger spatial mapping (SNARC-like) effect size after training as compared to pre-training. The distance effect is an important aspect tied to spatial mappings and, as such, we will explore the distance effect from pre- to post-training.

Methods

Participants

Thirty-four native English speakers (22 females, $M_{age}=22.87$, SD = 4.22) participated in the present study. Participants were required to be right-handed, as assessed by the Flinders Handedness Survey (FLANDERS) (Nicholls et al. 2013), and aged between 18 and 35 years.

Participants were recruited on the University of South Australia Magill campus. Ethics approval was provided by the University of South Australia Human Research Ethics Committee. All participants received an honorarium of $15 per hour and provided written informed consent prior to their participation.

Materials and measures

Apparatus

E-Prime (Psychology Software Tools Inc. [E-Prime 2.0] 2012) was used to present stimuli and collect responses. Stimuli were presented on a 580 mm, LCD (Model: DELL P2314H), 1920 × 1080 resolution computer monitor. Participants were seated 500 mm from the screen and used a serial response box, with left and right buttons 65 mm apart, to make risk judgements. Participants pressed the left and right response buttons with their corresponding hands.

Stimuli

Risk stimuli were based on the risk activities used by Macnamara et al. (2019). Risk activities were ranked, using their respective micromort values, into low and high risks relative to the referent activity (see Table 1). Table 1 provides the distance position for each risk activity, relative to the referent, such that risk activities further from the referent have a larger distance position. Risk stimuli were presented as black text, size 22, Courier New font, displayed on a white background.

Table 1 Distance positions and micromort levels of risk activity stimuli

Risk level	Risk activity	Distance	Micromort value (μmt)
Low	Walking (22 km)	4	0.5
	Commercial aircraft (12,070 km)	3	1
	Cycling (90 km)	2	2
	Rock climbing (per climb)	1	3
Referent	Skydiving (per dive)	–	10
High	Motor biking (160 km)	1	17
	Giving birth (per birth)	2	120
	Base jumping (per jump)	3	430
	Climbing Mt. Everest (per climb)	4	12,000

Distance refers to distance position from referent activity. Micromort values obtained from: Soreide et al. (2007); Blastland and Spiegelhalter (2014); Ahmad et al. (2015); Fry et al. (2016)

Risk perception form

Participants' subjective beliefs of the risk order were assessed with a risk perception form based on Macnamara et al. (2019). Participants ordered the risk activities vertically, from low-to-high or high-to-low dependent on assigned risk training group.

Spatial mapping

Participants' spatial mapping of risk activities was assessed pre- and post-training using the spatial mapping task outlined by Macnamara et al. (2019). During this task, participants indicated whether risk activities portrayed a lower or higher risk compared to the referent activity by pressing either the left or right button on a serial response box. The task comprised of four trial blocks, with each of the eight risk stimuli randomly presented ten times in each block (4 × 80 trials).

The 320 total trials each began with a fixation point (presented for 500 ms), followed by the target stimuli (presented for max 2000 ms) which disappeared following participants' response. There was an inter-trial break (fixed at 250 ms) between each trial. No feedback about the accuracy of each response was provided.

The response mappings, congruent (A: left button = lower risk, right button = higher risk) and incongruent (B: left button = higher risk, right button = lower risk), were alternated between throughout the four blocks using two orders (ABBA, BAAB) that were also counterbalanced across participants. A practice block, comprising of ten trials, preceded each side of response change (3 × 10 trials) to enable participants to familiarise themselves with the new response mapping. Pre- and post-training spatial mapping tasks each took approximately 10 min to complete.

Risk training

Risk training comprised a learning phase and a training phase, based on procedures outlined by Previtali et al. (2010). Participants learned the order of the nine risk stimuli (including the referent) either high-to-low or low-to-high, with this risk training order counterbalanced across participants. Risk training order was incorporated across all risk training tasks, determining sequence order during the learning phase as well as the display and correct answers for training phase tasks. All learning and training was presented vertically to avoid horizontal priming.

The learning phase comprised two blocks. During both blocks, the risk stimulus order was shown three times, with each risk stimuli presented sequentially and individually on screen for 2000 ms. But only during the second learning block did the participants read each risk stimuli aloud as they were displayed on screen. After each learning block, participants repeated aloud the risk order from memory, with no feedback provided.

The training phase comprised three tasks: ‘Triplet’, ‘What comes next?’ and ‘What comes before?’ In the ‘Triplet’ task, three sequential risk stimuli were ordered vertically on screen, with the middle risk missing. Participants were required to report the missing risk. In the high-to-low condition, the highest risk was in the bottom position (see Fig. 1), and vice versa for the low-to-high condition. Each of the seven possible triplets was randomly displayed three times.

Participants then completed ‘What comes next?’ then ‘What comes before?’ where they verbally reported the activity following or preceding the one visually presented in the risk sequence. In the high-to-low condition, the next lowest risk activity followed and the next highest preceded, with the opposite sequence for the low-to-high condition. The eight risk stimuli (excluding the first and last in the sequence, respectively, for ‘What comes before?’ and ‘What comes next’) were each randomly displayed three times.

The 69 total trials across the three training tasks each began with a central fixation point (500 ms) after which the target stimuli appeared and remained until participants’ verbal response. The primary researcher provided verbal feedback (“Correct”/“Incorrect”), and the correct option was displayed on screen for 2000 ms before the next trial began (see Fig. 1 for trial sequence). One risk training session lasted approximately 15 min.

Procedure

Participants were assigned to one of four counterbalanced conditions based on order of response side mappings (ABBA or BAAB) and risk training order (low-to-high or high-to-low) prior to participation.

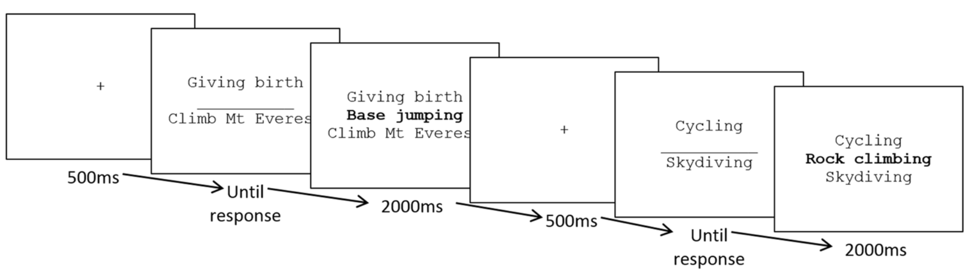
Participants were seated centrally, relative to the sagittal-body middle, to the PC and serial response box and completed the pre-training spatial mapping task. Participants were instructed to indicate whether each randomly presented risk stimuli carried a lower or higher risk of death, per day, than the referent activity by pressing the left or right button of a serial response box.

Upon completion of the pre-training spatial mapping task, participants completed a risk perception form, and then began risk training, advancing through the learning and training phases, as shown in Fig. 2.

Immediately after completion of the training phase, participants repeated aloud the risk order from memory twice. If correct both times, we concluded that they had sufficiently learned the risk activity order, and progressed to the post-training spatial mapping task. If incorrect either time, they repeated the training phase. The repeated training phase was preceded by one presentation of the correct risk stimulus order, individually and sequentially, on screen. If, after repeating the training phase once, participants again repeated the order incorrectly either time, they were removed from further analyses.

Following successful completion of risk training, participants completed another risk perception form before commencing the post-training spatial mapping task, which was identical to the pre-training spatial mapping task.

Fig. 1 Illustration of triplet task trial sequence, comprising fixation point, target stimuli and correct response for the high-to-low group



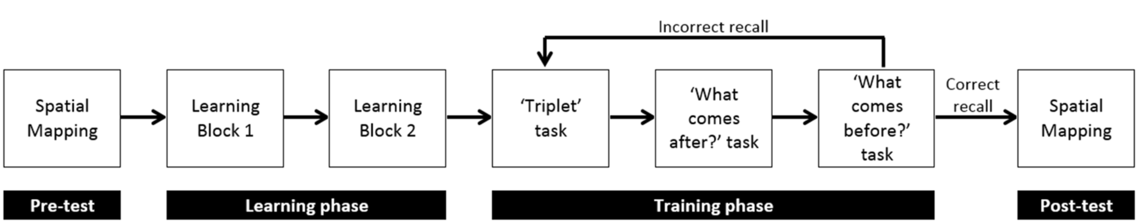


Fig. 2 Illustration of experimental procedure with pre- and post-test design, with learning and training phases

Total session duration varied from 40 to 65 min ($M = 47.42$, SD = 7.79), largely dependent on whether participants required one or two risk training sessions.

Data analysis

Invalid trials in which there was no response, a reaction time (RT) greater than 2000 ms, or less than 100 ms, were removed. Inaccurate risk response trials were also removed.

STATA v15.1 was used to run linear mixed-effects modelling with individual trial data and ID set as random intercept. All models had RT as the outcome, with 0.05 alpha level. Two different linear mixed-effects models were both ran on pre- and post-training session data: objective risk and distance effect. These models match two of the four ran by Macnamara et al. (2019). We were able to replicate Macnamara et al.'s (2019) pre-training findings for the two remaining models, based on subjective rankings and subjective responses, but for the purpose of this paper we refrained from reporting these analyses.

The objective risk model comprised three predictor variables (fixed effects): side of response (1 = left, 2 = right), magnitude (1 = low, 2 = high), and an interaction between side of response and magnitude. The interaction is indicative of spatial mapping: a SNARC-like effect. Risk magnitude in this model is based on an activity's micromort level relative to the referent micromort level.

The distance effect model included distance position (1, 2, 3, 4) as the predictor variable. Distance position was based on the objectively ordered risk activity list whereby distance position refers to distance from the referent (i.e. cycling and giving birth represent distance position 2).

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

Results

Participants who failed to correctly recall the risk order after two risk training sessions ($n = 4$) were excluded from analyses to isolate successful learning as the factor impacting post-training spatial mapping. The data from the remaining thirty participants (21 females, $M_{age} = 23.15$, SD = 4.40) underwent further analyses. Six participants required two risk training sessions to sufficiently learn the risk order.

Removal of invalid trials resulted in 0.81% and 0.73% of pre- and post-training data being excluded, respectively. Removal of incorrect trials resulted in the further removal of 28.10% and 8.79% of pre- and post-training data, respectively.

Spatial mappings

The pre- and post-training objective risk linear mixed-effects model results are presented in Table 2. A significant side of response by magnitude interaction was revealed for the pre-training analyses, with small effect sizes. On average, RTs were longer post-training ($M = 670.17$ ms) compared to pre-training ($M = 611.33$ ms). Post-training effects did not reach conventional significance levels. Pre- and post-training RTs by hand and risk magnitude are detailed in "Appendix 1".

Distance effect

At pre-training there was a significant main effect of distance position ($b = -18.83$, $p < .001$, $f^2 = 0.011$). According to these results, for every one unit increase in distance position away from the referent, participants responded 18.83 ms faster.

Post-training there was a significant main effect of distance position ($b = -35.50$, $p < .001$, $f^2 = 0.041$), indicating participants responded 35.50 ms faster with every one unit increase in distance position from the referent.

Table 2 Pre- and post-training linear mixed-effects results for objective risk models

Variables	*b*	SE	*p*	f^2	95% CI	
					LL	UL
Pre-training						
Side of response	45.35	14.64	.002	0.001	16.66	74.04
Magnitude	81.22	15.23	< .001	0.004	51.37	111.06
Side of response × magnitude	− 32.92	9.61	.001	0.002	− 51.76	− 14.09
Post-training						
Side of response	− 12.61	13.44	.348	< 0.001	− 38.96	13.73
Magnitude	− 12.32	13.41	.358	< 0.001	− 38.61	13.97
Side of response × magnitude	7.80	8.50	.358	< 0.001	− 8.85	24.45

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

Average RTs for each distance position at both pre- and post-training are illustrated in Fig. 3 (see "Appendix 2" for specific RT values).

Explorative analyses

Analyses revealed a significant SNARC-like effect pre-training and, contrary to expectation, no significant post-training SNARC-like effect. Exploratory analyses were undertaken to investigate this.

It is possible that the pre-training SNARC-like effect was driven by responses to individual risk stimuli that may be more intuitively recognised as low or high risk, such as walking, which was categorised as low risk by all participants pre-training. To ensure this was not the case, the pre-training linear mixed-effects model was run eight additional times, removing one risk stimuli from each analysis (i.e. seven risk stimuli were included in each). Effects did not change: all side of response by magnitude interactions remained significant, and 95% CIs were all overlapping (see "Appendix 3"). These results demonstrate that no individual risk stimuli were driving the pre-training SNARC-like effect.

Faster RTs are usually seen for responses to more familiar stimuli (Gut and Staniszewski 2016), thus greater risk activity familiarity post-training should have led to a RT decrease. However, participants' post-training RTs were slower than pre-training. Participants with more incorrect pre-training responses may have had greater post-training RT increases due to learning a risk order greatly different from their subjective interpretation. A Pearson's correlation supported this, showing a significant negative correlation between pre-training objective risk order accuracy and change in median RT, $r = -0.610$, $p = .001$, demonstrating that as pre-training accuracy increases, change in median RT decreases.

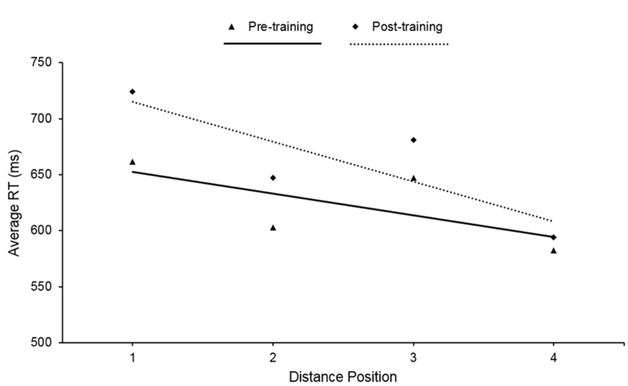


Fig. 3 Illustration of average RT (ms) and regression line for each risk activity distance position (relative to referent activity) for pre-training and post-training

Discussion

The aim of this study was to investigate the effect of risk magnitude sequence training on SNARC-like and distance effects in responses to the risk magnitude activities. Previous research has demonstrated stronger spatial mapping effects for responses to subjectively ranked risk activities (Macnamara et al. 2019). Thus, spatial mapping for an objectively ordered risk activity list was expected to be larger following training to increase risk-order knowledge. As anticipated, pre-training results demonstrated small spatial mapping effects, replicating those reported by Macnamara et al. (2019). The pre-training spatial mapping effect is somewhat surprising, as participants were unaware of the objective risk order. However, this finding is in line with other magnitude-based sequences and suggests that participants have some intuitive idea of the risk order (e.g. rock climbing is riskier than walking). This is supported by Keage and Loetscher (2018), who demonstrated that individuals judged activities with greater objective risk (higher micromort level) to be riskier. The removal of incorrect trials also increases the potential to expose any present spatial representation, as it isolates responses in which risk activities were rated in line with the objective risk order. However, contrary to expectation, no statistically significant spatial mapping was present post-training. A distance effect, however, was present in both pre- and post-training analyses. The distance effect was larger post-training, revealing a larger effect size compared to pre-training.

Apart from decrease in errors, another indication participants learned the objective risk order was that all participant responses on the post-training risk perception form matched the objective ranking. Risk training aimed to increase participants' knowledge of the objective risk stimulus order. Frequently used and well-known stimuli (e.g. numbers, months) have more efficient retrieval and consequently evoke faster response times (Gut and Staniszewski 2016). In spite of larger post-training accuracy levels, indicating greater post-training knowledge of the risk order, participants' reaction times slowed. The SNARC effect has been shown to increase with longer response latencies (Wood et al. 2008; Didino et al. 2019). Despite the demonstrated post-training increase in reaction time thus indicating a greater likelihood of stronger post-training spatial mapping effect, none was found. It is possible that participants did not achieve a sufficiently high level of risk order expertise. Participants may still require increased cognitive processing efforts, and thus increased time, to retrieve information regarding whether each activity represents a low or high risk.

An increased cognitive processing load associated with recalling the newly learned objective risk order may be implicated in the lack of spatial mapping found post-training. Presence of the SNARC effect depends on the availability of working memory resources (Gut and Staniszewski 2016). Previous research has demonstrated disappearance of the SNARC effect under conditions of increased verbal or spatial working memory load, depending on the resources required for the specific judgement task (Herrera et al. 2008; Van Opstal et al. 2009; Ginsburg et al. 2014). If participants' level of expertise for the risk order was not comprehensive enough post-training, there may have been a conflict between their intuitive subjective idea of the risk order and the newly learned objective order in working memory. This conflict and increased task load may be responsible for the lack of post-training spatial mapping.

Risk training in the present study lasted approximately 15 min. While this was sufficient for participants to remember and recall the risk stimulus order, it may have been too brief to allow participants to retrieve risk magnitude information with the speed and minimal working memory resources necessary for a spatial mapping effect to appear. Risk training was based on training procedures employed by Previtali et al. (2010), in which all participants successfully learned the novel, meaningless order of nine short words following one brief training session. In contrast to stimuli used by Previtali et al. (2010), risk stimulus order carries inherent meaning, referring to risk of death from an activity, and all participants had pre-existing interpretations of the order. Another aspect of difference is highlighted by a study in which the existing spatial representation of numbers was altered through training of a new digit order, where only five-digit sequences were trained (Ginsburg et al. 2014). Our nine-activity risk order may have been too large to become automated within a short space of time, thus leading to higher processing costs for correct answers post-training and possibly explaining the lack of post-training spatial mapping.

Furthermore, participants with lower initial accuracy had a larger pre- to post-training increase in reaction time. This indicates participants with a preconceived idea of the risk order more different from the objective order had inadequate time within training to override their preconceptions, resulting in slower post-training responses. An extended training design could ensure preconceived ideas are overridden and adequate familiarity with the objective risk order is obtained. Further research is required to ascertain the necessary duration and number of training sessions to achieve these goals. Additionally, future research would benefit from an investigation of risk training on neutral stimuli. This would allow conclusions on whether spatial mappings of risk can be trained without the interference of pre-existing subjective risk associations.

While spatial mapping effects disappeared post-training, distance effects were larger at post-training than pre-training. Distance effects, unlike SNARC effects, are unaffected by increased cognitive processing load (Herrera et al. 2008; Ginsburg et al. 2014). This might be due to distance effects being evoked purely through the activation of magnitude, not through associations between response side and magnitude (Ginsburg et al. 2014).

The presence of distance effects in the absence of horizontal spatial mapping effects may indicate spatial mappings of a different orientation. Distance effects demonstrate an analogue mental representation of stimuli, but not the direction of this representation (Moyer and Landauer 1967). To prevent horizontal priming in the present study, all displayed risk orders were presented to participants vertically throughout risk training. It is possible that through avoiding horizontal priming, participants were vertically primed and developed a vertical spatial conceptualisation of the risk order. If this vertical spatial mapping orientation was present post-training, this may indicate increased malleability of weak spatial mappings, such as risk activity orders.

Such flexibility in spatial mappings is not new; spatial mappings have demonstrated extensive flexibility following changes in situated influences such as task demands (Fischer et al. 2010; Lindemann et al. 2011; Georges et al. 2015; Li et al. 2016; Cipora et al. 2018). For example, imagining a ruler, with smaller numbers on the left, during a magnitude comparison task results in a standard left-to-right SNARC, while imagining a clock face, with smaller numbers on the right, leads to a reversal in SNARC directionality (Bächtold et al. 1998). The weak implicit nature of spatial mappings in responses to risk activities demonstrated by Macnamara et al. (2019) and replicated in the present study may leave them more malleable to changes in directionality following changes in risk presentation. A short, vertically presented risk training session might have, therefore, been enough to change the spatial mapping directionality.

This malleability is at odds with popular theories which credit spatial mapping directionality with exposure to a specific, culturally determined reading direction, whereby those from a left-to-right reading culture have a left-to-right SNARC directionality, and vice versa for those from a right-to-left reading culture (McCrink and Shaki 2016; Nuerk et al. 2005, 2015). Instead, the directionally flexible spatial mapping of risk being suggested supports the working memory account (van Dijck and Fias 2011; Abrahamse et al. 2016; Fias and van Dijck 2016). This account suggests that, rather than stable, long-term associations, spatial mappings arise from current task demands and the temporary positional coding they evoke in working memory. While this flexibility appears to undermine the importance of spatial mappings, it also demonstrates their dynamic adaptability to different circumstances.

It has been suggested that spatial mappings are the result of simultaneous activations of pre-existing long-term memory positions and temporary, task-related space associations in working memory (Ginsburg and Gevers 2015). In the context of the current study, it could thus be that long-term bindings of risks on space (subjective rank based on lifelong experiences) interfered with the learned task-relevant bindings of risks on space (objective risks), resulting in the absence of spatial mapping effects post-training.

Improvements to spatial mapping effects for various stimuli have been shown to transfer to other tasks, such as improving non-musicians estimations of pitch differences (Loudwin and Bannert 2017) and children's spatial estimates and counting abilities (Fischer et al. 2011). Should our findings transfer to the real world, they highlight an increased difficulty overcoming subjective perceptions of risk order. Since current risk communication tools are quite basic, generally comprising a simple diagram or percentage (Spiegelhalter 2017), this exposes a need for improvements to risk communication tools.

With previous research demonstrating stronger spatial mappings for responses to risk magnitude orders with greater familiarity, it was thought that increasing knowledge of an objective risk order would in turn increase spatial mapping and distance effects. Instead of an enhancement of spatial mappings in responses to risk activities, the current investigation found the disappearance of spatial mappings following risk training designed to teach participants the objective risk order. These unexpected results provide some interesting insights into spatial mappings. The post-training disappearance of spatial mapping indicates the necessity of working memory resources for spatial mapping to occur. Furthermore, it is possible that weak spatial mappings have an increased propensity to change following directional priming. This possibility requires further exploration, but may reflect a great adaptability of spatial mappings to recently viewed orientations, providing evidence against long-standing accounts claiming stability in spatial mapping directionality.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Appendix 1

See Table 3.

Appendix 2

See Table 4.

Appendix 3

See Table 5.

Table 4 Average reaction times (ms) for distance position at each session

	Pre-training		Post-training	
	M	SE	*M*	SE
Distance position				
1	661.37	7.50	723.94	5.17
2	603.01	5.44	647.28	4.59
3	647.29	5.89	681.12	4.71
4	582.47	4.28	594.20	3.89

Distance position calculated as distance of activity from referent activity (skydiving)

Table 3 Average reaction times (ms) for side of response by magnitude at each session for each model

	Left hand		Right hand	
	Low risk *M*(SE)	High risk *M*(SE)	Low risk *M*(SE)	High risk *M*(SE)
Objective risk				
Pre-training	581.84 (5.18)	665.79 (5.96)	596.34 (5.64)	643.24 (5.37)
Post-training	662.60 (4.85)	657.95 (4.55)	659.58 (4.68)	660.10 (4.72)

Table 5 Results of pre-training objective risk linear mixed-effects models excluding individual risk stimuli

Risk stimuli removed	Magnitude order	Side of response × magnitude				
		b	SE	*p*	95% CI	
					LL	UL
Walking	1	−34.49	10.76	.001	−55.59	−13.39
Commercial aircraft	2	−32.23	10.21	.002	−52.23	−12.23
Cycling	3	−36.72	10.53	<.001	−57.36	−16.09
Rock climbing	4	−29.16	9.68	.003	−48.13	−10.19
Motorbiking	5	−29.38	10.13	.004	−49.24	−9.52
Giving birth	6	−28.97	10.31	.005	−49.17	−8.76
Base jumping	7	−40.37	10.40	<.001	−60.75	−19.99
Climbing Mt. Everest	8	−32.87	11.04	.003	−54.51	−11.23

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