Memory & Cognition (2023) 51:129–142
https://doi.org/10.3758/s13421-022-01341-y

Survival processing advantage demonstrated with virtual reality-based survival environment: A promising tool for survival processing research

Yamin Wang[1] · Leran Zhang[1] · Hong Kan[1] · Jidong Gao[1]

Accepted: 11 June 2022 / Published online: 5 July 2022

Abstract
Many studies have been conducted to demonstrate the survival processing advantage (SPA) as an evolutionary-oriented memory effect. But few studies were conducted to demonstrate this effect in real-life or simulated survival environments. This study tested whether the SPA could be replicated in a survival virtual reality environment (VRE). In Experiment 1, the SPAs were measured in VREs (survival grasslands, survival battlefield, nonsurvival moving) in which Experiment 1A used the standard long instructions and Experiment 1B used the modified short instructions. In Experiment 2, the SPAs were measured again with the scenarios corresponding to the VREs used in Experiment 1A. All experiments demonstrated typical SPAs, suggesting that the survival VRE is a reliable tool in designing and delivering a survival situation. The potential problems of applying survival VRE to survival processing research are discussed at the end.

Keywords Survival processing advantage · Free recall · Virtual reality environment · Emotional activation

The survival processing memory advantage is a robust adaptive memory phenomenon, in which a surprising free recall after the survival-relevance rating of an arbitrary word list reveals better incidental memory than that after moving- or vacationing-relevance rating (e.g., Nairne & Pandeirada, 2010; Nairne et al., 2008; Weinstein et al., 2008). Important as this evolutionary-oriented memory effect is, few studies were conducted to demonstrate its effect in a real-life or a simulated survival environment. In this direction, the present study aimed to replicate the survival processing advantage (SPA) with survival virtual reality environment (VRE).

Survival processing paradigm

The survival processing paradigm was originally developed by Nairne and colleagues to assess the functionality of memory and test the survival value of human recollections (Nairne et al., 2007). In this paradigm, participants are typically instructed to imagine themselves being stranded in a foreign land (i.e., the grasslands) without any survival materials, deprived of food and water, and in danger of predators (or attackers, enemies). Hereafter, participants need to rate words according to their relevance in that survival scenario. This is followed by a short distractor task and afterwards, participants are confronted with a surprise memory test. During the procedure, processing stimuli for survival relevance facilitates memory performance beyond that of processing stimuli according to other instructions (i.e., moving). This effect is labeled as the SPA and has been widely used to support the idea that our memory is functionally designed (Nairne & Pandeirada, 2010).

The advantages of survival VRE

VRE is a computer-simulated, three-dimensional environment in which a user can interact with the environment and experience presence (Steuer, 1992). The term "presence" is widely used in virtual reality research to describe the feeling of "being there" that users experience in a VRE (Nash et al., 2000). The survival VRE

✉ Yamin Wang
wangym@cnu.edu.cn

[1] Beijing Key Laboratory of Learning and Cognition, College of Psychology, Capital Normal University, Beijing, China

refers to the virtual reality-based survival environment. In the present study, we built a survival VRE of Savannah-like grasslands and a survival VRE of modern battlefield.

Technically, VREs allow for a high degree of experimental control. In a single VRE, all stimuli and virtual objects (i.e., weather, water, terrain, animal, voice) are created by a computer, and all the interactions are controlled and recorded by a program. Therefore, VREs can ensure that the survival and non-survival environments presented to the participants in any given experiments remain constant. Besides, the survival VREs can provide multimodal survival-related information, such as voices of predators, noise of wilderness, and so on. Using fully immersive virtual reality technology, this multimodal information will greatly enhance the immersive experience of the survival situations. In this sense, VREs can help reconstruct environments that have played a key role in the long evolutionary past. Therefore, the survival VREs offer researchers the opportunity to design a survival processing study with good internal validity and qualified ecological validity.

In addition to experimental control, the SPA revealed in survival VRE would provide additional evidence for survival processing research. Some researchers proposed that the survival processing was formed in the Pleistocene to solve specific adaptive problems facing our hunter-gatherer ancestors (e.g., Klein et al., 2002; Röer et al., 2013). By its implication, the information closely related to survival in the real-life environments plays an important role in shaping the mechanism underlying survival processing. In other words, the process of imagining a survival situation is different from that of perceiving a survival situation. Therefore, examination of SPA should not be limited to the imagination-based survival scenarios. With the virtual reality technique, it is plausible to simulate the imaginary ancestral survival environment and thus examine whether and how the SPA is really related to the ancestral survival environment. Undoubtedly, the classic survival scenario (i.e., ancestral grasslands) is an ingenious tool in probing survival processing with regard to its efficiency. But immersing participants in a simulated ancestral survival environment could offer researchers an opportunity to observe the relation between the SPA and the real-life survival environment.

The simulations of survival environments

In existing studies, survival scenarios can be divided into two categories: ancestral survival scenario and modern survival scenario. In order to investigate whether and how the SPA can be demonstrated with survival VREs, we built a simulation of the ancestral grasslands and a simulation of the modern battlefields in the present study. There are two reasons for choosing the battlefield as modern survival VRE. First, an urban-combat situation is a typical survival situation faced by modern people. Second, the battlefields are the typical survival environments that have been related to the course of modern history. In previous studies, researchers have examined some other modern survival scenarios, like the city-attacker scenario (Nairne & Pandeirada, 2010; Weinstein et al., 2008). However, the SPAs were found to be lower with these scenarios than with ancestral grasslands. Battlefields, as the typical survival threats to modern people, deserve a close examination.

Among existing studies, whether the scenario of ancestral grasslands is special to SPA remains controversial. According to the ancestral priority hypothesis, memory mechanisms work optimally when the encoding conditions prime or reinstate ancestrally based problems, particularly those present in ancestral foraging environments (Nairne & Pandeirada, 2010; Nairne et al., 2009; Weinstein et al., 2008). Although some studies have found that ancestral grasslands lead to stronger SPAs than modern survival scenarios (e.g., Nairne & Pandeirada, 2010; Weinstein et al., 2008), others have demonstrated typical SPAs using modern threats or modern supernatural threats (e.g., Kazanas & Altarriba, 2016; Kostic et al., 2012; Soderstrom & McCabe, 2011). Thus conceived, including these two types of survival VREs would help readers and researchers to get a full picture of whether the SPA can be demonstrated with VREs.

Literature of virtual-reality-based survival processing

In recent decades, VREs have been frequently used in episodic memory, spatial cognition, and psychotherapy research (Cieślik et al., 2020; Lloyd et al., 2009; Sauzéon et al., 2012), and many studies have shown that VREs can promote episodic memory relative to the traditional 2D presentation (see Smith, 2019, for a review). However, few studies were conducted to examine the feasibility of applying VREs to survival processing when considering their ability to simulate ancestral survival environments. There was only one study that used a VRE to simulate a natural jungle and demonstrated typical attentional bias to the threatening stimuli (snake and spider) in a visual search task (Yuan et al., 2018), replicating Öhman and his colleagues' (2001) finding in 2D environments (present on the screen of a desktop computer). Our study is the first one that seeks to provide the evidence for the feasibility of applying immersive VRE to survival processing research.

To our knowledge, no studies were insofar conducted to examine SPA with survival VRE. One study examined the SPA with a virtual hunting and gathering task (Brown et al., 2016). The tasks used in this study were actually a series of 2D computer games, in which a matrix of images with background stimuli was presented on the computer screen to either simulate a scenario of hunting and gathering task in grasslands or showcase an interface of a figure-collection game. The comparison between these two conditions showed no difference. This is an interesting computer simulation study, but it is not a VRE-based study.

Based on the above analyses, we hypothesized that survival VREs would be effective in demonstrating SPA, and that both ancestral and modern survival VREs would lead to typical SPA. Compared with the survival scenario, the survival VRE does not need a standard long instruction to state what threats might appear in the survival environment. The immersive survival VRE enables participants to naturally perceive survival threats. To test our hypothesis, the SPAs were measured in VREs (ancestral grasslands, modern battlefield, moving) in Experiment 1, in which Experiment 1A used the standard long instruction and Experiment 1B used the simplified short instruction. In Experiment 2, we measured the SPA again with the conventional survival scenarios corresponding to the VREs used Experiment 1A to confirm the effectiveness of the chosen battlefield scenario.

Experiment 1

Method

All experimental procedures were approved by the Institutional Review Board of Capital Normal University. The methods were carried out following relevant guidelines and regulations. All participants signed an informed consent approved by the Institutional Review Board of our university and were compensated monetarily.

Participants

A sample of 88 healthy participants with normal or corrected-to-normal vision was recruited from Capital Normal University and other universities. Eligible participants indicated via a questionnaire that they did not have agoraphobia and that they had had experience with 3D games before. Forty participants (12 males, 28 females; aged from 21 to 28, 24.25±1.71) completed Experiment 1A, and 48 participants (15 males, 33 females; aged from 19 to 26, 22.19±1.94) were enrolled in Experiment 1B. Both experiments had a within-subject design. The sample size calculated by G*Power (Version 3.1.9; Faul et al., 2007) was 31 (α: 0.05; repeat measurements: 3; f: 0.3), where the f value was determined by referring to a prior study (Nairne et al., 2007).

Apparatus

The experiment was performed with a VR system comprising an Oculus Rift DK2 head-mounted VR helmet (Oculus, Irvine, CA; 100° horizontal field of view; resolution 960 × 1,080 pixels per eye; refresh rate 75 Hz; and delay 2~3ms) and an infrared tracking subsystem composed of eight ART Track 5 intelligent tracking cameras (refresh rate, 300 Hz) covering a 6-m^2 floor area and a central controller running DTrack2 software (ART Technology Co., Weilheim, Germany). The virtual reality environment (VRE) was presented on the head-mounted helmet, which was tracked by the infrared tracking subsystem via a pair of glasses with six passive markers. Sounds were presented via a Wharfedale Pacific Evolution 40 stereo subsystem (Wharfedale, Britain). Notably, the real-time refresh rate recorded during the experiment was about 79 Hz. The data were processed at an HP workstation (CPU E5-2667 3.20 GHz, RAM 56.0 GB, GPU NVIDIA Quadro K6000). The software used included 3dsmax 2012 (Autodesk, San Rafael, CA, USA) for modeling, and Unity3d (Unity Technologies, Inc., Shanghai) for VR scenery and interaction.

Materials and design

Materials used in the current study consist of scales for emotional assessment, VREs, and stimuli. Given that materials and design in Experiment 1B were similar to those used in Experiment 1A, the differences will only be stated after introducing the corresponding contents in Experiment 1A.

Scales for emotional assessment Experiment 1A used a 5-point Likert scale [anchored by *not at all* (1), *moderately* (3), and *extremely* (5)] to assess "stress" and "familiarity" of the VREs. In Experiment 1B, a similar scale was used to assess seven dimensions of each scene, including "stress," "interest," "arousal," "novelty," "danger," "motivation," and "threat" (see Appendix A).

VREs Three VREs were created in Experiment 1 including a VRE of grasslands, a VRE of battlefield, and a VRE of moving.

Grasslands VRE The grasslands VRE comprised an Africa Savanah-like skybox and an endless grass-textured ground. Eagles, stones, and shrubs were arranged in the form of wild

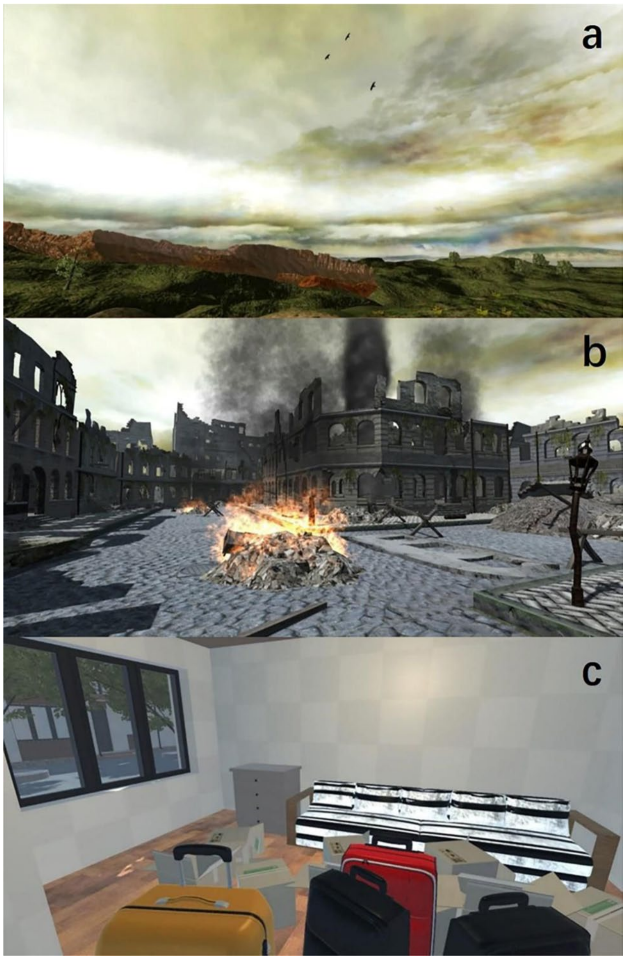

Fig. 1 The VREs used in Experiment 1A a: Grasslands, simulation of ancestral survival scene. b: Battlefield, simulation of modern survival scene. c: Moving, simulation of control scene

grasslands. The voice of an eagle, the sound of wind, and the noise of wilderness were added to make a vivid ancestral grasslands. In order to reduce screen door effect, a mesh-like appearance due to low resolution, a cloudy rather than sunny day was designed (see Fig. 1a).

Battlefield VRE The modern survival VRE presented a scene of modern warfare, including collapsed buildings, streets, street lamps, rubble, scorched earth, and burning ashes. Particle systems of fires and black smoky trails were created to make a strengthening effect. A voice of gunfire was added to the noise of wilderness. The skybox was identical to that of the grasslands scene (see Fig. 1b).

Moving VRE The moving scene displays a normal house moving situation consisted of suitcases, piles of packaged goods, and an empty house. Stair sounds and community noise were added to strengthen the sense of presence (see Fig. 1c).

VREs used in Experiment 1B were identical to those in Experiment 1A except that a rainy day replaced the cloudy day and dead animals were added to promote the experience of wildness.

Stimuli Both Experiment 1A and Experiment 1B used 60 two-character Chinese words, which were taken from the words used by Li (2009). Most of the words were translated from the words used by Nairne et al. (2007). In the present study, all the 45 words were divided into three word lists according to Chinese word frequency dictionary (Liu, 1990). The three word lists were randomly assigned to the three conditions and were kept the way the word lists corresponded to the conditions unchanged for all subjects. The word lists are shown in Appendix B.

Design Both Experiment 1A and Experiment 1B were a one-factor within-subject design. In all conditions, participants were instructed to experience the VRE and then rate the 15 words. There were three blocks with each containing 15 trials, resulting in 45 trials in total for each experiment. The order of the blocks was counterbalanced among participants.

Procedure

For each participant, the whole experiment had two phases: the rating phase and the questionnaire phase. The rating phase included a relevance rating task, while the questionnaire phase consisted of a free recall test and a questionnaire.

In the rating phase, the participants were asked to perform a relevance rating task in each of the VREs. After arriving at the laboratory, the participants first listened to the experimenter's instruction of VR equipment, and then attached the VR headgear with the help of the experimenter. Immediately, the participants were shown a fully immersive VRE, and a 10-second audio instruction began to play, telling the participants that they "are stranded in the foreign grasslands/embattled city" or "are moving" and asking them to take a few steps and look around. Five seconds later, another 30-second audio instruction was played, telling the participants what they were about to face. The 30-second instructions matched the VREs. In previous studies, the standard long instructions were used to instruct participants to imagine specific survival situations, which was not necessary for VREs. Accordingly, we used the standard instruction and the short instruction in Experiment 1A and Experiment 1B, respectively. All the 30-second instructions used in Experiment 1A and Experiment 1B are shown below.

Experiment 1A

Ancestral survival. "You are stranded in the grasslands of a foreign land, without any basic survival materials. Over the next few months, you'll need to find steady supplies of food and water and protect yourself from predators. We are going to show you a list of words, and we would like you to rate how relevant each of these words would be for you in this survival situation. Some of the words may be relevant and others may not—it's up to you to decide" (Nairne et al., 2007).

Modern survival. "You are stranded in the city of a foreign land, without any basic survival materials. Over the next few months, you'll need to find steady supplies of food and water and protect yourself from attackers. We are going to show you a list of words, and we would like you to rate how relevant each of these words would be for you in this survival situation. Some of the words may be relevant and others may not—it's up to you to decide." This instruction was created from that used for ancestral survival by replacing "predators" with "attackers."

Moving. "In this task, we would like you to imagine that you are planning to move to a new home in a foreign land. Over the next few months, you'll need to locate and purchase a new home and transport your belongings. We are going to show you a list of words, and we would like you to rate how relevant each of these words would be for you in accomplishing this task. Some of the words may be relevant and others may not—it's up to you to decide." (Nairne & Pandeirada, 2010).

Experiment 1B

Ancestral survival. "In this task, we would like you to imagine that you'll stay at the grasslands over the next few months. We are going to show you a list of words, and we would like you to rate how relevant each of these words would be for you in this situation. Some of the words may be relevant and others may not—it's up to you to decide."

Modern survival. "In this task, we would like you to imagine that you'll stay in the city over the next few months. We are going to show you a list of words, and we would like you to rate how relevant each of these words would be for you in this situation. Some of the words may be relevant and others may not—it's up to you to decide."

Moving. "In this task, we would like you to imagine that you'll need to locate and purchase a new home and transport your belongings over the next few months. We are going to show you a list of words, and we would like you to rate how relevant each of these words would be for you in accomplishing this task. Some of the words may be relevant and others may not—it's up to you to decide."

Immediately after the 30-second instructions, a virtual whiteboard appeared in the VREs with an instruction indicating that the relevance rating task was to follow. Press the A button on the Xbox (joystick) to start. The to-be-rated words were presented on the board individually for 8,000 ms each, with a scale ranging from 1 (*totally irrelevant*) to 5 (*extremely relevant*) just below the words. Participants were instructed to select the value on the rating scale by pressing the left or right buttons on Xbox, and then press the button "B" on Xbox to confirm their choice. Each word was presented on the board for 8,000 ms or disappeared after the participants pressed the "B" button. After a randomized interval between 1,200 ms and 1,800 ms, the next word appeared for rating. There were five practice words before 15 experimental words. The average time the participants spent on survival- or nonsurvival-relevance rating tasks was about 12 minutes. No word was mentioned of a later retention test. The relevance rating task in the last VRE ended with a two-minute distractor task in which participants were asked to subtract 7 from a random number continuously. After the participants finished the distractor task in the last VRE, the experimenter would help them take off the VR headgear, and the participants were entered the questionnaire phase.

The questionnaire phase did not require VR apparatus, so all the tasks were not performed in VREs. In this phase, participants were asked to first perform an unexpected free recall and then finish a questionnaire. In the free recall task, participants were asked to write down the words they had rated earlier, in any order, on a paper provided by the experimenter. The free recall test proceeded for 10 minutes. The questionnaire contained either two (Experiment 1A) or seven (Experiment 1B) Likert scales that were used to assess emotion-related dimensions of the VREs. All the scales were presented on a computer screen and participants were instructed to make their choices with a computer mouse.

Participants' responses in the rating task were recorded by a program automatically while the results of the free recall test were scored in terms of the to-be-rated word lists by the experimenter. Each successfully recalled word (two-character Chinese word) was marked as 1, while synonym which has only one-character right was marked as 0.5.

Results and discussion

Experiment 1A

Free recall, response times, and relevance ratings Table 1 shows proportion correct recall for each condition. An

Table 1 Correct proportions of free recall, response times (second), and relevance ratings (ranged from 1 to 5) in Experiment 1A (means and standard deviations)

Measurements	Grasslands	Battlefield	Moving
Free recall	0.42 (0.14)	0.47 (0.14)	0.33 (0.11)
Response time	4.31 (0.97)	4.25 (0.90)	4.26 (0.84)
Relevance rating	2.71 (0.52)	3.02 (0.52)	2.66 (0.50)

analysis of variance (ANOVA) revealed a significant effect of condition on free recall rates, $F(2, 78) = 13.55$, $p < .001$, η2 p = .26. Post hoc analyses with LSD indicated better retention for either ancestral survival or modern survival condition compared with moving condition, $MD_{\text{grasslands-moving}} = 0.10$, $p < .001$, $MD_{\text{battlefield-moving}} = 0.14$, $p < .001$. There was no significant difference between ancestral survival and modern survival conditions, $MD_{\text{grasslands-battlefield}} = -0.05$, $p > .05$. An ANOVA on response times showed no difference between conditions, $F(2, 78) = 0.16$, $p > .05$. A similar ANOVA on relevance ratings showed a significant effect of condition, $F(2, 78) = 8.30$, $p < .01$, η2 p = .18. Post hoc analyses with LSD indicated lower relevance ratings for either ancestral survival or moving condition compared to modern survival condition, $MD_{\text{battlefield-grasslands}} = 0.31$, $p < .01$, $MD_{\text{battlefield-moving}} = 0.37$, $p < .01$. There was no difference in relevance ratings between ancestral survival and moving conditions, $MD_{\text{grasslands-moving}} = 0.06$, $p > .05$. No significant correlations were found between the SPAs (free recall: $MD_{\text{grasslands-moving}}$, $MD_{\text{battlefield-moving}}$) and the relevance ratings of either survival condition or moving condition. There was a significant correlation between the SPAs and the corresponding rating differences (Rating $\text{Difference}_{\text{grasslands-moving}}$, Rating $\text{Difference}_{\text{battlefield-moving}}$) for both ancestral survival condition ($r = .458$, $p = .003$) and modern survival condition ($r = .408$, $p = .009$).

In the free recall test, participants also reported several intrusions of VRE objects though they were asked to write down the to-be-rated words: for grasslands VRE, “animal” (three participants), “eagle” (one participant), and “grassland” (one participant); for battlefield VRE, “smoke” (one participant), “road lamp” (one participant); for moving VRE, “box” (one participant), and “sun” (one participant). In addition, several participants also reported words in the instruction of survival VRE: “grasslands” (two participants), “food” (two participants).

Scales for emotional assessment The data of emotional assessments are shown in Fig. 2. An ANOVA on stress assessment data revealed an effect of condition, $F(2, 78) = 123.55$, $p < .001$, η2 p = .76. Post hoc with LSD indicated higher ratings for both ancestral and modern survival conditions compared to moving condition, $MD_{\text{grasslands-moving}} = 2.10$, $p < .001$, $MD_{\text{battlefield-moving}} = 2.35$, $p < .001$. There was no difference between ancestral and modern survival conditions, $MD_{\text{grasslands-battlefield}} = -0.25$, $p > .05$. A similar ANOVA on familiarity assessment data showed an effect of condition, $F(2, 78) = 84.71$, $p < .001$, η2 p = .69. Post hoc with LSD indicated lower ratings for both ancestral and modern survival conditions compared to moving condition, $MD_{\text{grasslands-moving}} = -1.78$, $p < .001$, $MD_{\text{battlefield-moving}} =$

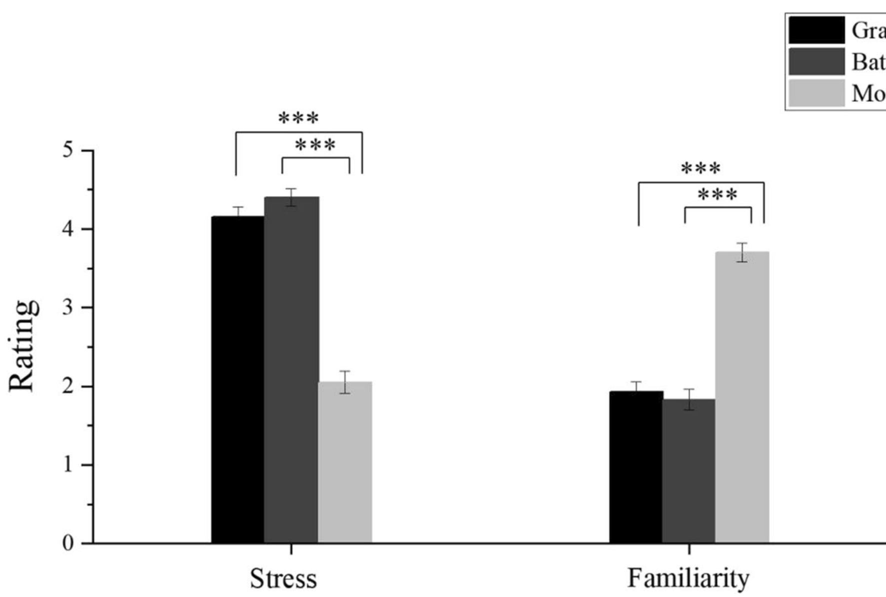

Fig. 2 The results of emotional assessments (ranged from 1 to 5) in Experiment 1A. Error bars indicate standard errors of the means. ***$p < .001$.

Table 2 Correct proportions of free recall, response times (second), and relevance ratings (ranged from 1 to 5) in Experiment 1B (means and standard deviations)

Measurements	Grasslands	Battlefield	Moving
Free recall	0.46 (0.15)	0.44 (0.18)	0.33 (0.12)
Response time	4.13 (0.92)	4.05 (1.08)	4.07 (0.92)
Relevance rating	2.47 (0.40)	2.69 (0.47)	2.39 (0.55)

−1.88, $p < .001$. There was no difference between ancestral and modern survival conditions, $MD_{\text{grasslands-battlefield}} = 0.10$, $p > .05$. The correlations between the SPA and the level of familiarity or stress were not significant.

Experiment 1B

Free recall, response times, and relevance ratings The Table 2 shows proportion correct recall for each condition. An analysis of variance (ANOVA) revealed a significant effect of condition, $F(2, 94) = 15.18$, $p < .001$, η2 p = .24. Post hoc analyses with LSD indicated better retention for both ancestral and modern survival-processing conditions compared to non-survival-processing condition, $MD_{\text{grasslands-moving}} = 0.13$, $p < .001$, $MD_{\text{battlefield-moving}} = 0.11$, $p < .001$. There was no difference between ancestral and modern survival-processing conditions, $MD_{\text{grasslands-battlefield}} = 0.02$, $p > .05$. An ANOVA on response times showed no difference between conditions, $F(2, 94) = 0.18$, $p > .05$. Similar ANOVA on relevance ratings showed a significant effect of condition, $F(2, 94) = 7.77$, $p < .01$, η2 p = .14. Post hoc analyses with LSD indicated lower relevance ratings for either ancestral survival or moving condition (moving scene) compared to modern survival condition, $MD_{\text{battlefield-grasslands}} = 0.22$, $p < .01$, $MD_{\text{battlefield-moving}} = 0.30$, $p < .01$. There was no difference in relevance ratings between ancestral survival and moving conditions, $MD_{\text{grasslands-moving}} = 0.07$, $p > .05$. The correlations between the SPAs (free recall: $MD_{\text{grasslands-moving}}$, $MD_{\text{battlefield-moving}}$) and the relevance ratings for either survival condition or moving condition were not significant. Moreover, no significant correlations were found between the SPA and the corresponding rating difference for either ancestral or modern survival condition (Rating $\text{Difference}_{\text{grasslands-moving}}$, Rating $\text{Difference}_{\text{battlefield-moving}}$).

Despite being asked to report the to-be-rated words, several participants wrote down words corresponding to the VRE elements: for grasslands VRE, "animal" (four participants), "eagle" (one participant), "birdsong" (the cry of the eagle, one participant); for battlefield VRE, "smoke" (two participants), "lighting" (one participant); for moving VRE, "box" (two participants). The words that appeared in the instructions were reported: "grasslands" (two participants).

Scales for emotional assessment The results of emotional assessments are shown in Table 3. An ANOVA on emotional assessment data revealed an effect of condition in all dimensions. Post hoc with LSD showed higher emotional ratings for both ancestral and modern survival conditions compared with moving condition, except for the dimension of "Interest." There was no difference between the ancestral and the modern survival conditions except for the dimensions of "Interest" and "Threat." On the dimensions of "Interest" and "Threat," the emotional ratings were higher for the ancestral survival VRE than for the modern survival VRE. There were no significant correlations between the SPAs (free recall: $MD_{\text{grasslands-moving}}$, $MD_{\text{battlefield-moving}}$) and the emotional ratings in all dimensions, except for that between the SPAs and Interest ratings in the ancestral survival VRE ($r = .339$, $p = .018$).

In Experiment 1, the typical SPAs revealed in both ancestral and modern survival VREs suggested that SPA was not limited to survival scenarios. Particularly, Experiment 1B replicated the typical SPA with a short instruction that did not mention any specific survival threats. The response times for all conditions in either Experiment 1A or Experiment 1B showed no difference. Although the relevance ratings of the items showed a difference between survival and nonsurvival conditions, there was no significant correlation between the SPAs and the relevance ratings of either survival or moving condition in both experiments. The results are consistent with previous findings that the SPA is independent of congruity effect and applicable to a variety of scenarios (Kostic et al., 2012; Nairne & Pandeirada, 2011).

The results of emotional assessments showed that survival VREs led to stronger emotion-related experiences relative to nonsurvival VRE, including *stress*, *arousal*,

Table 3 Emotional assessments for dimensions (ranged from 1 to 5) in Experiment 1B (means and standard deviations)

Conditions	Stress	Interest	Arousal	Novelty	Danger	Motivation	Threat
Grasslands	4.31 (0.12)	3.52 (0.19)	4.13 (0.14)	4.23 (0.13)	4.56 (0.09)	4.00 (0.13)	4.46 (0.10)
Battlefield	4.23 (0.10)	2.71 (0.20)	3.94 (0.14)	4.08 (0.15)	4.48 (0.11)	3.92 (0.14)	4.10 (0.14)
Moving	1.96 (0.12)	2.81 (0.16)	2.83 (0.14)	2.38 (0.13)	1.40 (0.08)	3.17 (0.16)	1.56 (0.09)

novelty, *danger*, *motivation*, and *threat*. The only exception was *interest*, in which ancestral condition was higher than the other two conditions. However, there were no consistent correlations between these emotional assessments and the SPAs in both experiments. The results on some emotion-related dimensions, such as familiarity, stress, interest, arousal, are consistent with previous findings (e.g., Nairne & Pandeirada, 2010; Smeets et al., 2012; Kazanas et al., 2020).

In total, the results of Experiment 1 supported that the survival VRE was effective in triggering survival processing. The findings provide new evidence for the SPA that information processed for its importance for survival is better remembered than that in other contexts (Nairne & Pandeirada, 2010; Otgaar & Smeets, 2010). To further examine the selected survival scenario in the battlefield condition which had never been tested before, the SPA was measured again in Experiment 2 with the scenarios corresponding to the VREs used in Experiment 1A.

Experiment 2

According to our hypothesis, survival VRE is effective in demonstrating SPA the same as in traditional survival scenario. As such, Experiment 2 attempted to identify similar SPA patterns with the corresponding ancestral and modern scenarios. To keep the procedure constant, Experiment 2 used the same procedure as in Experiment 1A. Meanwhile, the seven dimensions assessed in Experiment 1B were also used in Experiment 2 to show the potential difference between the ancestral and modern scenarios.

Method

Participants

A sample of 48 healthy participants (24 males, 24 females; aged from 19 to 25, 20.96 ± 1.4) reporting normal or corrected-to-normal vision took part in the present experiment. Eligible participants indicated via a questionnaire that they did not have agoraphobia.

Materials

The materials used in Experiment 2 were identical to those in Experiment 1A, except for the VREs and the questionnaire. Specifically, the VREs were changed to the corresponding scenarios, while the two-dimension questionnaire was replaced with the seven-dimension questionnaire of Experiment 1B.

Design and procedure

Experiment 2 used the same design as Experiment 1A because it contained the standard long instructions. As did in previous studies, the instructions for three scenarios were presented on a computer screen. The computer and laboratory were held constant across participants. The procedure was identical to that of Experiment 1A except that the to-be-rated words were presented individually (centered on the screen) for 5 s per word.

The procedure contained two phases: the rating phase and the questionnaire phase. At the beginning of the rating phase, all participants were asked whether or not they could imagine themselves in a survival situation. If the participants answered "yes" or nodded, they would continue the experiment. This was used not only as a practice for imagination but also as a signal for confirmation. Although a questionnaire had indicated that no participants had agoraphobia, we asked for confirmation anyway. Following the practice, one of the three instructions (30-s instruction) that were previously used in Experiment 1A was presented on the computer screen. After the instruction, stimuli were presented individually for 5 s each, and participants were asked to rate the words on a 5-point Likert scale that appeared just below the words. Participants were instructed to make their choices with a computer mouse. Everyone was cautioned to respond within the 5-s presentation window, and no mention was made of a later retention test. A short practice session containing five to-be-rated words preceded the actual rating task in each scenario condition. After the last word was rated, instructions appeared for a 2-minute distractor task, in which participants were asked to subtract 7 from a random number continuously. Following the distractor task, participants entered the questionnaire phase in which participants were asked to first perform an unexpected free recall, and then finish a questionnaire.

Results and discussion

Free recall, response times, and relevance ratings

The mean proportions of correct free recall for all the conditions are shown in Table 4. An overall analysis of variance (ANOVA) revealed a significant effect of condition, $F(2, 94) = 7.32$, $p < .001$, η2 p = .14, Post hoc analyses with

Table 4 Correct proportions of free recall, response times (second), and relevance ratings (ranged from 1 to 5) in Experiment 2 (means and standard deviations)

Measurements	Grasslands	Battlefield	Moving
Free recall	0.31 (0.13)	0.31 (0.15)	0.23 (0.11)
Response time	2.16 (0.56)	2.06 (0.56)	2.02 (0.47)
Relevance rating	2.78 (0.68)	3.22 (0.55)	2.66 (0.54)

LSD indicated better retentions for both ancestral and modern survival conditions compared with moving condition, $MD_{\text{grasslands-moving}} = 0.08$, $p < .001$, $MD_{\text{battlefield-moving}} = 0.08$, $p < .001$. There was no difference between ancestral condition and modern survival condition, $MD_{\text{grasslands-battlefield}} = -0.001$, $p > .05$. An ANOVA on response times showed no difference across conditions, $F(2, 94) = 2.63$, $p > .05$. A similar ANOVA on relevance ratings showed a significant effect of condition, $F(2, 94) = 23.28$, $p < .001$, η2 p = .33. Post hoc analyses with LSD indicated lower relevance ratings for both grasslands and moving conditions compared with battlefield condition, $MD_{\text{battlefield-grasslands}} = 0.44$, $p < .001$, $MD_{\text{battlefield-moving}} = 0.55$, $p < .001$. There was no difference on relevance ratings between ancestral survival condition and moving condition, $MD_{\text{grasslands-moving}} = 0.12$, $p > .05$. No significant correlations were found between the SPAs (free recall: $MD_{\text{grasslands-moving}}$, $MD_{\text{battlefield-moving}}$) and the relevance ratings of survival condition or moving condition. Moreover, there was no significant correlation between the SPAs and the rating differences ($MD_{\text{grasslands-moving}}$, $MD_{\text{battlefield-moving}}$) for either ancestral survival condition or modern survival condition.

In the free recall test, some participants wrote down the words that appeared in the instructions: "grasslands" (four participants), "food" (five participants), and "war" (two participants).

Scales for emotional assessment

The data of emotional assessments is shown in Table 5. An ANOVA on assessment data revealed three main findings: (1) Emotional ratings were higher for the modern survival scenario than for the nonsurvival scenario and ancestral survival scenario, except for "motivation" and "interest"; (2) no differences were found between the ancestral survival scenario and the moving scenario except for the dimensions of "stress," "danger," and "threat"; and (3) no significant correlations were found between the SPAs (free recall: $\text{Mean}_{\text{grasslands-moving}}$, $\text{Mean}_{\text{battlefield-moving}}$) and the emotional ratings in almost all self-reported dimensions except for the "danger" dimension ($r = .341$, $p = .018$) and "threat" dimension ($r = .334$, $p = .020$) of the modern survival scenarios. Additionally, emotional ratings on most of the dimensions were higher for the modern survival scenario than for the ancestral survival scenario.

In total, Experiment 2 replicated the SPA pattern of Experiment 1. Both the ancestral grasslands scenario and modern battlefield scenario led to typical SPAs, supporting that the SPA is robust and applicable to both ancestral and modern survival scenarios (Kostic et al., 2012). Assessments on seven emotion-related dimensions showed participants reported stronger emotional experience in survival condition than in moving condition, consistent with Experiment 1B. However, no consistent correlations between SPAs and the relevance ratings of survival or moving condition across experiments. Moreover, there was no significant correlation between SPAs and emotional dimensions ratings in all dimensions across experiments. The findings support that the survival VRE is a useful tool in survival processing research.

General discussion

The purpose of the present study is to investigate whether the SPA can be demonstrated with survival VRE. Using the survival processing paradigm, we successfully demonstrated in Experiment 1 the typical SPAs with new ancestor and modern survival VREs instead of the traditional survival scenarios. Then, in Experiment 2, we went back to the scenarios and still successfully demonstrated typical SPAs with the scenarios corresponding to the survival VREs used in Experiment 1. The results of these two experiments support

Table 5 Emotional assessments for dimensions (ranged from 1 to 5) in Experiment 2 (means and standard deviations)

Conditions	Stress	Interest	Arousal	Novelty	Danger	Motivation	Threat
Grasslands	3.98 (0.12)	3.60 (0.19)	2.71 (0.14)	3.19 (0.13)	3.88 (0.09)	2.94 (0.13)	3.71 (0.10)
Battlefield	4.52 (0.10)	3.65 (0.20)	3.69 (0.14)	3.90 (0.15)	4.44 (0.11)	2.38 (0.14)	4.42 (0.14)
Moving	2.67 (0.12)	3.33 (0.16)	2.67 (0.14)	2.92 (0.13)	1.94 (0.08)	3.56 (0.16)	1.98 (0.09)

that survival VRE is a reliable tool in designing and delivering a survival situation.

Survival processing is one of the core problems for psychologists in understanding the memory mechanism. From the evolutionary perspective, the ancestral grasslands scenario is crucial for forming of survival processing, but the mechanism underlying SPA is more likely adaptive to the key survival challenges in subsequent stages (Nairne & Pandeirada, 2016). In the time dimension, both ancestral and modern survival situations can lead to typical SPA (e.g., Kostic et al., 2012; see also the findings of the present study). Correspondingly, in the category of specific survival threats, both real ancestral predators and modern supernatural threats can lead to typical SPA (Kazanas & Altarriba, 2016; Soderstrom & McCabe, 2011; Weinstein et al., 2008). Therefore, it is reasonable to believe that survival processing is a universal adaptation mechanism as well as a basic pillar of the human cognitive system.

The SPA identified in the survival VRE or scenario with short instruction supports that survival processing is not just semantically related to the survival situation. For example, in Experiment 1B of the present study, participants were just informed that they were "stranded in the foreign grasslands/embattled city," but the SPAs were still found. A similar finding has also been reported by Klein (2013) in a scenario-based survival processing task, in which a short instruction like "stay to alive" could trigger a typical SPA. These findings suggested the SPA might be independent of the specific information of survival contexts. However, in the present Experiment 1B, the effect of a short instruction might have been offset by some survival-related information, including rainy weather, dead animals. Therefore, whether the SPA is independent of the specific information about survival threats displayed in a survival VRE remains to be verified in later studies.

Another issue arising from the use of survival VRE is whether the additional information added to a survival VRE contributes to the SPA. Among existing studies, survival scenarios were usually based on standard instructions. It seemed that all information was included in the instructions. But in effect, a large amount of information was not mentioned in the survival instructions but was embedded in the scenarios, such as terrains, sky, weather, shrubs, plants, noise of wilderness, and so on. In the corresponding survival VREs, such information must be visible. Moreover, some additional information (i.e., voices, animals, rain) has to be added to promote the presence of the survival environment. Similarly, to build nonsurvival VREs, additional information is also necessary. Previous studies have revealed that reducing some specific information in survival instruction can diminish SPA (Kroneisen & Erdfelder, 2011; Otgaar et al., 2015). There exists the possibility that the additional information, in one way or another, had contributed more to survival processing just as the richness of encoding would predict (e.g., Kroneisen & Erdfelder, 2011; Röer et al., 2013). In fact, some participants were found to have reported some items from VRE but not from the rated words in the relevance task, though they were asked to just recall the words that appeared in the rating task. Because the frequency of intrusion was very low, it was difficult to analyze the possible difference between the conditions. In any case, many studies have demonstrated an environmental context effect in free recall (e.g., Isarida & Isarida, 2007). Although this kind of intrusion does not necessarily support the richness of encoding hypothesis, there is a need to further examine whether the richness of survival VRE plays a role in the SPAs. On the other hand, the additional information added to strengthen the survival situation also included some animals. In terms of the animacy advantage (e.g., Nairne et al., 2017; Popp & Serra, 2016), it was possible that the animate-related information facilitated encodings or retrieval of the to-be-rated words in the survival VREs more than in moving VRE. The design of the present study did not aim to directly compare the survival VREs with the corresponding survival scenarios. More examinations are needed in further research.

Survival VREs differed from survival scenarios in emotion-related experience. All self-reported dimensions indicated higher scores in survival VREs than in nonsurvival VREs, except for the dimension of interest. But for the scenarios in Experiment 2, there were just three dimensions (stress, danger, threat) that showed a similar pattern. The dimension of motivation even displayed a reversed pattern. Additionally, the emotional ratings in five of seven self-reported dimensions were higher for the modern survival scenario than for the ancestral survival scenario. In contrast, no differences were found between the modern and ancestral survival VREs in most of the self-reported dimensions (Experiment 1B). There are many different dimensions of emotional correlation that have been assessed in existing studies. In Experiment 2 of the current study, which also used traditional scenarios, the assessment of emotion-related dimensions was comparable with other studies. For example, the dimensions of "interest" and "arousal" in Experiment 2 were consistent with a recent study that found no difference between survival grasslands and moving conditions on those two dimensions (Kazanas et al., 2020). The comparison between Experiment 1B and Experiment 2 in the present study showed that the simulated grasslands led to higher emotional ratings than imagined grasslands on most emotional dimensions. In view of the independent relationship between survival processing and reward motivation (Forester et al., 2020), the opposite results of Experiment 1B and Experiment 2 on the motivation dimension may also be related to the use of survival VREs. But whether the difference between VREs and scenarios accounted for the difference on the self-reported dimensions in the present study remains unknown.

There are many scenario properties that may affect the SPA, but there is still a lack of consistency. In the present study, although there were differences between survival VREs and survival scenarios, these differences did not affect SPA pattern. Similarly, some previous studies have found that scenario properties, such as stress, threat and motivation, do not affect the SPAs (e.g., Bell et al., 2013, 2015; Forester et al., 2020; Smeets et al., 2012). However, some other studies have reached the opposite results, showing that the level of threat is closely related to the SPAs (e.g., Olds et al., 2014). We argue that the way of presenting survival situations based on instruction-based imagination may be one of the reasons for the differences in results.

The correlation analyses between the relevance ratings and the SPAs in the present study support an independent relationship in consistence with previous findings (e.g., Nairne & Pandeirada, 2011). Across three experiments, no consistent correlations were found between the SPAs and the relevance ratings of either survival condition or moving condition, and that between the magnitude of SPA and the rating difference for either ancestral survival condition or modern survival condition. These findings suggest that the SPAs demonstrated in the present study cannot be completely explained by the congruity effect. Given the lack of control over the to-be-rated words in the present study (e.g., Butler et al., 2009; Röer et al., 2013), our findings do not necessarily contradict with the coexistence of congruity effect and SPAs. Interestingly, the intrusions observed in Experiments 1A and 1B suggested a possible relationship between rating task and the context information. In future study, we argue that survival VREs can help to examine these two effects, considering the advantages of the VREs in experimental control.

Although the present results clearly support that survival VRE is an effective tool in survival processing research, it is appropriate to recognize several potential limitations. First, in addition to experimental control, the advantages and disadvantages of survival VREs relative to survival scenarios remain unknown. For example, questions such as, what is the role of the multimodal information in SPA, and what are the criteria for defining a survival VRE, remain to be clarified. In future studies, more direct comparisons between survival VRE and survival scenarios would help address these problems. Second, it is necessary to directly measure the dimensions related to emotion to further investigate the relationship between these dimensions and the magnitudes of SPA. Third, a quantitative measurement of the presence in either survival VRE and the survival scenario might help rule out the possibility of immersive presence contributing to the SPA. Last but not least, the three word lists were pseudo-randomly assigned to the three conditions based on Chinese word frequency dictionary and remained fixed for all participants during the experiment. Therefore, the word list assignment was exactly the same for all participants, but this could also lead to a bias. Especially when considering the possible animacy effect, the survival processing conditions contain more animal words (grassland, five; battlefield, three), while the nonsurvival processing condition does not contain such words.

Despite these limitations, this research can be credited as a first step towards applying survival VRE to survival processing research, that, to our knowledge, has never been directly linked. All in all, the present research contributes to a growing body of evidence suggesting that survival processing effects are designed by nature to help organisms deal with survival challenges.

Appendix A

1. Please rate the stress of each scene according to the stress you experienced in the scene.

1------------------2------------------3------------------4------------------5

not at all lower moderately higher extremely

2. Please rate the interest of the scene.

1------------------2------------------3------------------4------------------5

not at all lower moderately higher extremely

3. Please rate the emotional arousal intensity of each scene based on the emotional arousal intensity you experienced in the scene.

1------------------2------------------3------------------4------------------5

not at all lower moderately higher extremely

4. Please rate the novelty of the scene.

1------------------2------------------3------------------4------------------5

not at all lower moderately higher extremely

5. Please rate the danger of the scene.

1------------------2------------------3------------------4------------------5

not at all lower moderately higher extremely

6. Please rate your level of motivation for the task in the scene.

1------------------2------------------3------------------4------------------5

not at all lower moderately higher extremely

7. Please rate how threatened you feel in the scene.

1------------------2------------------3------------------4------------------5

not at all lower moderately higher extremely

Appendix B

The grasslands:

disease	sun	snow	veteran	monk
cartoon	woman	cabin	pepper	physician
friend	storm	vapour	blood	coast

The battlefield:

truck	emerald	car	flute	soccer
potato	cotton	alcohol	juice	string
child	dinner	doctor	timepiece	soldier

The moving:

sea	lemon	liver	silk	tobacco
lime	lumber	landscape	village	slipper
garden	flood	meadow	drug	computer

References

Bell, R., Röer, J. P., & Buchner, A. (2013). Adaptive memory: The survival processing memory advantage is not due to negativity or mortality salience. *Memory & Cognition, 41*, 490–502. https://doi.org/10.3758/s13421-012-0290-5

Bell, R., Röer, J. P., & Buchner, A. (2015). Adaptive memory: Thinking about function. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 41*(4), 1038–1048. https://doi.org/10.1037/xlm0000066

Brown, M. F., Batterman, J. M., Leman, J., Taylor, B., Kim, J., Ruff, J., Saxon, M. E., & Stokesbury, A. (2016). No evidence for effects of fitness relevance or sex differences in a virtual hunting and gathering task. *Evolutionary Psychological Science, 2*, 84–100. https://doi.org/10.1007/s40806-015-0038-0

Butler, A. C., Kang, S. H., & Roediger 3rd, H. L. (2009). Congruity effects between materials and processing tasks in the survival processing paradigm. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 35*(6), 1477–1486. https://doi.org/10.1037/a0017024

Cieślik, B., Mazurek, J., Rutkowski, S., Kiper, P., Turolla, A., & Szczepańska-Gieracha, J. (2020). Virtual reality in psychiatric disorders: A systematic review of reviews. *Complementary Therapies in Medicine, 52*, 102480. https://doi.org/10.1016/j.ctim.2020.102480

Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G*Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*, 175–191. https://doi.org/10.3758/BF03193146

Forester, G., Kroneisen, M., Erdfelder, E., & Kamp, S.-M. (2020). Adaptive memory: Independent effects of survival processing and reward motivation on memory. *Frontiers in Human Neuroscience, 14*, 588100. https://doi.org/10.3389/fnhum.2020.588100

Isarida, T., & Isarida, T. K. (2007). Environmental context effects of background color in free recall. *Memory & Cognition, 35*(7), 1620–1629. https://doi.org/10.3758/BF03193496

Kazanas, S. A., & Altarriba, J. (2016). Did our ancestors fear the unknown? The role of predation in the survival advantage. *Evolutionary Behavioral Sciences, 11*(1), 83–91. https://doi.org/10.1037/ebs0000074

Kazanas, S. A., Altarriba, J., & O'Brien, E. G. (2020). Paired-associate learning, animacy, and imageability effects in the survival advantage. *Memory & Cognition, 48*(2), 244–255. https://doi.org/10.3758/s13421-019-01007-2

Klein, S. B. (2013). Does optimal recall performance in the adaptive memory paradigm require the encoding context to encourage thoughts about the environment of evolutionary adaptation? *Memory and cognition, 41*, 49–59. https://doi.org/10.3758/s13421-012-0239-8

Klein, S. B. (2014). The effects of thoughts of survival and thoughts of death on recall in the adaptive memory paradigm. *Memory, 22*(1), 65–75. https://doi.org/10.1080/09658211.2012.740486

Klein, S. B., Cosmides, L., Tooby, J., & Chance, S. (2002). Decisions and the evolution of memory: Multiple systems, multiple functions. *Psychological Review*, *109*(2), 306–329. http://doi.org/https://doi.org/10.1037/0033-295X.109.2.306

Kostic, B., McFarlan, C. C., & Cleary, A. M. (2012). Extensions of the survival advantage in memory: Examining the role of ancestral context and implied social isolation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38*(4), 1091–1098. https://doi.org/10.1037/a0026974

Kroneisen, M., & Erdfelder, E. (2011). On the plasticity of the survival processing effect. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 37*(6), 1553–1562. https://doi.org/10.1037/a0024493

Li, J. G. (2009). *Are people better able to remember information about survival?* [Master's thesis, East China Normal University, Shanghai].

Liu, Y. (1990). *Dictionary of frequency of common words in modern Chinese.* China Aerospace Publishing House.

Lloyd, J., Persaud, N. V., & Powell, T. E. (2009). Equivalence of real-world and virtual-reality route learning: a pilot study. *CyberPsychology and Behavior, 12*(4), 423–427. https://doi.org/10.1089/cpb.2008.0326

Nairne, J. S., & Pandeirada, J. N. (2011). Congruity effects in the survival processing paradigm. *Journal of Experimental Psychology. Learning, Memory, and Cognition, 37*(2), 539–549. https://doi.org/10.1037/a0021960

Nairne, J. S., & Pandeirada, J. N. (2016). Adaptive memory: The evolutionary significance of survival processing. *Perspectives on Psychological Science: A Journal of the Association for Psychological Science, 11*(4), 496–511. https://doi.org/10.1177/1745691616635613

Nairne, J. S., & Pandeirada, J. N. S. (2010). Adaptive memory: Ancestral priorities and the mnemonic value of survival processing. *Cognitive Psychology, 61*(1), 1–22. https://doi.org/10.1016/j.cogpsych.2010.01.005

Nairne, J. S., Pandeirada, J. N. S., Gregory, K. J., & Van Arsdall, J. E. (2009). Adaptive memory: Fitness-relevance and the hunter-gatherer mind. *Psychological Science, 20*(6), 740–746. https://doi.org/10.1111/j.1467-9280.2009.02356.x

Nairne, J. S., Pandeirada, J. N. S., & Thompson, S. R. (2008). Adaptive memory: The comparative value of survival processing. *Psychological Science, 19*(2), 176–180. https://doi.org/10.1111/j.1467-9280.2008.02064.x

Nairne, J. S., Thompson, S. R., & Pandeirada, J. N. S. (2007). Adaptive memory: Survival processing enhances retention. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 33*(2), 263–273. https://doi.org/10.1037/0278-7393.33.2.263

Nairne, J. S., Van Arsdall, J. E., & Cogdill, M. (2017). Remembering the living: Episodic memory is tuned to animacy. *Current*

Directions in Psychological Science, 26(1), 22–27. https://doi.org/10.1177/0963721416667711
Nash, E. B., Edwards, G. W., Thompson, J. A., & Barfield, W. (2000). A review of presence and performance in virtual environments. *International Journal of Human–Computer Interaction, 12*(1), 1–41. https://doi.org/10.1207/S15327590IJHC1201_1
Öhman, A., Flykt, A., & Esteves, F. (2001). Emotion drives attention: detecting the snake in the grass. *Journal of Experimental Psychology: General, 130*(3), 466–478. https://doi.org/10.1037/0096-3445.130.3.466
Olds, J. M., Lanska, M., & Westerman, D. L. (2014). The role of perceived threat in the survival processing memory advantage. *Memory, 22*(1), 26–35. https://doi.org/10.1080/09658211.2013.806554
Otgaar, H., Jelicic, M., & Smeets, T. (2015). Adaptive memory: Identifying the proximate roots of the survival processing advantage. *The Journal of Psychology: Interdisciplinary and Applied, 149*(4), 339–355. https://doi.org/10.1080/00223980.2013.879848
Otgaar, H., & Smeets, T. (2010). Adaptive memory: survival processing increases both true and false memory in adults and children. *Journal of Experimental Psychology Learning Memory and Cognition, 36*(4), 1010–1016. https://doi.org/10.1037/a0019402
Popp, E. Y., & Serra, M. J. (2016). Adaptive memory: Animacy enhances free recall but impairs cued recall. *Journal of experimental psychology. Learning, Memory, and Cognition, 42*(2), 186–201. https://doi.org/10.1037/xlm0000174
Röer, J. P., Bell, R., & Buchner, A. (2013). Is the survival-processing memory advantage due to richness of encoding? *Journal of Experimental Psychology: Learning, Memory, and Cognition, 39*(4), 1294–1302. https://doi.org/10.1037/a0031214
Sauzéon, H., Pala, P. A., Larrue, F., Wallet, G., Déjos, M., Zheng, X., Guitton, P., & N'Kaoua, B. (2012). The use of virtual reality for episodic memory assessment: Effects of active navigation. *Experimental Psychology, 59*(2), 99–108. https://doi.org/10.1027/1618-3169/a000131
Smeets, T., Otgaar, H., Raymaekers, L., Peters, M. J. V., & Merckelbach, H. (2012). Survival processing in times of stress. *Psychonomic Bulletin& Review, 19*, 113–118. https://doi.org/10.3758/s13423-011-0180-z
Smith, S. A. (2019). Virtual reality in episodic memory research: a review. *Psychonomic Bulletin & Review, 26*, 1213–1237. https://doi.org/10.3758/s13423-019-01605-w
Soderstrom, N. C., & McCabe, D. P. (2011). Are survival processing memory advantages based on ancestral priorities? *Psychonomic Bulletin & Review, 18*, 564–569. https://doi.org/10.3758/s13423-011-0060-6
Steuer, J. (1992). Defining virtual reality: dimensions determining telepresence. *Journal of Communication, 42*(4), 73–93. https://doi.org/10.1111/j.1460-2466.1992.tb00812.x
Weinstein, Y., Bugg, J. M., & Roediger, H. L. (2008). Can the survival recall advantage be explained by basic memory processes? *Memory & Cognition, 36*, 913–919. https://doi.org/10.3758/mc.36.5.913
Yuan, X. J., Cui, X. X., Cao, Z. C., Kan, H., Wang, X., & Wang, Y. M. (2018). Attentional bias towards threatening visual stimuli in a virtual reality-based visual search task. *Acta Psychologica Sinica, 50*(6), 622–636. https://doi.org/10.3724/SP.J.1041.2018.00622

Open practices statements

Experimental materials are available from the corresponding author and the data are available online (https://www.scidb.cn/anonymous/QkZKSnZl). The data of this study have been published with a DOI number (https://doi.org/10.11922/sciencedb.01535).

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.