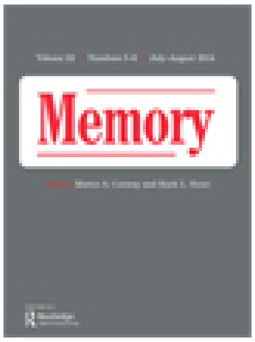

Memory

ISSN: 0965-8211 (Print) 1464-0686 (Online) Journal homepage: http://www.tandfonline.com/loi/pmem20

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https://doi.org/10.1080/09658211.2018.1515317

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The opportunity to choose enhances long-term episodic memory

Nuphar Rotem-Turchinski[a,b], Ayelet Ramaty[a,b] and Avi Mendelsohn [a,b]

[a]Sagol Department of Neurobiology, University of Haifa, Haifa, Israel; [b]Institute of Information Processing and Decision Making, University of Haifa, Haifa, Israel

ABSTRACT

Episodic memory is typically studied under conditions that treat participants as passive agents. Here we sought to explore how actively engaging in ongoing naturalistic occurrences affects long-term episodic memory. Participants viewed 40 short movie clips that depicted a protagonist that conversed with the participants. In each clip, they were either offered the chance to (supposedly) determine the clip's continuation (*active* condition), or let the computer decide for them (*passive* condition). Participants returned either two days or one week after the experience to undergo a true/false memory test for the clips' details and a two-alternative recognition test for the choices made. Memory performance for both groups was superior for information and choices conveyed in the *active* vs. *passive* condition. These findings suggest that the sense of actively influencing the unfolding of events is beneficial to long-term memory of the experience at large, baring potential interventions in the fields of education and cognitive enhancement.

ARTICLE HISTORY
Received 13 March 2018
Accepted 16 August 2018

KEYWORDS
Episodic memory; sense of agency; long-term memory

Empirical studies of episodic memory have been largely dominated by experimental designs in which discrete units of information are presented to passive individuals (Cohen, 2008). The neurocognitive concept of episodic memory, however, is defined as the uniquely human capacity to reinstate multi-sensory, content-rich information from the past, typically characterised by meaningful, often socially mediated, occurrences, and contextual detail (Tulving, 1983). Indeed, real-life events entail a rich array of occurrences, spanning from passively experiencing (seeing, hearing), to actively engaging in an influencing the unfolding of the event (doing, interacting, choosing, etc.). Whether encoded experiences will be successfully retained in long-term memory depends on multiple factors, key of which are prior schemas, novelty, emotional valence, and motivation (Gruber, Gelman, & Ranganath, 2014; van Kesteren, Ruiter, Fernández, & Henson, 2012). Here we sought to examine whether the perceived influence on the unfolding of naturalistic events impact long-term memory of the occurrence.

There is in fact evidence that active learning, both in the motor and cognitive domains, can benefit certain types of memory (Brandstatt & Voss, 2014; Butler & James, 2013; Carassa, Geminiani, Morganti, & Varotto, 2002; Murty, DuBrow, & Davachi, 2015; Plancher, Barra, Orriols, & Piolino, 2013). For example, motor learning was shown to be both faster and more accurate when participants were required to use an object, rather than merely view it (Butler & James, 2013). Similarly, spatial memory performance in a virtual environment seems to benefit from active vs. passive exploration of an environment (Brooks, 1999; Carassa et al., 2002; Plancher, Tirard, Gyselinck, Nicolas, & Piolino, 2012). Memory performance was indeed found to increase after active engagement in simple cognitive tasks such as filling a word to complete a sentence (Vinogradov et al., 2006), and recognising verbs that subjects were instructed to actively perform (Cohen, 1981; Engelkamp & Cohen, 1991; Engelkamp & Zimmer, 1989).

Besides memory benefits from active behaviours, individuals can improve memory performance by deciding which items they wish to learn. When given the opportunity to choose which words to learn from presented paired associates, the opportunity itself was shown to enhance memory for those words (Monty & Permuter, 1975), as well as for other words presented in the task (Monty, Perlmuter, Libon, & Bennet, 1982; Watanabe, 2001). Similar findings have been hypothesised to involve self-referential processes, whereby information that is processed in relation to the self is deemed advantageous to subsequent memory performance (Cunningham, Brady-Van den Bos, & Turk, 2011; Symons & Johnson, 1997).

A recent study examined whether the act of choosing what to learn affects declarative memory for the information relevant to that choice (Murty et al., 2015). Participants were instructed to choose between two occluding screens to reveal a stimulus behind it. The opportunity to choose, the researchers posited, evoked a sense of

CONTACT Avi Mendelsohn amendels1@univ.haifa.ac.il; avi.mendelsohn@gmail.com Sagol Department of Neurobiology, University of Haifa, Haifa 3498838, Israel; Institute of Information Processing and Decision Making, University of Haifa, Haifa 3498838, Israel

control over the environment (feeling of agency), sufficient to improve memory performance. Indeed, they found that the opportunity to choose which screen to unveil led to an increase in memory performance for the stimuli behind the chosen screens compared to ones that were assigned to them randomly. Here, the improvement in memory performance was linked to interactions between striatum activation immediately before choice phases and hippocampus activity thereafter during successful memory encoding of presented items.

These studies provide insight as to how the mode of encoding may influence learning of items, stressing the roles of self-involvement and "ownership" of encoded material (Cloutier & Neil Macrae, 2008; Cunningham et al., 2011; Toyota & Tsujimura, 2000), and attention allocation to self-referential information (Macrae, Moran, Heatherton, Banfield, & Kelley, 2004) as mediators of the enhanced memory effect. However, whether choices affect memory for narrative events is still unknown. Moreover, the bulk of choice-related memory effects were demonstrated shortly after encoding, bringing into question the durability of such effects, and what are the time scales by which actively engaging in the encoding phase may affect memory retrieval.

Exercising control over one's environment in the form of executing an action seems to be a rewarding behaviour (Leotti & Delgado, 2014), even when no external reward is afforded (Eitam, Kennedy, & Higgins, 2013; Leotti & Delgado, 2011). Influencing the environment by action or choices is closely linked with "sense of agency" – loosely defined in the psychology realm as the experience that one has initiated and controlled an action (Haggard & Eitam, 2015). Recent studies on the effect that active choices have on memory have in fact suggested that the act of choosing may enhance subsequent memory for contaminant information through connections between the brain's reward system and the hippocampus (Murty et al., 2015). Interestingly, information generating a state of curiosity towards it seem to modulate hippocampus-dependent learning as well, via dopaminergic circuits (Gruber et al., 2014). These findings coincide with a burgeoning literature that provides evidence that striatal signals, essential for mediating reward-based learning, convey information to the hippocampus, thereby forming a functional link between the reward-related mesolimbic system and declarative memory (Shohamy & Adcock, 2010; Wittmann et al., 2005; Wittmann, Dolan, & Düzel, 2011). The primary aim of the current study was to explore the impact of the sense of influence over ongoing naturalistic events on long-term incidental memory formation. Incidental memory refers to the formation of memory representations for information that were not directly intended to be encoded and memorised (McLaughlin, 1965). Most of our every-day memories are formed incidentally, devoid of explicit intent to memorise. Thus, incidental memory is a key feature of episodic memory, and studying it in an ecological setting can serve to illuminate the mechanisms that underlie memory formation and performance in natural environments (Clemens et al., 2015). Participants were given the opportunity to choose between different alternatives while observing and interacting with characters in different situations presented in short movie clips (see Figure 1). Despite its decay across time, memory for narrative films appears to persist for long durations (Furman, Dorfman, Hasson, Davachi, & Dudai, 2007; Furman, Mendelsohn, & Dudai, 2012; Mendelsohn, Furman, & Dudai, 2010). Thus, using short narratives as memoranda enabled us to examine whether active participation in the encoding stage would increase memory performance, regardless of the natural decay of memory performance overall. We found enhanced long-term episodic memory for incidental information presented in clips that participants felt they actively chose their outcome, as opposed to clips that the computer chose for them. The act of choosing also benefited memory for the choices themselves.

Material and methods

Participants

Ethical approval was obtained from the Institutional Review Board (IRB) of University of Haifa's Department of Psychology. Fifty-eight volunteers aged 20–35 participated in the study, all of which gave written informed consent to participate in the study. All participants were right handed, fluent Hebrew speakers, with no learning disorders/ ADHD/ neurological conditions, intact hearing and intact/corrected vision. The participants were divided into two groups: a two-day retention group (28 participants, mean age 27.03 ± 0.62) and a one-week retention group (30 participants, mean age 25.63 ± 0.56). Twelve participants were excluded from memory and confidence analysis for not reaching a threshold criterion of influence feeling (see below). Participants were remunerated for their participation.

Experimental protocol

The experiment consisted of two phases: an *encoding phase* and a *retrieval phase*. During the encoding phase, the participants played a character in a computer game that presented naturalistic situations. The naturalistic situations consisted of short clips, filmed on a home video camera by N.R. in a shopping mall. Subsequent to filming, the raw footage was edited into 40 short clips (see below). During half of the events, the participants were actively involved in the ongoing events by choosing between 2 options that pertained to the content of the presented clip (*active condition, see below*); in the other half of the events, they were also presented with options regarding the events' content, but the answers were chosen automatically by the computer (*passive condition*).

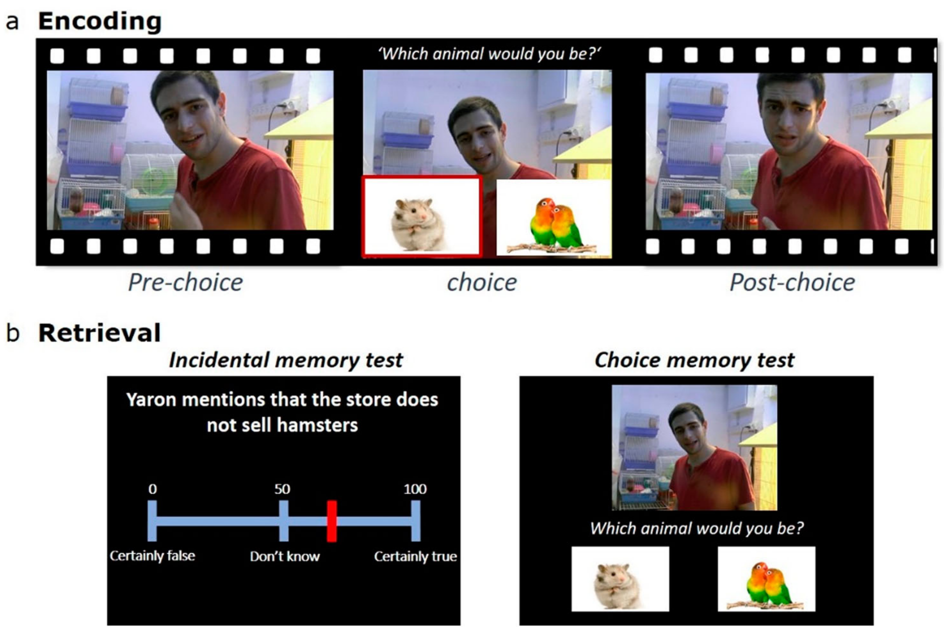

Figure 1. Experimental design. (a). The encoding stage consisted of active and passive conditions. In both conditions, participants watched clips that paused after 3 s (Pre-choice), upon which they were prompted to either choose one of two options presented on screen (active trials) or to press a button corresponding to the computer's choice (passive trial). This followed by the continuation of the film (Post-choice. (b) Either two days or one week later, participants returned for the retrieval stage, which consisted of an incidental true/false memory test about information conveyed in the clips, and a two-alternative recognition memory test for the choices they or the computer made during encoding.

During the retrieval phase, the participants underwent a true/false memory test, which consisted of right/wrong statements about the content of the events in the game. The study included two groups, the first group underwent the retrieval phase two days after the encoding phase, and the second group performed it one week after encoding.

Detailed procedure

Encoding phase: The participants first filled out a demographic questionnaire, performed a short practice task (5 min), followed by the encoding task (20 min). The practice task was similar to the encoding task, but with different movie clips that were not tested later. The encoding task consisted of a computerised task in the same vein of a quest game that simulates a realistic experience, in which the participant is presented with movie clips depicting a protagonist strolling in a shopping centre. The task was built from short movie clips that were filmed by N.R. in a shopping mall, and included various situations in which the protagonist addresses the subject and asks him questions regarding occurrences that unfold during the shopping experience. The encoding task was separated into two parts, and included two conditions: an *active condition* and a *passive condition*. The order of active/passive conditions was assigned pseudo-randomly, such that half of the participants were assigned with the first part as the active condition and the second part as the passive condition (group a), and vice versa for the other half of the participants (group b). Each part included 20 sequential events, each lasting 30 sec. An event included a video clip that was divided into two parts (pre-option and post-options), and an *option stage* that was presented between these two clip parts (see Figure 1).

The difference between the active condition and the passive condition was in the options stage. In the *active* option stage, participants were presented with two pictures on screen, representing two different opti7ons for the questions they were asked regarding the current video clip. For example, in a clip that involved the protagonist walking into an animal shop, he turned to the camera at some point and supposedly asked the participant what animal he would be if he would have turned into an animal. Then, the clip paused, and options of a hamster and a lovebird were presented as pictures on the screen. In another clip, the protagonist asked the participant for a book recommendation, and options of a fiction book and a science fiction book were presented as pictures on screen. Two buttons were available on the keyboard, one for each option, and when the participant chose one of the pictures, it was enlarged (to represent the chosen option) and the remainder of the clip played.

Before starting the active condition part of the task, the participants were informed that in this part of the task, their choices would affect the remaining part of the filmed experience and its outcomes. In practice, the subjects' choices did not affect the clips' outcomes, and the clip part that was displayed after the option stage was pre-defined. For example, after the participant chose between a hamster and a lovebird, the protagonist says he would also choose to be the same animal and then they would be roommates. In the second example, after the participant chose a fiction or a science fiction book, the friend says that he will borrow the book from the library. The purpose of presenting pre-defined clips was for ensuring that all participants be exposed to the same input for later comparison in the true/false memory test.

In the *passive* option stage, participants were also presented with two pictures in the options stage, but they were not able to choose between them, as one of them was automatically enlarged by the computer after 1.5 sec. Before starting the passive condition part, participations were informed that they would not be able to choose and affect this part of the filmed experience, and that they should press the button corresponding to the enlarged option to continue the video. The button press was introduced for controlling for possible motoric confounds of the *active* phase, and maintaining the subject's attention. In order to prevent interferences that related to specific movie clips or to the time each condition was presented, the clips assigned to the active and passive conditions were counterbalanced across participants.

Retrieval phase: Either two days or one week after the encoding phase, participants returned to carry out the retrieval phase. This phase included three computerised questionnaires: a *true/false memory test*, a *subjective assessment questionnaire*, and a two-alternative *recognition memory* test. The true/false memory test consisted of 80 statements, two statements for each movie clip – one for the pre-option clip, and one for the post-option segment. Each statement was presented separately on screen, and participants were instructed to decide if it was true or false and rate his/her confidence regarding the correctness of the given answer. For example: "Yaron said that the shop-keeper is a wizard that turns his costumers into animals" (true), "Yaron said that he will buy the book that you recommended" (false – Yaron said he will borrow the book from the library). All The participants were presented with the same statements, which were presented in chronological order. The answers to both accuracy and confidence were made by using a combined scale that ranged between 0 and 100, such that a score of 50 meant "I don't know"; 100 meant that the participant was certain that the statement was true, and 0 meant that the participant was certain that the statement was false (see Figure 1(b)).

The subjective assessment questionnaire, administered after the completion of the true/false memory test, consisted of questions regarding the participants' feelings throughout the first and the second part of the encoding experience on a scale from 0 to 100 for their sense of influence on the unfolding of the film, their involvement, identification with the character they portrayed, identification with the situations they encountered, curiosity, enjoyment, amusement and concentration.

In the final test – the recognition choice test – participants were tested on their memory for the options they had chosen or were chosen for them throughout the encoding phase. On the screen, three elements were presented: a reminder picture from each clip, the question that was asked in the encoding phase, and the two pictures that were presented as options during the encoding phase (Figure 1(b)).

Statistical analysis

The ratings from the combined scale were separated to binary indices of true/false ($x > 50 = \text{true}$, $x < 50 = \text{false}$), and converted to a unified confidence rating scale ranging 0–100 ("true" answers value minus 50 * 2 for hits/FA, and 50 minus "false" answers value * 2 for miss/CR). Applying a signal detection approach, the participants' answers in the true/false memory test (for details of the movie clips) were divided into four bins: hits ("yes" responses to factual statements), misses ("no" responses to factual statements), correct rejections (CR; "no" responses to fictitious statements) and false alarms (FA; "yes" responses to fictitious statements). Memory performance was assessed by a *Discriminability index (d')* – an index typically used in *signal detection theory*, which has been successfully applied to memory (Wixted, 2007), and provides the separation of retention-based aspects of memory performance from the decision aspects. The d' estimate was calculated as the difference between hit rate (the rate of hits from all answers to factual statements) and false-alarm rate (the rate of FA from all answers to fictitious statements; $d' = Z(\text{hit rate}) - Z(\text{FA rate})$).

The d-prime values of both groups and for each condition separately were entered into a mixed-effects ANOVA, using choice condition as a within-subject factor (active/passive) and memory test interval group as a between-subject factor (2-days/1-week). Continuing this line of exploration, we went on to test whether memory for information presented in active vs. passive choice conditions may have differed for clip parts preceding the choices and post-choice clip parts. We therefore conducted a mixed-effects ANOVA on memory performance indices (d-prime) using two within-subject factors (choice type – active/passive and film part – pre-choice/post-choice), and a between-subject factor of retention time (2-days/1-week).

For the subjective assessment questionnaire, the eight parameters – among them four subjective indices of feeling-of-activeness (feelings of influence, involvement, identification with the character and identification with the situations) and four subjective parameters that we considered as not related to the sense of subjective activeness (curiosity, enjoyment, amusement and concentration), were assessed for the active and passive conditions of the experiment separately, and compared using Paired-sample t-tests or Wilcoxon signed-rank tests (depending on whether the ratings on each parameter were normally distributed or not).

Since the primary aim of the current study was to explore the impact of the sense of actively impacting events with later memory measurements, participants who reported to not have felt their choices had an influence on the occurrences were excluded from analysis. The distribution of subjects' self-reports on this matter showed a clear binomial distribution, where the bulk of participants ($n = 46$) gave reports of 50 and above (from them 44 subjects rated 70 or above), whereas 12 participants gave a 30 or below rating. Therefore, participants who rated their feeling of influence on the occurrences in the active part 30 and below were excluded from subsequent analysis. This criterion was employed to exclude participants who seemed to have realised during the encoding phase that they did not actually influence the clip continuations.

Choice memory analysis: Independent sample t-tests were used to compare between the participants' memory of their choices or the computer choices, to their actual choices or to the computer choices during encoding. In addition, we checked for each participant if his/her performance in the active part of the choice recognition test was above 50% success; a 50% chance-level performance could imply that the participant was not attentive during the experience, and simply pressed randomly instead of actually choosing.

Memory performance for first/second parts of the experiment: As mentioned above, half of the participants performed the first part as an active condition and the second part as a passive condition, while the other half of the participants performed the opposite. We compared between the memory performance in the first and second part of the experiment using a paired-sample *t*-test, in order to examine a possible influence derived from the order of the parts or from the content of each part. We also used a mixed-design ANOVA to examine if there is an effect of the interaction between the first/second part and the active/passive condition on memory performance.

Analysis of confidence ratings: Average confidence ratings were divided by memory performance (hit, miss, CR and FA answers), and compared using a one-way ANOVA. In addition, differences in confidence ratings for active vs. passive conditions were examined for each bin separately, using paired-sample t-tests. All the above-mentioned analyses where performed separately for the two study groups – two-day group and one-week group.

Results

All subjective parameters that we regarded to be relevant to sense of activeness were heightened in the active vs. passive conditions. Although most of the participants rated their feeling of influence as high (70%–100%) for the active condition and low (0%–30%) for the passive condition, there were some that rated their feeling of influence as low for both the active and the passive conditions. We assumed that the latter group understood the manipulation (i.e., they realised that they did not actually have any influence on the events), and we therefore excluded them from subsequent analysis. Altogether, five participants from the two-day group and seven participants from the one-week group were excluded from the memory and confidence effects analyses as they did not pass the predefined threshold criterion of rating more than 30% feeling of influence on the occurrences in the active part of the experiment.

We first examined the degree to which members of each group assessed subjective properties of the encoding experience, as indicated in the subjective assessment questionnaire. Sample t-tests and Wilcoxon signed-rank tests found significant differences between active and passive conditions in all the subjective parameters – both for indices of active participation, and for parameters that we did not consider related to sense of activeness – such that all the subjective parameters were rated higher for the active condition than for the passive condition (Table 1, 2 for the 2-day and 1-week groups, respectively). As for the two-day group, we found significant differences between active and passive conditions in all the subjective parameters in the one-week group, such that all the subjective parameters were rated higher for the active vs. passive condition (Table 2).

Memory performance

Our main objective was to test the hypothesis that long-term memory performance for incidental information presented in the context of naturalistic occurrences will benefit from a sense of active engagement in the ongoing events. Indeed, participants' memory was significantly better, as measured by d', for details of movie clips that involved active choices regardless of time interval, as indicated by a main effect for the choice condition ($F(1,44) = 8.78$, $p < 0.01$) (Figure 2(a-b)). As expected, memory performance deteriorated with time, revealing a significant between-group main effect for time interval test ($F1,44) = 5.51$, $p < 0.05$). Mean d' values in the 2-day

Table 1. Mean responses of the 2-day group on the subjective assessment questionnaire.

Measurement	Active condition Mean ± SE	Passive condition Mean ± SE	Statistic	Significance
Influence	72.50 ± 5.55	7.5 ± 2.85	$Z_{(27)} = 4.55$	$p < 0.001$
Involvement	76.07 ± 4.64	26.07 ± 5.38	$Z_{(27)} = 4.13$	$p < 0.001$
Identification with character	67.14 ± 5.29	32.5 ± 5.21	$Z_{(27)} = 4.03$	$p < 0.001$
Identification with situation	66.43 ± 5.8	33.57 ± 6.26	$Z_{(27)} = 3.93$	$p < 0.001$
Curiosity	71.43 ± 4.17	48.93 ± 5.18	$Z_{(27)} = 2.78$	$p < 0.005$
Enjoyment	66.07 ± 4.67	48.57 ± 5.14	$t_{(27)} = 4.52$	$p < 0.001$
Amusement	61.79 ± 5.8	48.21 ± 5.89	$t_{(27)} = 2.15$	$p < 0.05$
Concentration	82.13 ± 3.27	67.14 ± 5.49	$t_{(27)} = 3.23$	$p < 0.005$

Table 2. Mean responses of the 1-week group on the subjective assessment questionnaire.

Measurement	Active condition Mean ± SE	Passive condition Mean ± SE	Statistic	Significance
Influence	68.00 ± 6.11	9.67 ± 3.54	$Z(29) = 4.39$	$p < 0.001$
Involvement	68.00 ± 6.39	22.67 ± 5.71	$Z(29) = 3.79$	$p < 0.001$
Identification with Character	58.00 ± 6.26	27.67 ± 5.16	$Z(29) = 3.41$	$p < 0.005$
Identification with situation	57.00 ± 5.39	33.00 ± 4.96	$t(29) = 3.71$	$p < 0.005$
Curiosity	64.33 ± 5.38	38.67 ± 6.15	$t(29) = 3.29$	$p < 0.005$
Enjoyment	68.33 ± 4.91	39.67 ± 5.43	$t(29) = 5.06$	$p < 0.001$
Amusement	52.67 ± 5.81	39.33 ± 5.32	$t(29) = 3.29$	$p < 0.05$
Concentration	83.00 ± 3.46	65.33 ± 5.20	$Z(29) = 3.52$	$p < 0.001$

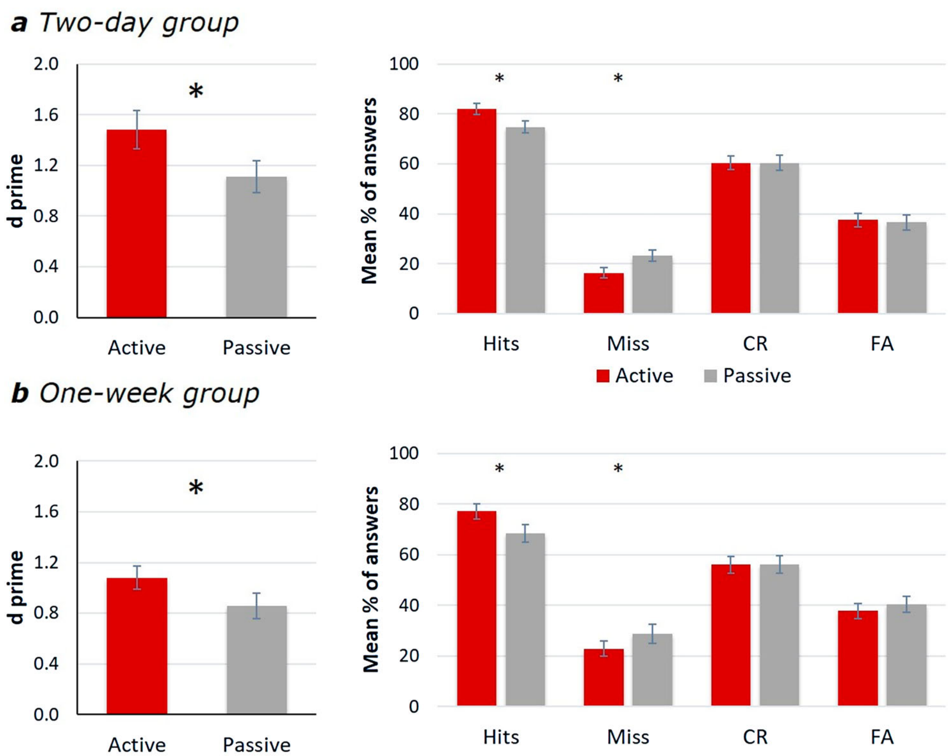

Figure 2. Memory performance for the two-day group (a) and one-week group (b). Both groups demonstrate heightened memory performance in the true/false memory test, as indicated by d-prime measurements for active (red) vs. passive (grey) conditions. Mean percentage of answers are shown for hits, misses, CRs and FAs for each group and condition separately. $*P < 0.05$.

group were 1.48 ± 0.29 (average ± standard error) and 1.11 ± 0.24 for the active and passive conditions. For the 1-week retention group memory performance was 1.08 ± 0.18 and 0.86 ± 0.16 for active and passive conditions.

Interestingly, no active vs. passive memory performance effect was apparent for the participants who were excluded from analysis due to low sense of influence self-reports (active vs. passive in the 2-days group: 1.17 ± 0.23 and 1.33 ± 0.25; 1-week group: 0.95 ± 0.09 and 1.04 ± 0.2). These findings should be treated with caution, as they are based on very small samples ($n = 5$ and $n = 7$ in the 2-days and 1-week groups, respectively). We also tested whether mean reaction times during active choices correlated with the memory enhancement effect across participants, an analysis that yielded low, non-significant correlations ($r = -0.046$ and $r = -0.039$ for the 1-week and 2-days groups, respectively. This analysis argues against a direct relationship between deliberation time of choice making and subsequent memory performance.

Entering the pre/post-choice trials as a further within-subject factor to a mixed-effects ANOVA yielded both a main effect for choice type and an interaction effect for choice type X clip part (see Table 3). The expected main effect indicated that memory for the active condition was superior across groups and regardless of clip part ($F(1,44) = 10.38$, $P < 0.05$). The interaction effect indicated that the active vs. passive memory effect was particularly strong regarding pre-choice information, and less so for post-choice ($F(1,44) = 3.79$, $P < 0.05$).

To delineate the source of the active vs. passive effect found in both groups, we tested memory performance effects separately for hits, misses, correct rejections (CR) and false alarms (FA). In the two-day group, a significant

Table 3. Mean memory performance (*d*-prime) for pre- and post-choice clip parts.

	Memory performance (d′)
2-day group	Mean (s.e.)
Active trials	
Pre-choice	2.03 (1.17)
Post-choice	1.4 (1.1)
Passive trials	
Pre-choice	1.0 (0.64)
Post-choice	1.44 (1.0)
1-week group	
Active trials	
Pre-choice	1.44 (1.16)
Post-choice	1.23 (0.82)
Passive trials	
Pre-choice	0.86 (1.12)
Post-choice	1.03 (0.77)

difference was found for hits ($t(22) = 2.26$, $p < 0.05$) for active vs. passive events, and a corresponding effect for misses ($t(22) = 2.23$, $p < 0.05$) for the passive > active condition. There were no significant differences in the CR and FA answers (Figure 2(a)). It should be noted that since participants were provided the opportunity to give a "don't know" response, hits and misses do not necessarily sum up to 100% of factual questions. Similar results were obtained for the one-week group for active vs. passive hits ($t(22) = 3$, $p < 0.05$) and misses ($t(22) = 2.23$, $p < 0.05$) (Figure 2(b)).

To rule out the possibility that the memory effect was not the result of memory clips that were presented at early vs. late stages of the encoding stage, we tested for recency/primacy memory effects regardless of active/passive conditions. For both groups, paired-sample t-tests did not reveal significant differences between the memory performance in the first and the last part of the experiment. In addition, a mixed-design ANOVA did not yield an interaction effect between the first/last part and the active/passive condition on memory performance, for each group separately.

Choice memory

All participants correctly remembered above 50% of their choices in the active part; most of them (except two) remembered correctly above 50% of the computer choices in the passive part too. We therefore conclude that overall, participants were attentive during both encoding conditions.

Nevertheless, participants remembered their own choices better than those of the computer, both in the two-day group ($t(22) = 7.25$, $p < 0.001$) and in the one-week group ($t(22) = 3.45$, $p < 0.005$) (see Figure 3). As might be expected, memory performance for choices decayed with time, such that the two-day group outperformed the one-week group for initiated choices ($t(44) = 2.48$, $p < 0.01$), as well as for computer-made choices ($t(44) = 1.52$, $p = 0.06$).

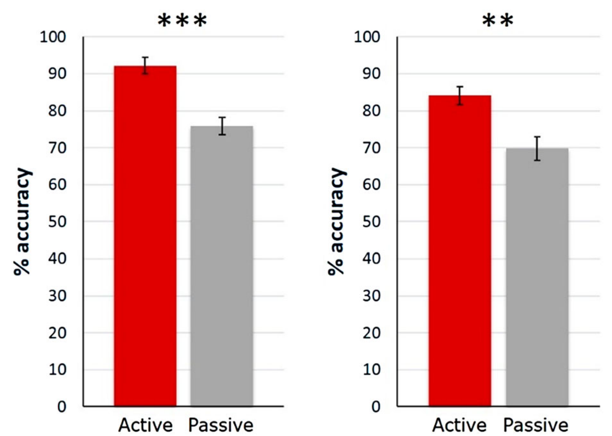

Figure 3. Memory for choices. Memory performance for the choice recognition test is presented for the choices made by participants (red) and the computer (grey) two days after encoding (left) and one-week after encoding (right). $^{**}P < 0.01$, $^{***}P < 0.001$.

Confidence ratings

No significant differences were found for confidence ratings between the active and passive conditions for hits, miss, CR and FA, in neither of the groups. In both groups, hit responses were accompanied with the highest confidence ratings (2-day group: active – 84.84 ± 2.75, passive – 83.60 ± 2.70; 1-week group: active – 77.37 ± 2.24, passive – 75.86 ± 2.98), followed by Correct rejections (2-day group: active – 71.99 ± 3.81, passive – 70.90 ± 3.92; 1-week group: active – 65.17 ± 3.62, passive – 64.77 ± 3.77). Wrong answers were provided with much lower confidence, as demonstrated for misses (2-day group: active – 11.95 ± 1.03, passive – 12.19 ± 1.21; 1-week group: active – 39.34 ± 4.33, passive – 43.84 ± 4.47) and for false alarms (2-day group: active – 28.38 ± 3.42, passive – 32.49 ± 3.25; 1-week group: active – 33.12 ± 3.54, passive – 37.94 ± 4.02).

Discussion

We demonstrate that actively engaging in choosing the way events will unfold heightens long-term memory for information presented in narrative events. This effect holds true two days as well as one week after encoding, and is complemented by increased memory for choices made by participants, as compared to choices made for them.

Behaving as an active agent has been shown to affect memory formation and future recollection of experiences (Butler & James, 2013; Plancher et al., 2013). Long-lasting memories for personal experiences can be formed whether the individual is a passive part of the occurrence or an active agent, one that interacts with its immediate surroundings. There are now several lines of evidence supporting the notion that actively interacting with the environment can benefit the formation of certain types of memory (Brandstatt & Voss, 2014; Carassa et al., 2002;

Plancher et al., 2013). For instance, spatial memory in a virtual environment was found to be better when individuals performed active vs. passive exploration of the environment (Carassa et al., 2002). Similarly, memory for words that were generated by participants (Vinogradov et al., 2006) or which participants chose to learn (Monty et al., 1982) was superior than memory for words that were passively assigned to the subjects. Bearing relevance to the current study is a recent exploration of the effect that a simple choice opportunity exerts on declarative memory performance (Murty et al., 2015), emphasising the involvement of the mesolimbic-dopaminergic system in enhancing hippocampal-dependent memory encoding in humans (Murayama & Kitagami, 2014; Murty et al., 2015). This study is an example of memory amplification in the absence of external reinforcement – in this case the opportunity to choose devoid of an explicit "correct answer". The working hypothesis was that by providing the opportunity to choose, individuals generated a feeling of control and ability to affect the environment, which could in turn improve memory performance. From the aspect of brain activity, the improvement in memory performance was linked to interactions between striatum activation immediately before choice phases and hippocampal activity thereafter during successful memory encoding of presented items (*ibid*).

As we hypothesised, and similarly to previous studies that demonstrated effects of active involvement on learning and memory (Cloutier & Neil Macrae, 2008), our study revealed that memory was superior for initiated choices than choices made by the computer. Our results extend these findings by showing that not only the choices themselves, but also the memory for incidental information presented in the situations that surrounded the choices were better remembered.

As opposed to some of the abovementioned studies and to a dominant approach of laboratory-based episodic memory studies that use simple items and discrete stimuli as memoranda, we designed an ecological experiment using short narrative clips displayed from a first person view. The retrieval of such "real-life-like events", containing rich and multisensory information and a sense of self-involvement, captures more of the properties of the original definition of episodic memory (Cabeza et al., 2004; Tulving, 1983), rendering this study's findings highly relevant to memory for real life events. This also enabled us to test for long-term memory effects, in this case up to one week after encoding.

A rising notion in the field of interactive memory systems is that ventral tegmental area inputs to the hippocampus mediate a functional link between the reward-related mesolimbic system and declarative memory formation (Shohamy & Adcock, 2010; Wittmann et al., 2005, 2011). In light of the results of Murty and colleagues, and particularly their finding that the striatum is involved in the active-induced memory effect, it can be argued that the act of choosing is in itself rewarding. The rewarding aspect of actively choosing is also implicated by self-reports of increased curiosity, enjoyment and amusement, indicating that encoded information may have been linked with positive emotional responses, increasing the chances of successful consolidation (Allen et al., 2005; McGaugh, 2015). Gruber et al. (2014) found that heightened states of curiosity benefit hippocampus-dependent learning via the dopaminergic circuit. These studies support the notion that the opportunity to choose is perceived as a positive occurrence in itself, generating a motivational signal that may affect diverse memory systems (Shohamy & Adcock, 2010).

That participants tended to remember more information that surrounded the time of active choices resonates with the idea of "depth of processing" (Craik & Tulving, 1975). Associating rich semantic meaning to discrete units of information can increase its subsequent memory, a process that may have occurred to a higher extent during the active choice trials. However, as the encoded information was heavily reliant on semantic schemas and rich contextual information to begin with, it is safe to assume that intentional deep encoding was brought about in both choice conditions. A more compelling account of the current findings stresses the influence that active involvement may exert on the sense of control. The experience of controlling one's own actions – and through them events in the outside world – is closely related to the idea of "sense of agency" (Chambon & Haggard, 2012). Indeed, the human tendency to gain control over the environment and act upon it is arguably one of the key motivators of behaviour (Haggard, 2017). In line with this, behavioural performance has been shown to benefit from nothing else than the sense of control over the environment, as expressed for example by increases in speed and action frequency associated with control (Karsh & Eitam, 2015). The mere sense of control is thus sufficient to modify behaviour. We demonstrate here that the choice type memory effect was particularly strong for information presented in the parts of the clip that preceded the choices. This observation implies that the knowledge or mind set of being able to choose and influence the events' outcome had a substantial impact on the encoding and consolidation of information, possibly more than specific choices made for specific clips.

In addition to the subjective parameters that we regarded as indices of activeness, participants gave higher ratings in the active condition to subjective measurements that we did not consider directly related to activeness (curiosity, enjoyment, amusement and concentration). This suggests that although participants did not receive reinforcement in the form of rewards, their involvement in itself served as a reinforcement signal, which in turn may have impacted their memory. This claim coincides with previous demonstrations that preferences to specific items can be modulated by non-reinforcing cues (Eitam et al., 2013; Schonberg et al., 2014), which may give rise to enhanced self-referential processes. Given that the continuation of the clips occurred both after active choices and simple button presses, it seems that the memory effect shown in the current study reflects processes that were evoked by the opportunity to choose and not necessarily by the post-choice outcome or feedback.

The differences in memory for active vs. passive conditions in both groups were found to be driven exclusively by responses to factual statements (i.e., hit and miss responses), such that there were more correct identifications and less misses in the active condition. No significant differences were found in in responses to fictitious statements (i.e., correct rejections and false alarms). Whereas relevant and appropriate cues facilitate successful retrieval, mistaken or misrepresented cues can be misleading, causing competition between retrieved traces and increasing false alarms (Schacter, Norman, & Koutstaal, 1998). False memories are suggested to be caused by erroneous attribution of source to retrieved traces (Johnson & Raye, 1998), competition among traces from similar encoded events (Schacter et al., 1998), or retrieval of traces that relate to internal schemata (Neuschatz, Lampinen, Preston, Hawkins, & Toglia, 2002). In contrast, failing to recollect previously presented information, as in miss responses, is suggested to reflect a state of weak or inaccessible memory traces (Habib & Nyberg, 2008; Wais, 2008). Taken together, rejecting factual statements, a tendency found particularly in passive trials, may indicate weaker encoding of information in the relevant clips.

To conclude, we show that allowing participants the opportunity to influence the unfolding of events by active choices improves their memory for the information depicted in the events, as well as for the choices themselves. Actively participating in an experience is also characterised by both increased subjective ratings of influence and engagement, and feelings of reward and attention. These findings may have significant implications in the evolving field of active learning in educational and rehabilitative settings, stressing the importance of playing an active role in the to-be encoded material and encouraging pupils to participate in the learning events.

Acknowledgement

The authors would like to thank Genela Morris for insightful comments and discussions.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Avi Mendelsohn http://orcid.org/0000-0003-4582-2668

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