ACCEPTED MANUSCRIPT

Published in Memory & Cognition, https://doi.org/10.3758/s13421-023-01414-6

Repeated simulation increases belief in the future occurrence of uncertain events

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Abstract

The feeling that an imagined event will or will not occur in the future—referred to as *belief in future occurrence*—plays a key role in guiding our decisions and actions. Recent research suggests that this belief may increase with repeated simulation of future events, but the boundary conditions for this effect remain unclear. Considering the key role of autobiographical knowledge in shaping belief in occurrence, we suggest that the effect of repeated simulation only occurs when prior autobiographical knowledge does not clearly support or contradict the occurrence of the imagined event. To test this hypothesis, we investigated the repetition effect for events that were either plausible or implausible due to their coherence or incoherence with autobiographical knowledge (Experiment 1), and for events that initially appeared uncertain because they were not clearly supported or contradicted by autobiographical knowledge (Experiment 2). We found that all types of events became more detailed and took less time to construct after repeated simulation, but belief in their future occurrence increased only for uncertain events; repetition did not influence belief for events already believed or considered implausible. These findings show that the effect of repeated simulation on belief in future occurrence depends on the consistency of imagined events with autobiographical knowledge.

Keywords: autobiographical memory; belief in occurrence; episodic future thinking; repetition; truth effect

Repeated simulation increases belief in the future occurrence of uncertain events

Future projections are associated, in varying degrees, with a sense that imagined events will or will not happen in the future – referred to as *belief in future occurrence* (Ernst & D'Argembeau, 2017). This cognitive feeling conveys a sense of personal "truth" or subjective veridicality to imagined events, which can then be leveraged to make decisions and guide behavior. Belief in future occurrence is largely determined by the consistency of the event with autobiographical knowledge (e.g., personal goals) and is also modulated by the quality of mental imagery and ease of imagination (Ernst et al., 2019; Ernst & D'Argembeau, 2017; Scoboria et al., 2020). Recent research has shown that repeated simulation of future events makes mental representations easier to construct and more detailed (Wiebels et al., 2020). This raises the question: if a future event is repeatedly simulated and becomes more detailed and easier to imagine, does our sense that it will actually happen increase?

Episodic future thinking and belief in future occurrence

Studies over the past two decades have provided important insights into the constructive process of episodic future thinking: information stored in episodic and semantic memory is flexibly selected and combined to create novel event representations (Irish & Piguet, 2013; Schacter et al., 2017; Suddendorf & Corballis, 2007). As the construction of episodic future thoughts became increasingly well understood, research indicated that different forms of episodic simulation rely on similar constructive processes, regardless of whether the simulation refers to the personal future or is atemporal, counterfactual, or purely imaginary (Addis, 2020; De Brigard & Parikh, 2019; Mullally & Maguire, 2014; Schacter et al., 2012). These findings suggest that although mental simulation is a necessary component of episodic future thinking, it is not sufficient for an imagined event to be perceived as a personal future occurrence (D'Argembeau, 2016; Klein, 2016; Mahr, 2020). Then, what makes us believe that an event represented in our mind refers to something that might happen

in our personal future? A recent theoretical framework proposed that this feeling emerges from the synergy between imagined events and autobiographical knowledge: personal goals and general expectations about one's life form a cognitive representational system – a personal timeline – onto which imagined events can be mapped (D'Argembeau, 2020). For an imagined event to be experienced as a possible future occurrence, it must be meaningfully connected with higher-order knowledge of the content and structure of our life. To illustrate this, if someone asked you to imagine visiting a museum, you would probably be able to construct a mental simulation of the situation. However, you would not experience this simulation as a future event unless you relate it to your personal life. This event could be experienced as a possible future event if, for example, you consider that it could happen during a city-trip to Paris that you have planned for later this year.

Recent research has shed light on the factors that modulate degrees of belief in future occurrence. Variations in the strength of belief are predicted by the personal plausibility of events and the extent to which they are integrated in an autobiographical context—as rated by personal importance, links with other events, and plans (D'Argembeau & Garcia Jimenez, 2020; Ernst et al., 2019; Ernst & D'Argembeau, 2017; Scoboria et al., 2020). Qualitative analysis revealed that people most frequently refer to personal goals, personal characteristics, and other personal events to justify and either support or suppress their sense that imagined events will materialize in the future (Ernst et al., 2019; Ernst & D'Argembeau, 2017). These results are in line with the idea that for an imagined event to be considered a possible future occurrence, it must be placed in an autobiographical context: the more an event is consistent with autobiographical knowledge, the greater the belief in its future occurrence.

Besides autobiographical knowledge, belief in future occurrence is related to other characteristics of imagined events, most notably the subjective quality of mental imagery, ease of imagination, and the event's familiarity (e.g., previous thoughts about the event and its

similarity to past experiences) (D'Argembeau & Garcia Jimenez, 2020; Ernst & D'Argembeau, 2017). These findings are consistent with earlier studies indicating that when people engage in vivid imagination, they subsequently believe the event to be more likely (Carroll, 1978; Garry et al., 1996; Koehler, 1991; Tversky & Kahneman, 1974). However, exactly how belief in future occurrence is generated remains poorly understood and the weight of its different determinants in different contexts have not yet been studied.

Repetition and judgments of truth

To gain a better understanding of the feeling of truth that accompanies some imagined future events, an interesting framework comes from research on the determinants of truth judgments for factual information. Current evidence suggests that truth judgments are constructed using different types of inferences drawn on the basis of base rates, existing knowledge stored in memory, and subjective feelings (for review, see Brashier & Marsh, 2020). A robust finding is that information is more likely to be judged as true when it has been encountered repeatedly, a phenomenon coined the repetition-induced truth effect (also known as the illusory truth effect; Hasher et al., 1977). A predominant explanation for this effect is that repetition increases processing fluency (i.e., the subjective ease with which information is perceived and processed; for a review, see Alter & Oppenheimer, 2009). Indeed, statements seem truer when they are easier to process; for example, people rate easy-to-read statements as relatively more true than difficult-to-read statements (Reber & Schwarz, 1999). Repetition increases the fluency of information processing, which in turn increases the perceived truth of information (Unkelbach, 2007; Unkelbach & Greifeneder, 2013). Feelings of familiarity, recognition likelihood, and subjective frequency have also been pointed as potential causes for this effect (for a review, see Unkelbach et al., 2019).

Unkelbach and Rom (2017) proposed a referential theory to explain the repetition-induced truth effect, which assumes that truth judgments are informed by the amount and the

coherence of corresponding references in memory. When encountering a statement, it activates references in memory that give meaning to the statement's elements. Subjective truth is then a function of the number of corresponding references and their coherence (Unkelbach & Rom, 2017). According to this view, people judge a statement as true or false when the corresponding references activated in memory are coherent or incoherent, respectively; when the statement provides no corresponding references in memory, it is judged as neither true nor false, but references to the statement's elements are created and stored in memory. With repetition of the statement, corresponding references are further linked in memory, such that the statement is processed more fluently and is perceived as true.

An interesting question is to what extent the repetition-induced truth effect depends on prior knowledge. An early meta-analysis by Dechêne et al. (2010) indicated that the effect of repetition on truth judgments occurs in a variety of contexts, but suggested that people must initially be uncertain about the truth status of the statements (i.e., they do not know whether the statements are actually true or not). Otherwise, they rely upon existing knowledge to make their judgments—when the truth status is already known, repetition may not change it. However, subsequent studies have shown that prior knowledge does not necessarily protect from the repetition-induced truth effect – people rely on repetition as a cue for truth even when the statements contradict their prior knowledge (Fazio et al., 2015, 2019). For example, Fazio et al. (2019) showed that repetition increased belief in the truth of statements across all levels of plausibility. Furthermore, Lacassagne et al. (2022) found that the truth value of statements known to be false (e.g., 'The earth is a perfect square') increased after several repetitions: these statements were still judged to be false, but not as false as the first time they were presented.

Repetition and belief in future occurrence

Consistent with the referential theory, previous studies have shown that the subjective truth of imagined future events (i.e., belief in future occurrence) mainly depends on their coherence with references stored in autobiographical memory, such as other planned events, personal characteristics, and goals (D'Argembeau & Garcia Jimenez, 2020; Ernst et al., 2019; Ernst & D'Argembeau, 2017; Scoboria et al., 2020). In addition, belief in future occurrence is modulated by the quality of mental imagery and ease of imagination, suggesting that processing fluency may also impact the subjective veridicality of imagined events. Interestingly, a study by Szpunar and Schacter (2013) showed that repeated simulation of future events increased estimates of event plausibility, a dimension closely related to belief in future occurrence (Ernst & D'Argembeau, 2017). Moreover, correlational analyses revealed that increases in plausibility were associated with concurrent increases in ease of simulation and event detail (see also van Mulukom et al., 2013; Wiebels et al., 2020).

A question that remains unknown is to what extent the effect of repeated simulation on the subjective veridicality of future events depends on prior knowledge pertaining to the event's occurrence. Considering that previous studies showed that repetition can increase subjective truth even for highly implausible statements (e.g., Fazio et al., 2019; Lacassagne et al., 2022), a first hypothesis would be that repeated simulation increases belief in occurrence regardless of the consistency of imagined events with autobiographical knowledge – we will refer to it as the repetition-over-knowledge hypothesis. However, given the key role of autobiographical knowledge in shaping belief in future occurrence, we suggest a competing hypothesis: the effect of repeated simulation on belief might be modulated by the degree to which an event is integrated with autobiographical knowledge. This knowledge-over-repetition hypothesis implies that repeated simulation increases belief in occurrence for events that initially appear uncertain but not for events that are already believed or not believed. On this view, the effect of repetition would only occur when autobiographical knowledge does

not clearly support or contradict the occurrence of the event, in which case belief in occurrence can be influenced by repetition-induced changes, such as processing fluency; otherwise, prior autobiographical knowledge would supersede the repetition effect.

Although parallels can be drawn between judgments of truth for factual statements and judgments of truth for future events, the mechanisms underlying these two types of judgments may not be identical—their targets being very different. First, episodic future thoughts involve detailed mental scenarios that are episodic in nature, whereas the statements used in the illusory truth literature are typically sentences that draw on general semantic knowledge. Second, the two kinds of judgments differ in their personal relevance: the repetition-induced truth effect literature is largely based on the use of trivia statements (75% of the studies identified by Henderson et al., 2021), whereas episodic future thoughts involve knowledge about personal goals and self-concepts (Conway et al., 2019; D'Argembeau & Mathy, 2011). The value attributed to self-related information may lead to a deeper processing strategy (D'Argembeau, 2013; Rogers et al., 1977; Sui & Humphreys, 2015) that supersedes the effect of incidental factors on judgments, such as processing fluency. Indeed, it has been shown that ease of processing has greater effect for judgments that are low in personal relevance, whereas for self-relevant judgements, people tend to use a systematic processing strategy and rely on the content of recalled information (Rotliman & Schwarz, 1998). In the case of future simulations, it could be that contradicting autobiographical knowledge confers more resistance to repetition-induced effect because belief in future occurrence has direct implications for personal goal pursuit.

The present study

To test these hypotheses, in the present research, we examined the effect of repeated simulation on belief in the future occurrence of events that were selected based on their level of integration with autobiographical knowledge. In a first experiment, we investigated the

repetition effect for events that were either plausible or implausible due to their coherence or incoherence with autobiographical knowledge (i.e., with the participants' personal goals and plans). To preview the results, we found that repeated simulation increased imagined details but did not influence belief in occurrence for these two kinds of events; belief in occurrence was already high or low and remained at similar levels across repetition. Then, in a second experiment, we investigated the effect of repeated simulation for events that initially appeared uncertain because they were not clearly supported or contradicted by autobiographical knowledge. We found that repeated simulation increased belief in the occurrence of such events, but not events that were strongly believed in the first place.

Experiment 1

The main purpose of Experiment 1 was to examine the effect of repeated simulation on belief in the occurrence of future events that were either consistent or inconsistent with autobiographical knowledge. Participants first selected a series of events that were either plausible or implausible to occur in their personal lives in the next month, given their goals and plans. They then simulated these events three times, while belief in occurrence, as well as construction times, event detail, and ease of imagination were measured. Consistent with previous studies, we predicted that construction times would decrease, and event detail and ease of imagination would increase, across repetitions (Szpunar & Schacter, 2013; van Mulukom et al., 2013; Wiebels et al., 2020). With respect to belief in occurrence, we considered two competing hypotheses. One possibility –the repetition-over-knowledge hypothesis– is that repeated simulation increases belief regardless of the integration and coherence of the event with autobiographical knowledge, in which case the effect of repetition should be observed even for implausible future events. Another possibility, however, is that the effect of repetition is only apparent when there is uncertainty about the occurrence of the

future event, in which case repeatedly simulating implausible events would not increase their subjective veridicality because their inconsistency with prior autobiographical knowledge would supersede the repetition effect – the knowledge-over-repetition hypothesis.

Method

Participants. Thirty-three young adults initially participated in this study, but one of them was excluded from the analyses for failure to follow the instructions. Thus, the final sample was composed of 17 women and 15 men, aged between 18 and 30 years (M = 23, SD = 2.73). The sample size was determined a priori based on a power analysis for linear mixed-effects models using SIMR (Green & MacLeod, 2016). This analysis indicated that a sample of 32 participants (with five events per participant) provided a statistical power of 85% to detect an increase of 0.5 on the belief scale with repetition. All participants provided informed consent and this study was approved by the Ethics Committee of the Faculty of Psychology of the University of Liège.

Materials and Procedure. Participants were presented with a list of 46 everyday events (e.g., going for a bike ride, celebrating a birthday, visiting a museum; see Supplemental Materials for the full list), and were asked to take a minute to think about their plans for the next month in relation to these events. Next, they were instructed to select a series of events from the list, based on their personal plausibility[1]. More specifically, they had to select five events that they

[1] Personal plausibility is the judgment that an event can plausibly happen to oneself. On the list, all events were generally plausible (i.e., they could potentially happen to people in general). The same event on the list could be personally plausible for one person and implausible for another. For example, it could be plausible for someone to imagine going for a bike ride in the next few weeks – they love riding their bike, they actually have some free time in the weekends and some exercise will do them good. But for another person, going for a bike ride is highly implausible: in addition to not having a bike, they barely know how to ride one and they do not want to get injured.

thought were plausible to happen in the next month (because they fit in with their projects, desires or plans for the next 30 days), and five events that they thought were implausible to occur in the next month (because they did not fit in with their projects, desires or plans for the next 30 days). They were asked to choose the five events that most clearly reflected each of these two categories. However, they were asked to select events that they had not already planned or thought about before the experiment. In addition, they were asked not to select routine events. After selecting the ten events, participants were told that they will have to imagine experiencing these events in the coming month. Each imagined future event had to be specific (i.e., to take place in a specific place and time and last less than a day) and unique (i.e., not identical to an event that has been experienced before).

The repetition task consisted of three identical simulation blocks. Each block contained ten trials (in random order), corresponding to the ten selected events. At the beginning of a trial, participants saw a screen with the instruction 'Imagine this future event' along with an event they previously selected (e.g., celebrating a birthday). Participants indicated when they had a specific event in mind by pressing the space bar and then continued imagining the future event in as much detail as possible for 15 s. After each simulation, three rating scales were completed at the participants' pace: belief in future occurrence (1 = *not at all*, 7 = *very much*; assessed using the item with the highest loading on the scale developed by Scoboria et al., 2020), level of detail (1 = *not at all*, 7 = *very much*), and ease of imagination (1 = *very difficult*, 7 = *very easy*). Rating scales were followed by a fixation cross that was presented for 3 s, then the next trial started. After the simulation block, participants were allowed to take a short break and resumed the experiment when they were ready. Before engaging in the second and third simulation blocks, participants were informed that they had to re-simulate all ten events as they did before, without radically changing the course of the events or important details such as their place and time.

After the repeated simulation task, participants further assessed and described the future events they imagined. For each of the ten events, they indicated whether they had already thought about the imagined event on a previous occasion (1 = *not at all*, 7 = *very often*), whether the imagined event is similar to previous experiences (1 = *novel*, 7 = *identical*), and they rated the emotional valence of the imagined event (-3 = *very negative*, 3 = *very positive*). Participants also rated the consistency of the imagined event across the three simulations (1 = *completely different*, 7 = *identical*). Finally, participants gave a short oral description of the event, which allowed the experimenter to make sure they imagined a single specific future event across the three simulations.

The experiment lasted approximately 1.5 hr and was conducted online via videoconference. All instructions were given in written form and then discussed orally with the experimenter. The repeated simulation task was presented using E-Prime 3.0 and E-Prime Go software (Psychology Software Tools, Pittsburgh, PA), which allowed for direct downloading and execution of the task on the participants' computers.

Analyses. Ratings for belief in future occurrence, ease of imagination, and level of detail were analyzed with ordinal mixed-effects models (Bürkner & Vuorre, 2019), using the ordinal package in R (Christensen, 2019). Construction times were analyzed with a robust linear mixed-effects model using the robustlmm package in R (Koller, 2016). For each model, the fixed-effects predictors were repetition (dummy coded, with the first block as baseline), event type, and their interaction. Random effect structures were determined with a model selection approach, using the backward selection heuristic(Matuschek et al., 2017) .

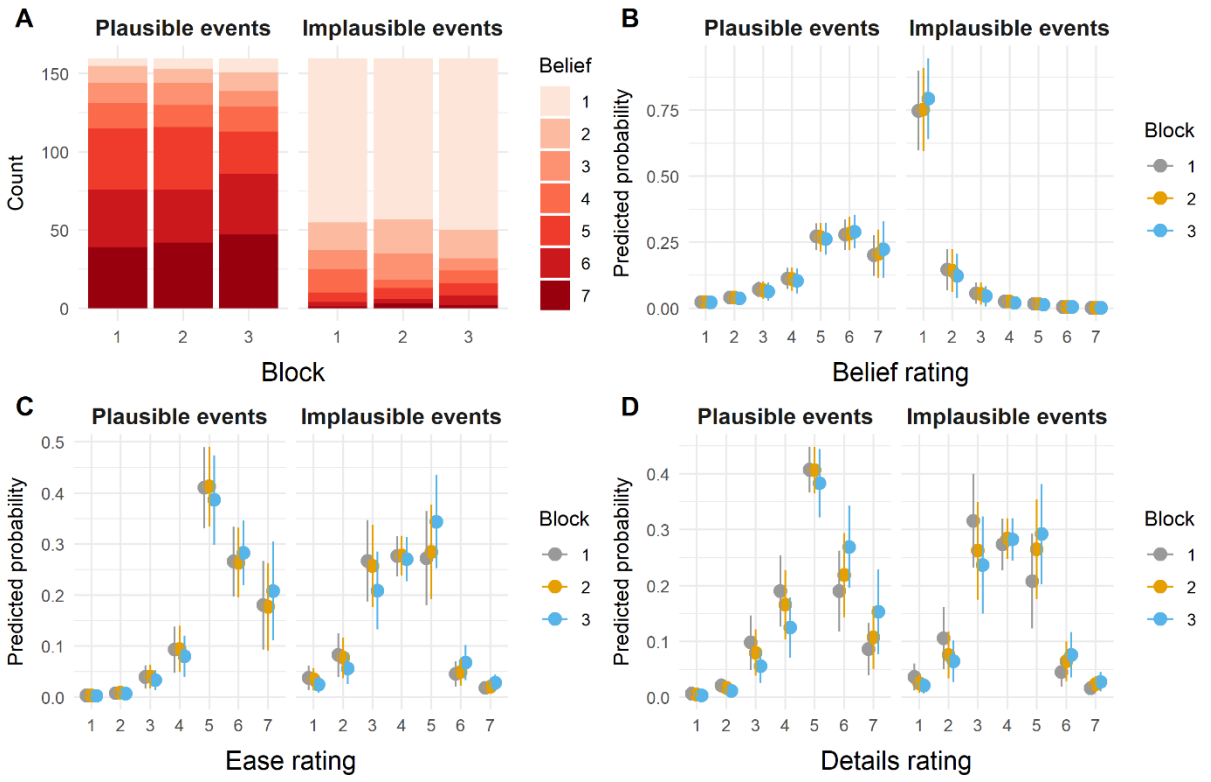
Results

All 320 events imagined by the participants were included in the analyses, for a total of 960 event simulations. The frequency of selection of each event from the list as plausible and

implausible is presented in the Supplemental Materials, along with an overview of the thematic content of the events. The distribution of belief in occurrence ratings for personally plausible and implausible events across the three simulation blocks is presented in Figure 1A. Distributions of ease of imagination and level of detail are available in the Supplemental Materials.

Figure 1

Belief in Future Occurrence, Ease of Imagination, and Level of Detail in Experiment 1.



Note. (A) Distribution of belief in occurrence ratings for plausible and implausible future events across the three simulation blocks. (B-D) Based on the ordinal mixed models, the plots show the predicted probabilities of belief in occurrence, ease of imagination, and level of detail ratings across the three simulation blocks.

Belief in future occurrence. The main goal of this experiment was to investigate whether belief in future occurrence for personally plausible and implausible events would increase with repeated simulations. We built an ordinal mixed-effects model with belief in future occurrence as outcome and repetition and type of event as predictors, as well as their interaction. Results showed an effect of event type, indicating that implausible future events were associated with lower belief ratings than plausible events (Table 1, Figure 1B). Repeated simulations did not increase belief in occurrence for future events and there was no interaction between repetition and type of event. Controlling for event characteristics that differed between plausible and implausible events (i.e., emotional valence, rehearsal, similarity to past experiences, and consistency) did not change the pattern of results (see Supplemental Materials).

We also calculated Bayes factors to quantify evidence in favor of the null hypothesis (BF_{01}) for the effect of repetition (i.e., no effect of repeated simulation on belief in future occurrence). The observed data were 11.19 and 7.25 times more likely under the null hypothesis than under the alternative hypothesis for plausible and implausible events, respectively.

Table 1

Effects of Repeated Simulations and Type of Event on Belief in Future Occurrence in Experiment 1.

Predictors	Estimate	*SE*	*z*-value	*p*
Block 2	0.04	0.21	0.18	.854
Block 3	0.13	0.23	0.59	.555
Event Type (Implausible)	-4.79	0.49	-9.87	<.001
Block 2 * Type (Impl.)	-0.06	0.35	-0.19	.852
Block 3 * Type (Impl.)	-0.39	0.36	-1.10	.270

Note. Data were analyzed using the following ordinal mixed model: Belief in occurrence ~ Block * Event Type + (Block + Event Type | Subject). The coefficients are log odds ratios.

Ease of imagination, level of detail, and construction time. Plausible events were easier to imagine than implausible events, but ease did not increase when events were repeatedly imagined and there was no interaction between repetition and type of events (Table 2, Figure 1C).

Table 2

Effects of Repeated Simulations and Type of Event on Ease of Imagination in Experiment 1.

Predictors	Estimate	*SE*	*z*-value	*p*
Block 2	-0.02	0.21	-0.10	.916
Block 3	0.18	0.21	0.87	.385
Event Type (Implausible)	-2.46	0.41	-6.02	<.001
Block 2 * Type (Impl.)	0.10	0.29	0.34	.736
Block 3 * Type (Impl.)	0.26	0.29	0.88	.377

Note. Data were analyzed using the following ordinal mixed model: Ease of Imagination ~ Block * Event Type + (Event Type | Subject). The coefficients are log odds ratios.

Regarding the level of detail, plausible events were imagined with more detail than implausible events (Table 3, Figure 1D). Here we found an effect of repetition, with level of detail increasing between the first and the third simulation. The repetition X event type interaction was not significant.

Table 3

Effects of Repeated Simulations and Type of Event on Level of Detail in Experiment 1.

Predictors	Estimate	*SE*	*z*-value	*p*
Block 2	0.23	0.20	1.15	.251
Block 3	0.65	0.20	3.17	.002

Predictors	Estimate	*SE*	*z*-value	*p*
Event Type (Implausible)	-1.77	0.38	-4.63	<.001
Block 2 * Type (Impl.)	0.16	0.29	0.56	.575
Block 3 * Type (Impl.)	-0.07	0.29	-0.24	.812

Note. Data were analyzed using the following ordinal mixed model: Level of detail ~ Block * Event Type + (Event Type | Subject). The coefficients are log odds ratios.

Finally, the analysis of response times (Table 4) showed an effect of repetition, indicating that events were constructed more rapidly with repeated simulations. Implausible events took longer to construct than plausible events. In addition, there was a significant repetition X event type interaction (Figure 2). Pairwise comparisons revealed that plausible and implausible events only differed for the first simulation, with implausible events displaying higher response times than plausible events (b = 1686, SE = 466, z = 3.61, p <. 001). When the events were repeated a second and a third time, response times decreased for the two types of events, and there was no longer any difference between implausible and plausible events (b = 371, SE = 466, z = 0.80, p = .426, and b = 204, SE = 466, z = 0.44, p = .662, respectively).

Table 4

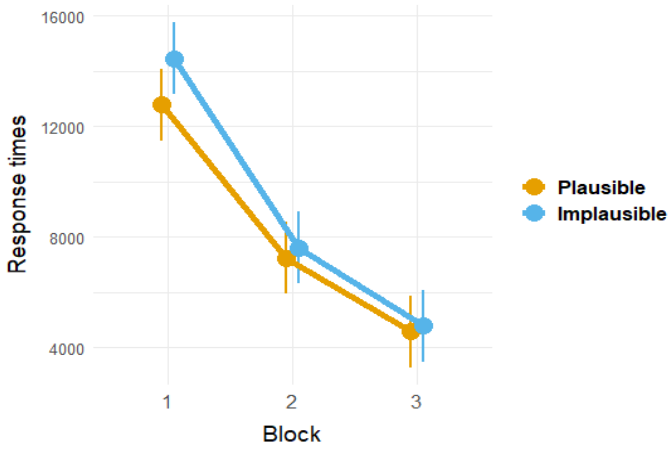
Effects of Repeated Simulations and Type of Event on Response Times in Experiment 1.

Predictors	Estimate	*SE*	*t*-value	*p*
Intercept	12780	665	19.22	<.001
Block 2	-5539	467	-11.87	<.001
Block 3	-8200	467	-17.58	<.001
Event Type (Implausible)	1686	467	3.61	<.001
Block 2 * Type (Impl.)	-1315	660	-1.99	.004
Block 3 * Type (Impl.)	-1482	660	-2.25	.002

Note. Data were analyzed using the following robust linear mixed model: Response Times ~ Block * Event Type + (1 | Subject)

Figure 2

Predicted Probabilities for Response Times across the Three Simulation Blocks in Experiment 1 – Based on the Robust Linear Mixed Model



Discussion

The first aim of Experiment 1 was to determine if repeated simulation would impact belief in the occurrence of future events that were either consistent or inconsistent with autobiographical knowledge. We did not detect any effect of repeated simulation on belief in the future occurrence of personally plausible and implausible events, and Bayes factors indicated that the data provided support in favor of the null hypothesis. These results do not support the repetition-over-knowledge hypothesis, which implies that repeated simulation would increase belief in occurrence regardless of the incoherence of imagined future events with autobiographical knowledge. Indeed, implausible future events did not increase in subjective veridicality with repetition. The distribution of belief in future occurrence showed that implausible events were predominantly not believed in, whereas plausible events were mostly associated with a strong belief that they will occur. The absence of a repetition effect for these events is consistent with the knowledge-over-repetition hypothesis: when prior autobiographical knowledge clearly supports or contradicts the possible occurrence of an

event, then this knowledge supersedes the repetition effect. It remains possible that the repetition effect only occurs when the truth status of the event is ambiguous and uncertain. We tested this hypothesis in a second experiment.

Experiment 2

Results from Experiment 1 showed that repeated simulation did not impact belief in the future occurrence of personally plausible and implausible events. Belief in occurrence stayed at high or low levels across the three simulations, suggesting that the (in)consistency of imagined events with autobiographical knowledge superseded the repetition effect. This knowledge-over-repetition hypothesis leads to the possibility that the effect of repeated simulation on belief in occurrence only occurs when imagined events are uncertain (i.e., when people are not sure whether or not they will occur).

When research participants are asked to freely select personal future events, they tend to retrieve and report events that are quite certain and high in belief in future occurrence (Scoboria et al., 2020). Cueing for uncertain events provides a more representative sampling of the range of believed mental representations, with less extreme distributions in belief in future occurrence (Ernst et al., 2019). Uncertain future events are events that could plausibly happen in our future, but for which we do not have a strong sense of belief in occurrence (Ernst et al., 2019). We may have reservations about the future occurrence of these events because they are not totally consistent with the knowledge we have about ourselves, such as other personal events and personal characteristics. In Ernst et al. (2019), these types of information were the most frequently mentioned justifications for belief in future occurrence for uncertain events. To give a concrete example of an uncertain event, imagine that a couple of friends have asked you to go to the movies next Friday. You have accepted the invitation

but you are not sure yet to go, as they insist on seeing a horror movie and you really don't like this genre (a personal characteristic). Also, you have a lot of work to finish before the weekend, so you might finish late and not make it to the cinema on time (links with other personal events). Continuing with this example, other information nevertheless supports belief in the future occurrence of this event: you already said that you would go, it has been a long time since you have not seen your friends and you would like to see them again, and it would be nice for you to go out this Friday because you will not have the opportunity to do so for a long time. This combination of information that is neither fully consistent nor inconsistent with autobiographical knowledge makes uncertain events distinct from events that are either believed or not believed.

Interestingly, the future events included in the study of Szpunar and Schacter (2013) demonstrating the effect of repeated simulation on estimates of plausibility might correspond to such uncertain events: on average, these future events were associated with a plausibility rating around 2.5 on a scale of 1 to 5 during the first simulation. Therefore, in Experiment 2, we sought to more directly test the hypothesis that the repetition effect depends on the initial uncertainty of imagined future events by asking participants to repeatedly simulate certain and uncertain future events. We expected that events that are uncertain (because they are not clearly consistent or inconsistent with autobiographical knowledge) would contain the necessary ambiguity to see their perceived truth influenced by repetition, and thus we predicted that they would be associated with an increase in belief in future occurrence across repeated simulation. By contrast, we did not expect any change in belief in occurrence for certain events because their consistency with autobiographical knowledge would supersede the repetition effect.

Method

Participants. Seventy-seven participants were recruited, but eight of them were excluded either because they failed to follow the instructions (n = 4), or because they were interrupted by some distractor in their environment (n = 4). The final sample was composed of 33 women and 36 men, aged between 18 and 35 years (M = 23.1, SD = 2.96). As noted in Experiment 1, a sample of 32 participants (with five events per participant) would be sufficient to provide a statistical power of 85% to detect an increase of 0.5 on the belief scale with repetition, but we had the opportunity to evaluate a larger sample of participants in the context of practical work for Bachelor students at the University of Liège, thus ensuring a sufficient sample size for accurate estimation of parameter estimates in our mixed models (Maas & Hox, 2005). All participants provided informed consent and this study was approved by the Ethics Committee of the Faculty of Psychology of the University of Liège.

Materials and Procedure. Materials and procedures were similar to Experiment 1, except for the nature of the events participants had to imagine. Participants were asked to self-generate ten future events: five events that they thought would certainly occur in the next month, and five events that they were uncertain would occur. It was required that all selected events could potentially occur in the future, but the two types of events differed depending on whether participants felt confident or unsure about their actual occurrence. Events that were already planned or thought about before the experiment were accepted, but participants were asked to avoid selecting routine events. As in Experiment 1, participants were told that they would have to imagine experiencing these events in the coming month, and each imagined event had to be specific and unique.

The experiment lasted approximately 1.5 hr and was conducted online via videoconference. All instructions were given in written form and then discussed orally with

the experimenter. We used the Gorilla Experiment Builder (www.gorilla.sc) to host our experiment (Anwyl-Irvine et al., 2019). This research platform enabled direct access to the experiment through the participants' web browser.

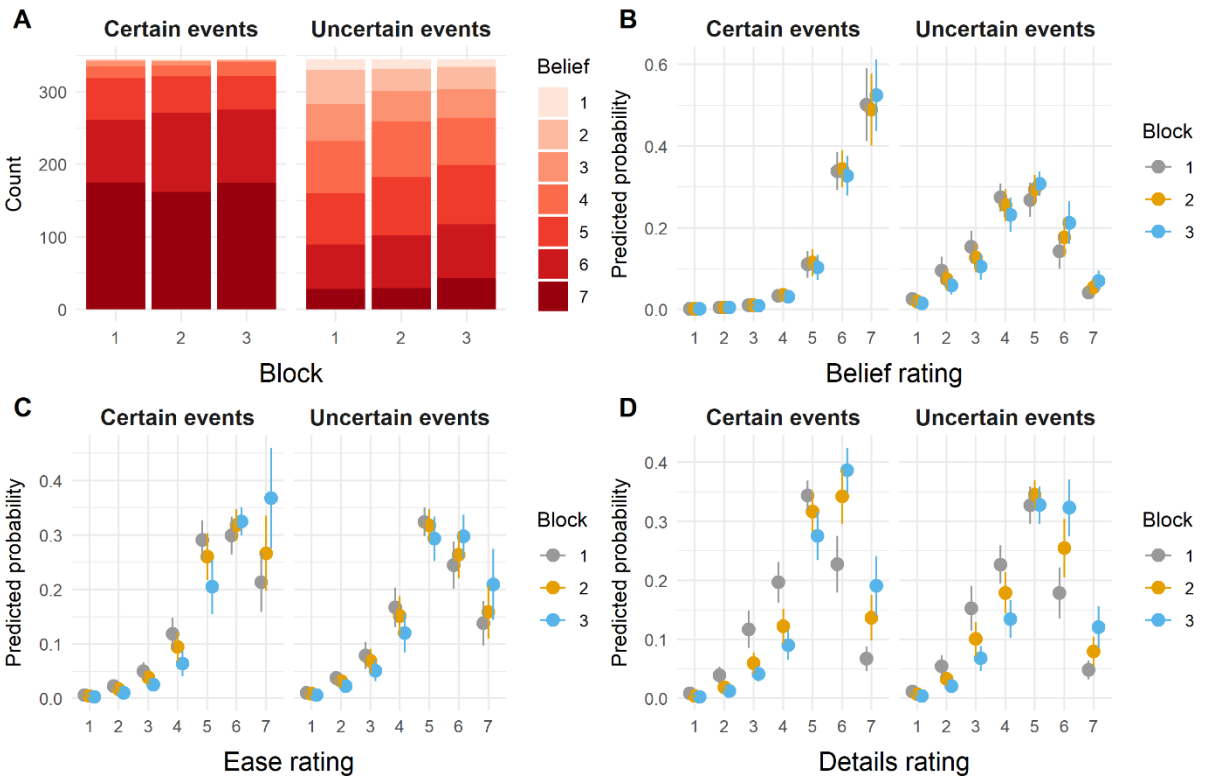
Analyses. The data were analyzed in the same way as Experiment 1.

Results

All 690 events imagined by the participants were included in the analyses, for a total of 2070 event simulations. An overview of the thematic contents of the events and a comparison with the events in Experiment 1 are presented in the Supplemental Materials. The distribution of belief in occurrence ratings for certain and uncertain events across the three simulation blocks are presented in Figure 3A. Distributions of ease of imagination and level of detail are available in the Supplemental Materials.

Figure 3

Event Ratings in Experiment 2



Note. (A) Distribution of belief in occurrence ratings for certain and uncertain future events across the three simulations. (B-D) Based on the ordinal mixed models, the plots show the predicted probabilities of belief in future occurrence, ease of imagination, and level of detail ratings across the three blocks of simulation.

Belief in future occurrence. Our main goal was to investigate whether belief in future occurrence for uncertain events would increase with repeated simulations. We anticipated that the selection of certain events would already lead to high scores on the belief in occurrence scale, so we did not expect any repetition effect for this type of event. Results showed an effect of event type, indicating that uncertain future events were associated with lower belief than certain events (Table 5). There was no effect of repetition, but there was an interaction between repetition and type of event (Figure 3B).

Table 5

Effects of Repeated Simulations and Type of Event on Belief in Future Occurrence in Experiment 2.

Predictors	Estimate	*SE*	*z*-value	*p*
Block 2	-0.05	0.15	-0.32	.744
Block 3	0.09	0.15	0.62	.537
Event Type (Uncertain)	-3.15	0.27	-11.77	<.001
Block 2 * Type (Unc.)	0.34	0.20	1.67	.095
Block 3 * Type (Unc.)	0.46	0.21	2.25	.024

Note: Data were analyzed using the following ordinal mixed model: Belief in occurrence ~ Block * Event Type + (Block + Event Type | Subject). The coefficients are log odds ratios.

In line with our hypothesis, pairwise comparisons revealed that repeated simulations did increase belief in future occurrence for uncertain events only. Imagining uncertain events a second and third time led to a significant increase in belief ratings compared to the first imagination (b = 0.29, SE = 0.14, z = 2.13, p = .033, and b = 0.56, SE = 0.14, z = 4.03, p <. 001, respectively)[2]; the gain in belief in occurrence from the second to the third simulation was only marginally significant (b = 0.27, SE = 0.14, z = -1.96, p = .050). Belief in future occurrence did not increase when imagining certain events a second and third time compared to the first simulation (b = -0.05, SE = 0.15, z = -0.33, p = .744, and b = 0.09, SE = 0.15, z = 0.62, p = .537, respectively), nor did it increase between the second and third simulation (b = 0.14, SE = 0.15, z = 0.96, p = .338).

We also calculated Bayes factors to quantity evidence for the presence (BF_{10}) or absence (BF_{01}) of an effect of repetition on belief in future occurrence. For uncertain events,

[2] Note that the coefficients give the changes in log odds. When transformed to the odds ratio, this means that imagining uncertain events a second and third time changes the odds of receiving a higher rating by a factor of 1.34 and 1.75 (i.e., 34% and 75% greater odds), respectively. In other words, the likelihood of a 7 versus a 1-6 on the rating scale is multiplied by 1.34 and 1.75, the likelihood of a 6 versus a 1-5 on the rating scale is multiplied by 1.34 and 1.75, the likelihood of a 5 versus a 1-4 is multiplied by 1.34 and 1.75, and so on.

the observed data were 83 times more likely under the alternative hypothesis than under the null hypothesis, whereas for certain events, the observed data were 12.88 more likely under the null hypothesis.

Emotional valence was the only event characteristic that differed between certain and uncertain events: the emotions felt when imagining events were more positive for certain (*Mdn* = 2) than uncertain (*Mdn* = 0) events (b = -1.87, SE = 0.26, z = -7.15, p <.001). Controlling for this difference did not change the pattern of results (see Supplemental Materials).

Given that ease of imagination and level of detail increased with repeated simulation (see below), we also investigated to what extent the increase in belief in future occurrence for uncertain events could be due to these factors. An ordinal mixed-effects model with belief in the future occurrence of uncertain events as outcome and repetition and ease of imagination as predictors showed that the effect of repetition on belief was no longer significant when ease of imagination was taken into account (first to second simulation: b = 0.02, SE = 0.10, z = 0.17, p = .862; first to third simulation: b = 0.08, SE = 0.10, z = 0.88, p = .379); ease of imagination was a significant predictor of belief (b = 0.62, SE = 0.06, z = 9.77, p <.001). Similarly, the effect of repetition on belief was no longer significant when the level of detail of imagined events was taken into account (first to second simulation: b = -0.15, SE = 0.10, z = -1.46, p = .143; first to third simulation: b = -0.14, SE = 0.10, z = -1.37, p = .170); level of detail was a significant predictor of belief (b = 0.59, SE = 0.03, z = 17.39, p <.001). These results suggest that the increase in belief in future occurrence for uncertain events with repeated simulation may be mediated by increases in ease of imagination and level of detail.

Ease of imagination, level of detail, and construction time. With respect to ease of imagination, certain events were easier to imagine than uncertain events, and ease increased

when future events – regardless of their type – were repeatedly simulated (Table 6, Figure 3C). The repetition X event type interaction was not significant.

Table 6

Effects of Repeated Simulations and Type of Event on Ease of Imagination in Experiment 2.

Predictors	Estimate	*SE*	*z*-value	*p*
Block 2	0.29	0.15	1.98	.048
Block 3	0.76	0.16	4.72	<.001
Event Type (Uncertain)	-0.53	0.19	-2.75	.006
Block 2 * Type (Unc.)	-0.13	0.20	-0.65	.515
Block 3 * Type (Unc.)	-0.26	0.20	-1.23	.196

Note. Data were analyzed using the following ordinal mixed model: Ease of imagination~ Block*Event Type + (Event Type | Subject). The coefficients are log odds ratios.

The analysis of level of detail showed that certain events were imagined with more detail than uncertain events (Table 7, Figure 3D). There was also an effect of repetition, with level of detail increasing across the three simulations, but no interaction between repetition and type of event.

Table 7

Effects of Repeated Simulations and Type of Event on Level of Detail in Experiment 2.

Predictors	Estimate	*SE*	*z*-value	*p*
Block 2	0.79	0.14	5.63	<.001
Block 3	1.19	0.14	8.41	<.001
Event Type (Uncertain)	-0.35	0.17	-2.03	.042
Block 2 * Type (Unc.)	-0.25	0.20	-1.28	.200
Block 3 * Type (Unc.)	-0.19	0.20	-0.95	.342

Note. Data were analyzed using the following ordinal mixed model: Level of Detail ~ Block * Event Type + (Event Type | Subject). The coefficients are log odds ratios.

Finally, the analysis of response times showed an effect of repetition, indicating that events were constructed more rapidly with repeated simulations (Table 8, Figure 4). There was no difference between uncertain and certain events, and no interaction between type of event and repetition.

Table 8

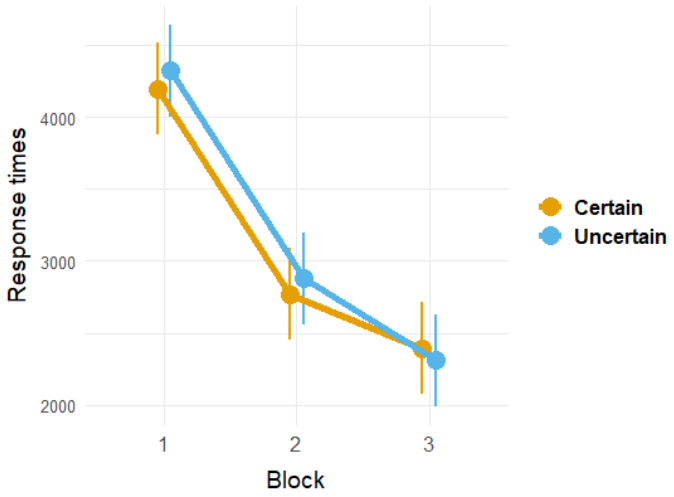
Effects of Repeated Simulations and Type of Event on Response Times in Experiment 2.

Predictors	Estimate	*SE*	*t*-value	*p*
Intercept	4195	163	25.73	<.001
Block 2	-1425	115	-12.34	<.001
Block 3	-1800	115	-15.59	<.001
Event Type (Uncertain)	125	115	1.08	.280
Block 2 * Type (Unc.)	-16	163	-0.10	.921
Block 3 * Type (Unc.)	-210	163	-1.29	.198

Note. Data were analyzed using the following robust linear mixed model: Response Times ~ Block * Event Type + (1 | Subject)

Figure 4

Predicted Probabilities for Response Times across the Three Simulation Blocks in Experiment 2 – Based on the Robust Linear Mixed Model



Discussion

The results of Experiment 2 indicate that uncertain future events (i.e., events that are neither clearly supported nor contradicted by autobiographical knowledge) are increasingly believed in across repeated simulation. As expected, belief in future occurrence for certain events did not increase with repeated simulation, as these events were initially strongly believed in. These findings are consistent with the knowledge-over-repetition hypothesis, which suggests that the repetition-induced truth effect occurs when imagined future events are initially uncertain but not when events are already believed or not believed.

General Discussion

In two experiments, we examined whether and how the feeling that an event will happen in the future is influenced by repeated simulation. Given the key role of autobiographical knowledge in shaping belief in future occurrence, we hypothesized that the effect of repeated simulation would depend on the coherence of the imagined events with such knowledge. To investigate this question, we examined the repetition effect for events holding different levels of integration with autobiographical knowledge. Our results provide evidence that repeated simulation can enhance belief in future occurrence, but that this repetition-induced effect only occurs for events that are neither clearly supported nor contradicted by autobiographical knowledge (i.e., uncertain events, Experiment 2); for events that are initially considered implausible (Experiment 1) or already believed (Experiments 1 & 2), repetition did not affect belief in occurrence. Taken together, these results give support to the knowledge-over-repetition hypothesis by showing that prior autobiographical knowledge conditions the effect of repetition on belief in the future occurrence of imagined events.

In both experiments, the episodic simulation process was influenced by repetition, regardless of the initial level of integration of the event with autobiographical knowledge: all types of future events became more detailed and took less time to construct after repeated simulation. These results are consistent with our hypotheses and corroborate previous research showing a decrease in construction time and an increase in event detail for future events across repetitions (Szpunar & Schacter, 2013; van Mulukom et al., 2013; Wiebels et al., 2020). When initially imagined, implausible events took longer to construct than plausible events, but repeated simulation decreased and evened out construction times for both events. This suggests that event construction is slower and more demanding when event components (e.g., locations, objects, places, actions, and so on) have not been previously associated (as was likely the case for implausible events), but that processing fluency and the associative strength between event components increase with the number of rehearsals (Addis, 2018).

Despite the fact that repeated simulation reduced construction times and increased the level of detail of implausible future events, belief in their future occurrence remained unchanged. As explained in the referential theory of the repetition-induced truth effect (Unkelbach & Rom, 2017), as information is repeated, the corresponding references are further linked in memory, which enhances processing fluency that can then be used as a cue to determine truth. However, processing fluency is not the only cue used to construct a judgment of truth (Brashier & Marsh, 2020). According to Unkelbach & Rom (2017), an information should be deemed ‘false’ if its elements have corresponding references in memory, but these do not form a coherent network because they are inconsistent with existing knowledge. Although the associative links between the components of an implausible future event may be strengthened by repetition, leading to faster and more detailed simulations, we suggest that the lack of integration and coherence of the event with autobiographical knowledge prevents the repetition-induced truth effect. Indeed, an imagined future event is not just a collection of

components pertaining to the mental simulation: for an event to be considered as a possible future occurrence, it has to be meaningfully linked with higher-order knowledge of the content and structure of our life (D'Argembeau, 2020). Repeated simulation of implausible events that have little connection to, or even contradict, personal goals and plans may not alter the incoherence between the imagined event and autobiographical knowledge – it may even strengthen it.

In contrast, our results showed that repeated simulation of events that were neither clearly supported nor contradicted by autobiographical knowledge (i.e., uncertain events) did increase the belief that these events will happen in the future. As already mentioned, a possible explanation is that repeated simulations tend to increase processing fluency by strengthening the associative links between event components and this increased fluency could lead to greater belief in occurrence; this is in line with our results suggesting that ease of imagination and level of detail mediate the increase of belief following repeated simulation of uncertain events. Another possible explanation is that repeated simulation increases the integration of uncertain events with preexisting autobiographical knowledge (e.g., by linking the events to personal goals or other planned events), thereby enhancing belief in their future occurrence. Specifically, repeated simulation reinstates not only patterns of activation and inhibition between event components, but also between event components and higher-order autobiographical knowledge structures (Addis, 2018; Conway, 2005; D'Argembeau, 2020). These two mechanisms are not mutually exclusive and may each play a role in the effect of repeated simulation on belief in the future occurrence of uncertain events.

It should be noted that our results and interpretations do not necessarily contradict the results from the repetition-induced truth literature showing that the effect of repetition occurs across all levels of plausibility (Fazio, 2020; Fazio et al., 2019). As mentioned in the introduction, while there are similarities between truth judgments for factual statements and

belief in occurrence for future events, the mechanisms underlying these two types of judgments are not necessarily identical. Contrary to trivia statements, personal future events are linked with an individual's life and identity and personal relevance plays an important role in shaping how information is processed and evaluated. For instance, Rotliman & Schwarz (1998) found that when information is highly self-relevant, people tend to focus on the content of the information rather than the ease with which it is processed. On the other hand, when information has low personal relevance, processing fluency has a greater impact on judgments. When evaluating truth for trivia statements, people may be more susceptible to the repetition-induced truth effect, where repeated statements are perceived as more true, simply because they are easier to process (Henderson et al., 2021). In contrast, personal future events are highly self-relevant and this may lead to a deeper processing strategy (D'Argembeau, 2013; Sui & Humphreys, 2015), which can confer greater resistance to repetition-induced truth effects driven by processing fluency. Another difference is that the present study involved episodic simulation (i.e., representation of unique events located in space and time), whereas studies on the repetition-induced truth effect involved semantic representations. Such differences in the nature of judged information might also account for differences in the mechanisms of truth judgments for future events and factual statements.

Taken together, our results suggest that autobiographical knowledge plays a major role in determining belief in future occurrence, not only as a predictor of the initial belief in novel future events, but also as a modulating factor in the evolution of belief over repeated simulation. This finding corroborates theoretical and empirical work highlighting the key role of autobiographical knowledge in the construction and organization of episodic future thoughts (e.g., D'Argembeau, 2020; D'Argembeau & Demblon, 2012; D'Argembeau & Mathy, 2011). In addition to shedding light on the cognitive processes underlying belief in future occurrence, studying the development and evolution of belief over time and repetition

may also have important implications for understanding everyday prospection and its pragmatic dimension. The varying degrees of belief in occurrence assigned to future projections could be used to prioritize future scenarios based on current goals and context, ultimately guiding our decisions and actions (Ernst et al., 2019; Ernst & D'Argembeau, 2017). According to the pragmatic dual process account of future thinking (Kvavilashvili & Rummel, 2020), people do not so much engage in the construction of novel future events as in thinking about already constructed future events and plans. These rehearsals seem to increase the likelihood that planned activities will be carried out in the future (Kvavilashvili & Rummel, 2020). In this perspective, studying the evolution of belief in future occurrence over time and repeated simulation may contribute to better understanding the mechanisms underlying the pragmatic nature of future thinking in daily life.

While this study provides the first evidence that the effect of repeated simulation on belief in future occurrence depends on the consistency of imagined events with autobiographical knowledge, there is still much progress to be made in understanding the interactions between repetition and belief in future occurrence. First, it is important to mention that this study constitutes a first attempt at studying the impact of repetition on belief in future occurrence for different types of events and the results should therefore be replicated. Second, in this study, future events were simulated three times in total, so the effect of more repetitions on belief in future occurrence remains to be investigated in detail. Presenting trivia statements up to 27 times, Hassan & Barber (2021) recently showed that the increase in perceived truth with repetition had a logarithmic shape, with the largest increase occurring on the second presentation, after which increases in perceived truth were progressively smaller and were no longer statistically significant after 9 repetitions. In future studies, it would be interesting to investigate whether the increases in belief in future occurrence with repeated simulation are also logarithmic in shape. In addition, the potential

effect of the time interval between repetitions should also be studied (see Udry et al., 2022). Second, regarding the pragmatic value of belief in future occurrence, a previous study has shown that belief predicts the actual occurrence of events (D'Argembeau & Garcia Jimenez, 2020). Considering these results, it would be interesting to investigate whether and how repeated simulations influence the predictive value of belief and the subsequent occurrence of events. Third, determining the effect of repetition on belief in future occurrence in more ecological settings (e.g., using experience sampling methods) also represents a promising avenue for future research.

Research on belief in future occurrence has potential implications in several areas of applied and clinical psychology. Here, we will outline possible contributions to the literature on intertemporal decision making and addiction. Future event simulation has been shown to help people resist immediate temptations by reducing delay discounting – the tendency to discount the value of future rewards (for a meta-analysis, see Rösch et al., 2022). However, waiting for a later reward is not necessarily the most adaptive choice if the reward is unlikely to materialize, or if the future is anticipated to be uncertain (Bulley et al., 2016). Thus, variations in belief in future occurrence may be adaptively used to make intertemporal decisions. The notion of belief in future occurrence may also be fruitfully used in interventions targeting patterns of future thinking in clinical populations. For example, addiction has been linked to imprecise prediction of goal-directed rewards, and Kinley et al. (2022) suggested that an intervention aimed at increasing belief in future occurrence may encourage the belief that long-term goals are achievable. Finally, it would be interesting to relate research on belief in future occurrence with other research fields. For instance, the theory of planned behavior views behavioral beliefs (i.e., accessible beliefs and expectancies regarding a behavior's likely consequences) as an important factor of behavior change (Ajzen & Kruglanski, 2019). Besides, mental simulation has been used in a multitude of

subdisciplines of psychology and is a useful technique for improving goal-directed behavior (for a meta-analysis, see Cole et al., 2021). Therefore, understanding how simulation of future events can modulate belief in future occurrence may be valuable to improve decision making and goal-directed behavior.

In conclusion, the present research shows that autobiographical knowledge conditions the effect of repeated simulation on belief in future occurrence: belief is enhanced only when imagined events are not clearly supported or contradicted by autobiographical knowledge. Although events that are inconsistent with autobiographical knowledge are imagined in greater detail after repeated simulation, they are not more believable. This provides an important boundary condition for the effect of repetition on subjective truth. From a functional perspective, given the role of belief in future occurrence in guiding decisions and actions, it would indeed not be adaptive to increase belief in events that are in fact unlikely to occur given one's goals and life circumstances. Knowing under what circumstances one can believe in an imagined future event, as well as how one can strengthen this belief, may be useful for interventions that promote goal pursuit and behavior change.

Declarations

Acknowledgments and Funding Information

Arnaud D'Argembeau is a Research Director of the Fonds de la Recherche Scientifique - FNRS, Belgium.

Conflicts of interest/Competing interests

The authors declare no conflicts of interest.

Ethics approval

This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the Ethics Committee of the Faculty of Psychology of the University of Liège (2020, September 19th/No. 3568).

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Consent for publication

Not applicable

Availability of data and materials

All data and research materials are available on OSF (https://osf.io/ep8yc/).

Code and availability

Analysis code is available on OSF (https://osf.io/ep8yc/)

Open Practices Statement

We report how we determined our sample size, all data exclusions, all manipulations, and all measures. All data, analysis code, and research materials are available on OSF (https://osf.io/ep8yc/). This study was not preregistered.

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