Uncertainty Salience Reduces the Accessibility of Episodic Future Thoughts

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Statements and Declarations

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Abstract

We live in uncertain times and how this pervasive sense of uncertainty affects our ability to think about the future remains largely unexplored. This study aims to investigate the effects of uncertainty salience on episodic future thinking—the ability to mentally represent specific future events. Experiment 1 assessed the impact of uncertainty on the accessibility of episodic future thoughts using an event fluency task. Participants were randomly assigned to either an uncertainty induction or control condition, and then were asked to imagine as many future events as possible that could happen in different time periods. The results showed that participants in the uncertainty condition produced fewer events, suggesting that uncertainty salience reduced the accessibility of episodic future thoughts. Experiment 2 investigated in further detail the mechanisms of production of episodic future thoughts that are affected by uncertainty. The results showed that uncertainty primarily reduced the accessibility of previously formed future thoughts (i.e., memories of the future) rather than affecting the ability to generatively think about the future and construct events. These findings shed new light on the impact of uncertainty on episodic future thinking, paving the way to further investigation into its implications for decision-making and future-oriented behavior.

Keywords: Uncertainty; Episodic future thinking; Autobiographical memory; Retrieval processes.

In the backdrop of current social, geopolitical, financial, and environmental issues, it becomes abundantly clear that our grasp on the future is marked by unpredictability and uncertainty (Gould-Davies, 2017). This sense of uncertainty extends beyond major collective events and seeps into the everyday aspects of life, where it impacts our decisions and actions in various domains. Uncertainty is fundamentally a mental state that can be described as the self-awareness of ignorance, a higher-order metacognition of not knowing (Anderson et al., 2019). Researchers have identified different sources of uncertainty depending on whether available information is limited to or characterized by probability (the likelihood of a future event), ambiguity (a multiplicity of possible states for a single event), or vagueness (a multiplicity of possible values on a continuum) (Han et al., 2011). These sources collectively contribute to informational uncertainty—situations where individuals have incomplete information for making decisions and judgments (Kahneman et al., 1982; Van den Bos, 2009). Another facet of uncertainty is personal uncertainty, which is characterized by subjective doubt and instability in self-views, worldviews, or the interrelation between the two (Van den Bos & Lind, 2002).

Different lines of research have shown that uncertainty has a strong impact on cognitive and emotional processing. Uncertainty constitutes a powerful stressor, which often leads to elevated levels of anxiety (Greco & Roger, 2003). Thus, people generally find uncertainty to be aversive (Hogg, 2007; Van den Bos & Lind, 2002), and are often willing to invest resources to alleviate it (Lovallo & Kahneman, 2000). Other studies have shown that uncertainty can lead to increased rigidity and close-mindedness, particularly in relation to one's attitudes, values, and self-consistent behaviors. For example, uncertainty tends to intensify intergroup bias (McGregor et al., 2001) and prompts people to react with negative emotions when confronted with experiences or people that threaten their worldviews (Van den Bos, 2007). Additional evidence suggests that uncertainty affects mental time travel—how

people mentally revisit the past and envision the future. When primed with self-uncertainty, people tend to psychologically distance themselves from adverse past experiences (Yang et al., 2020). Self-uncertainty can also reduce the accessibility of possible future identities (Smith et al., 2014) and influence the effort people invest in goal pursuit (Light et al., 2018). Furthermore, it has been proposed that uncertainty influences the way people mentally simulate possible futures, with important implications for understanding the relationship between uncertainty and affect (Anderson et al., 2019). To date, however, the impact of uncertainty on the mechanisms underlying future thinking remains to be investigated in detail.

Human actions are often shaped by the anticipation of forthcoming events, their envisioned outcomes, and the pursuit of specific goals and plans to achieve or avoid possible future states (Baumeister et al., 2016; Bulley & Irish, 2018; Kvavilashvili & Rummel, 2020). A particular form of prospective cognition—known as *episodic future thinking*—plays an important role in this respect, enabling people to mentally simulate specific scenarios (Atance & O'Neill, 2001; D'Argembeau, 2020; Schacter & Addis, 2007; Suddendorf & Corballis, 2007; Szpunar, 2010). Research from diverse domains, including cognitive, neuroimaging, developmental, and clinical studies, has shown that the construction of episodic future thoughts relies on the use of details from past experiences stored in episodic memory (Schacter & Addis, 2007), as well as semantic knowledge that furnishes the structural framework within which episodic details can be meaningfully integrated (Irish et al., 2012). Moreover, episodic future thinking involves higher-order knowledge about the self and one's life that contextualizes imagined events within an autobiographical framework: to be perceived as a possible future event, an imagined scenario must be integrated with our goals and general expectations about the future (D'Argembeau, 2020). Indeed, such autobiographical knowledge constrains and guides the imagination of specific future events (D'Argembeau & Mathy, 2011), organizes them in coherent themes and sequences

(D'Argembeau & Demblon, 2012), and contributes to their temporal location (Ben Malek et al., 2017). The consistency of events with autobiographical knowledge also shapes our subjective experience when envisioning the future, notably our belief that an imagined situation will (or will not) occur (Ernst & D'Argembeau, 2017; D'Argembeau & Garcia Jimenez, 2020). Finally, the evidence suggests that simulations of future events that are integrated with autobiographical knowledge are better encoded in memory and later recalled as "memories of the future," which can then be used to guide decisions and actions (Jeunehomme & D'Argembeau, 2021).

The accessibility and characteristics of episodic future thoughts are modulated by contextual factors. For example, research has shown that the accessibility of future thoughts is influenced by the induction of mood states, with reduced fluency for mood-incongruent events (Hepburn et al., 2006). Furthermore, the induction of different retrieval styles (e.g., a memory specificity induction or a brief training in recollecting details of past experiences) can modulate the specificity of imagined future events and the number of episodic details they contain (Madore et al., 2014; Williams et al., 1996). These experimental manipulations have provided important insight into the cognitive mechanisms underlying the imagination of future events (Schacter et al., 2017).

Capitalizing on such brief induction procedures, the present study aimed to examine the impact of uncertainty on the accessibility and mechanisms of construction of episodic future thoughts. As previously discussed, uncertainty frequently arises in our daily lives due to a lack of information or doubts about our view of ourselves and the world, which creates difficulties when we try to make informed judgments (Kahneman et al., 1982; Van den Bos, 2009). In such situations, the lack of information can cast doubt on the reliability and completeness of the knowledge we typically rely on to envision the future, such as our general goals and expectations (i.e., autobiographical knowledge). This, in turn, could hinder our

ability to access and draw upon this knowledge when generating representations of future events. In other words, uncertainty might induce doubts about the accuracy or reliability of what we know about ourselves and the world, so that it becomes harder to envision and plan for future scenarios. Uncertainty might thus decrease our ability to mentally project ourselves into the future and imagine the events and experiences it might hold. To test this hypothesis, we conducted two experiments in which we examined the effects of uncertainty induction on episodic future thinking using two complementary tasks. Experiment 1 used an event fluency task to test the hypothesis that uncertainty salience reduces the accessibility of episodic future thoughts, and Experiment 2 used a word cueing paradigm to further examine to what extent the two main modes of production of episodic future thoughts—direct and generative—are impacted by uncertainty.

Experiment 1

The aim of Experiment 1 was to test the hypothesis that uncertainty reduces the accessibility of future thoughts. Participants were randomly assigned to either an uncertainty induction or control condition, and the accessibility of their future thoughts was then assessed using an event fluency task—imagining as many future events as possible for a given amount of time (D'Argembeau et al., 2010). We hypothesized that future thoughts would become less accessible following uncertainty salience, so that participants would provide fewer thoughts in the fluency task.

Method

Participants. Participants were recruited on Prolific.ac (Palan & Schitter, 2018). An a priori power analysis indicated that 64 participants per group was necessary to reach 80% power to detect a statistically significant between-condition difference in the number of imagined future events, with a medium effect size (d = 0.50) and an alpha of .05. Thus, we decided to

test 200 participants in total to account for possible exclusions. Among the 200 tested participants, 18 were excluded because they failed to pass an attention check and 11 additional participants were excluded because they did not follow the instructions properly (i.e., to write one future event per line and then press the space bar; see below). The final sample included 171 participants (88 female, 81 male, 2 other; mean age = 44 years, *SD* = 13; mean of education = 15.2 years, *SD* = 2.95) residing in the U.S. or U.K. and whose first language was English. They were randomly assigned to the two conditions (n = 87 and n = 84, for the uncertain and control conditions, respectively). All participants provided informed consent and this study was approved by the Ethics Committee of the Faculty of Psychology of the University of Liège (ref. 2223-097).

Materials and Procedure. The experiment was administered using the Gorilla experiment builder (gorilla.sc) (Anwyl-Irvine et al., 2020). After providing informed consent, participants were randomly assigned to the uncertainty salience or control condition. Uncertainty was induced using a procedure developed by van den Bos and colleagues (see e.g., van den Bos, 2001). Participants were asked to think of aspects of their life that make them feel uncertain and to respond to two open-ended questions concerning their thoughts and feelings about being uncertain. (1) "Please, briefly describe the emotions that the thought of you being uncertain arouses in you" (2) "Please, write down, as specifically as you can, what you think physically will happen to you as you feel uncertain." Participants in the control condition were asked two questions that were similar in format but that did not remind them about their uncertainties: (1) "Please, briefly describe the emotions that the thought of you watching a movie or series arouses in you" and (2) "Please, write down, as specifically as you can, what you think physically will happen to you as you watch a movie or series."[1]

[1] As this method for inducing uncertainty has proved effective in many previous studies (for review, see van den Boss, 2009), we did not include a manipulation check. However, the written responses given by participants showed that all participants in the uncertainty group gave responses related to uncertainty (e.g., negative

The accessibility of future thoughts was then assessed using an event fluency task (see e.g., Coste et al., 2015; D'Argembeau et al., 2010; MacLeod & Byrne, 1996). Participants were asked to imagine as many future events as possible that could happen to them in the next week, the next month, and the next year. For each of the three temporal windows, they had to write down as many events as possible for 60 seconds, by typing a brief two- or three-words statement for each event and then pressing the space bar. It was specified that these events could be mundane or important but that they should refer to something that happens during a single day.

Finally, participants received an Instructional Manipulation Check (Oppenheimer et al., 2009) and provided demographic information. The instructions and materials that were used in this experiment are openly available in OSF at https://osf.io/ykdvj/.

Statistical analyses. The number of future events produced for each temporal window (i.e., next week, next month, next year) was summed for each participant. Since the distribution of the number of events was approximately normal in each condition, we analyzed data using parametric tests (i.e., independent samples *t*-test). Note, however, that parametric tests are not always appropriate for analyzing count data, so we also checked that similar results were obtained using Poisson regression. Since similar results were obtained, we only report results from the *t*-test. We also examined whether the effect of the uncertainty manipulation differed according to temporal windows, but as this was not the case, we report data pooled across the three temporal windows. Data are available in OSF at https://osf.io/ykdvj/.

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emotions), while almost all participants in the control group described watching movies and series as a positive experience, often stating that it was a way to relax and disconnect from the world. There were two exceptions in which participants described negative emotions, and one of them explicitly referred to a sense of uncertainty when watching movies/series. However, excluding these two participants did not change the pattern of results reported here.

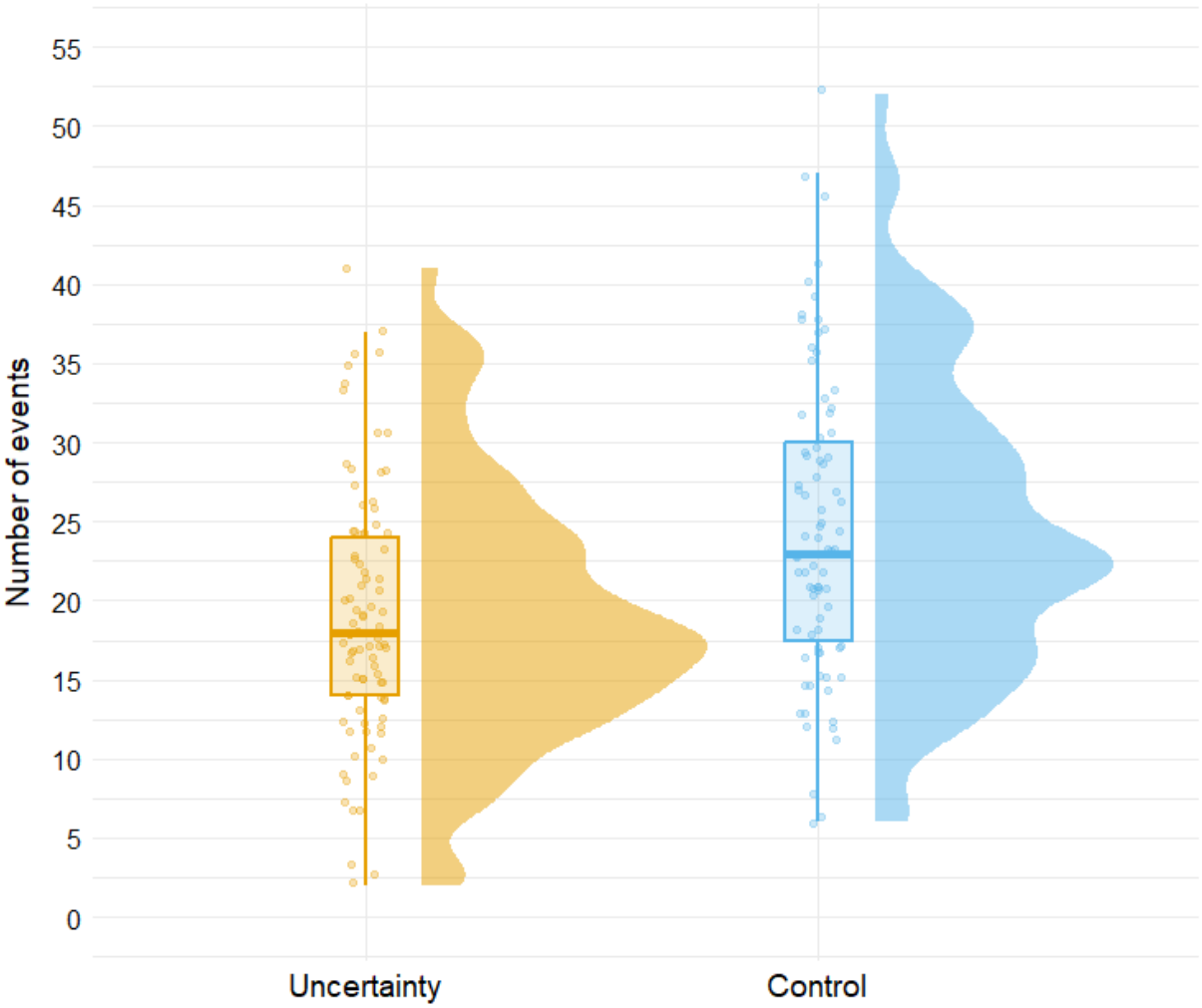
Results

The number of future events produced in the two conditions is shown in Figure 1. As predicted, the number of future events produced in the uncertainty condition (M = 18.9, SD = 8.04) was significantly lower than the number of future events produced in the control condition (M = 25.1, SD = 10.5), $t(169) = 4.29$, $p < .001$, $d = 0.66$. On average, participants produced almost 25% fewer future events when uncertainty was induced.[2] The two conditions did not significantly differ in terms of the length of event descriptions (Uncertainty: M = 3.83 words, SD = 1.90; Control: M = 3.79 words, SD = 2.13), $t(169) = 0.12$, $p = 0.907$, $d = 0.02$).

[2] It should be noted that some event descriptions were repeated, notably across time windows (i.e., next week, next month, and next year). As participants were asked to summarize each event in a brief statement of two or three words, it is difficult to know whether these repeated statements refer to the same event or to different events (e.g., the same statement "meet a friend" could refer to two separate events, such as meeting a different friend). However, to check that the reported results were not due to repetitions, we reran the analysis after excluding repeated statements (in total, 284 statements out of 3721 were excluded). This analysis indicated that the number of future events produced remained significantly lower in the uncertainty condition (M = 17.1, SD = 7.13) than in the control condition (M = 23.2, SD = 9.10), $t(169) = 4.95$, $p < .001$, $d = 0.76$.

Figure 1

Number of future events produced in the uncertainty and control conditions in Experiment 1.



Note: Raincloud plot showing data distribution (split-half violin plot), with jittered raw data (each point represents the number of events produced by a participant). A boxplot is superimposed to provide a visualization of central tendency and error.

Discussion

Experiment 1 provides initial evidence that uncertainty salience reduces the accessibility of future thoughts. In line with our hypothesis, inducing uncertainty led participants to produce fewer future events in an event fluency task compared to the control condition. In Experiment

2, we then aimed to further investigate the effect of uncertainty salience on the mechanisms of production of future events.

Experiment 2

Having established that uncertainty salience reduces the accessibility of future thoughts, in Experiment 2 we aimed to gain a deeper insight into the specific mechanisms of production of episodic future thoughts that are impacted by uncertainty. Previous studies have shown that, like autobiographical memories (Uzer et al., 2012), the production of episodic future thoughts involves two main mechanisms: direct and generative (Jeunehomme & D'Argembeau, 2016). The generative mode is a deliberate and effortful process that involves iterative searches in an autobiographical knowledge base, beginning with the elaboration of cues and gradually accessing general events which are then used to access specific episodic details (Conway & Pleydell-Pearce, 2000; Haque & Conway, 2001). In contrast, the direct production of episodic future thoughts is a more automatic and effortless mode in which internal or external cues trigger the activation of a specific future event without the need for extensive search or control processes.

Most of the time, directly activated future thoughts refer to events that have been imagined on a previous occasion and have been stored in memory (Jeunehomme & D'Argembeau, 2016). Our first hypothesis was that uncertainty salience might reduce the accessibility of such directly accessed future thoughts, as previously imagined events might seem less relevant or reliable in the face of uncertainty. So, when imagining future events in response to a set of cues, the proportion of directly produced events could be reduced as a result of uncertainty induction. Another possibility, which is not necessarily mutually exclusive, is that uncertainty could also have an impact on the generative mode of producing

future thoughts and, in particular, slow down the construction process, because autobiographical knowledge—which is generally used to initiate the construction process in the generative mode (D'Argembeau & Mathy, 2011)—may be perceived as less reliable. In line with previous studies, we also anticipated a general effect of event production mode on response latencies, with events being produced faster in the direct than generative mode (Haque & Conway, 2001; Jeunehomme & D'Argembeau, 2016; Uzer et al., 2012).

Another goal of Experiment 2 was to examine whether the impact of uncertainty salience is specific to future thinking. To do so, we assessed the modes of production of both past and future event representations. We expected that inducing uncertainty would impact the process of future thinking more than memory retrieval. Indeed, memories refer to events that have already occurred and are thus less malleable than future thoughts (although of course, memories are not necessarily accurate and are prone to various biases and distortions; Schacter, 2022).

Finally, we examined the impact of uncertainty and production modes on event characteristics. In particular, we hypothesized that uncertainty salience would lead to a lower belief that imagined future events would actually occur in the future (Ernst & D'Argembeau, 2017). In addition, we sought to replicate previous findings showing that directly produced future events are judged more important and have been thought about more frequently in the past (Jeunehomme & D'Argembeau, 2016).

To test these hypotheses, participants were randomly allocated to either the uncertainty induction or control condition and were then asked to produce a series of past and future events in response to cue words (Jeunehomme & D'Argembeau, 2016). They had to evaluate whether each event came to their mind directly (direct event production) or whether some active search was necessary (generative event production); the latency of event production

was also recorded. Finally, participants rated each event for belief in occurrence, personal significance, emotional valence, temporal distance, and frequency of previous thoughts.

Method

Participants. An a priori power analysis indicated that 40 participants per group was necessary to reach 80% power to detect a statistically significant between-condition difference, with the same effect size as Experiment 1 ($d = 0.64$) and an alpha of .05. Thus, we decided to test 100 participants in total to account for possible exclusions. Participants were recruited through social media or approached directly. Seven participants were excluded because they confused past and future events for some trials (4 participants), used wrong key responses (2 participants), or because of a computer malfunction in presenting the cues (1 participant). The final sample consisted of 93 participants (65 females and 28 males; mean age = 28 years, $SD = 11.50$) residing in Belgium, whose first language was French. They were randomly assigned to the uncertainty (n = 47) or control (n = 46) condition. The experiment was approved by the Ethics Committee of the Faculty of Psychology of the University of Liège.

Materials and Procedure. The experiment was conducted using the Gorilla experiment builder (gorilla.sc) (Anwyl-Irvine et al., 2020). After provided written informed consent, participants were randomly assigned to the uncertainty salience or control condition, which were manipulated using the same procedure as Experiment 1.

All participants then completed a task assessing the prevalence of direct and generative modes of production of past and future events (Jeunehomme & D'Argembeau, 2016). They had to recall five past events and to imagine five future events in response to a series of cue words. It was emphasized that the produced events should be specific (i.e.,

unique events occurring in a specific place, at a specific time, and lasting a few minutes or hours but no longer than a day). Ten cue words referring to common places (e.g., garden, restaurant) or objects (e.g., book, bike) were selected from previous research (Jeunehomme & D'Argembeau, 2016). They were divided into two lists of five words (one for each experimental condition), with each list matched for word length (number of letters), imageability, and frequency of use (Desrochers & Bergeron, 2000). The assignment of lists to temporal orientation (past or future) was counterbalanced across participants, and the five cue words were presented in random order within each temporal orientation. The order of presentation of temporal orientations was also counterbalanced across participants.

On each trial, a cue word was presented, and participants were instructed to press the spacebar as soon as a specific event came to mind in response to that cue. Then, they wrote a brief description of the event and reported whether the event came to their mind directly or whether some active search was necessary. Definitions of direct and generative access (which were adapted from Uzer et al., 2012) were provided before the experiment. Participants were told that memories or imagined future events can sometimes come to mind automatically (i.e., with little or no effort), whereas at other times they must be actively searched. It was explained that during the task, some memories or imagined future events could be triggered immediately by the cue word, but that they would sometimes need to actively search and reflect to find a suitable event. For each event, participants were instructed to press the *A* key if the event came directly to mind or the *B* key if the production of the event required an active search effort.

Finally, participants were asked to estimate the temporal distance of the event (in hours, days, weeks, months, and years), and to rate its personal importance (from 1 = not at all important, to 7 = extremely important), the frequency with which they had previously thought about it (from 1 = never, to 7 = very often), its affective valence (from -3 = very negative, to

+3 = very positive), and their belief that the event actually happened in the past or will actually happen in the future (from 1 = not at all, to 7 = very strong).

Demographic data was collected at the end of the experiment. Before beginning the experimental trials, participants were given two practice trials (with different cue words) to familiarize them with the entire procedure and to ensure that all instructions were correctly understood. The instructions and materials that were used in this experiment are openly available in OSF at https://osf.io/ykdvj/.

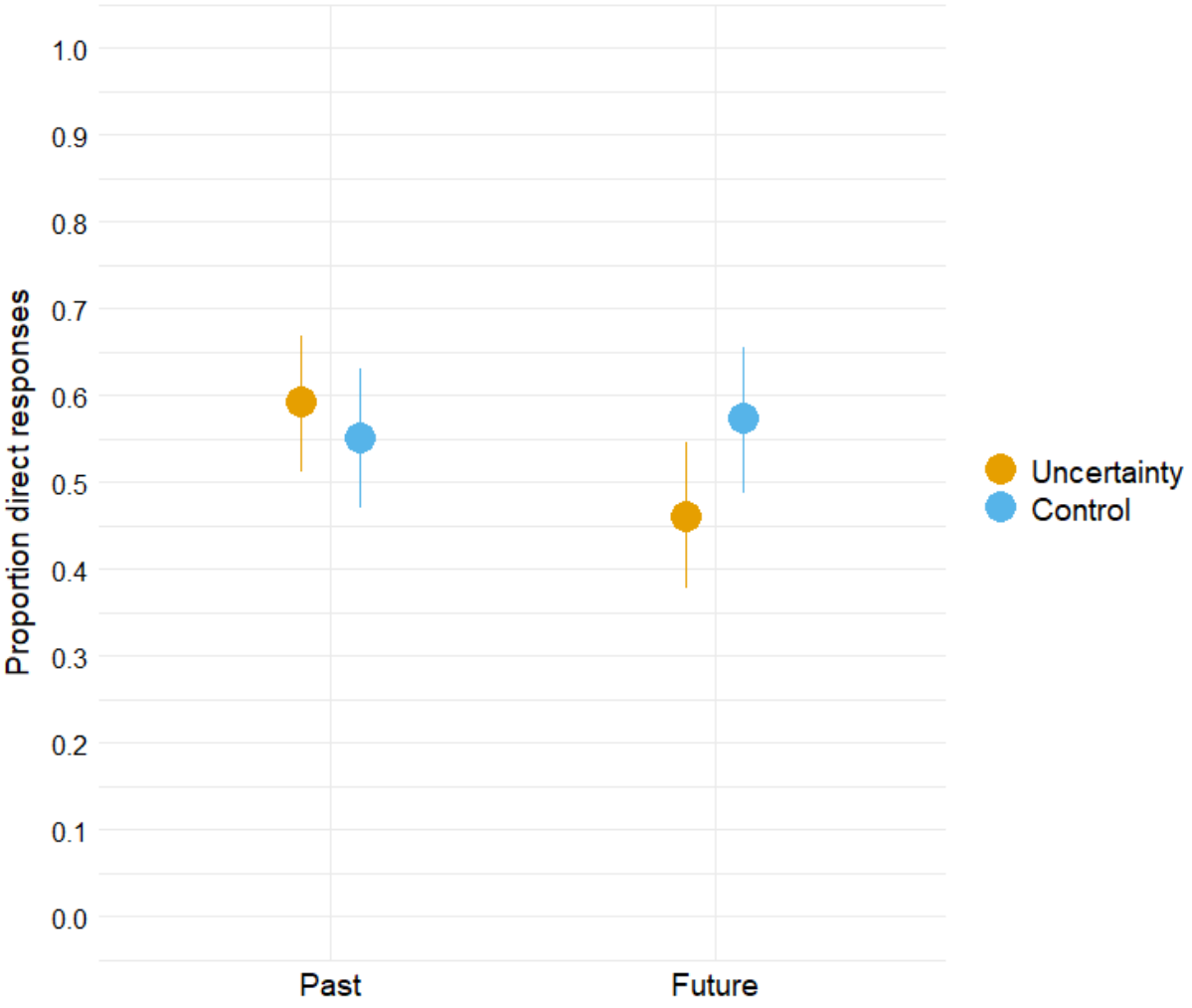
Statistical analyses. Data were analyzed with mixed-effects modeling, using the Jamovi software (The Jamovi Project, 2021). The effects of manipulation (uncertainty vs control) and temporal orientation (past vs future) on the modes of production of events (direct vs generative) were assessed using a logistic mixed-effects model, with mode of production as outcome and manipulation, orientation, and their interaction as predictors. The time needed by participants to produce events (measured by asking them to press the spacebar as soon as an event came to mind) was assessed using a linear mixed-effects model, with response time as outcome and manipulation, orientation, and mode of production (direct vs generative), as well as their interaction, as predictors. Similarly, each event characteristic (as assessed by rating scale) was analyzed using a linear mixed-effects model. Factors were coded using effects coding: manipulation (uncertainty = 0.5, control = -0.5), temporal orientation (past = 0.5, future = -0.5), mode of production (generative = 0.5, direct = -0.5). In all models, by-participant random intercepts and random slopes for within-subject predictors (i.e., temporal orientation, mode of production, and their interaction) were included (Barr et al., 2013). Data are available in OSF at https://osf.io/ykdvj/.

Results

Mode of production of events. The mean proportion of events that were directly produced is shown in Figure 2, as a function of temporal orientation (past vs. future) and experimental conditions (uncertainty vs. control). The logistic mixed-effects model revealed no main effect of manipulation (b = -0.146, SE = 0.1963, Z = 0.742, p = .458) or orientation (b = 0.224, SE = 0.1400, Z = -1.597, p = .110), but there was a significant manipulation by orientation interaction (b = 0.625, SE = 0.2798, Z = -2.232, p = .026). Post-hoc tests revealed that, in the uncertainty condition, the direct production of events was significantly lower for the future than for the past (Z = 2.718, p = .007), whereas it was not the case in the control condition (Z = -0.446, p = .656).

Figure 2

Mean proportion of directly produced past and future events in each experimental condition (Uncertainty vs Control) in Experiment 2.



Note: The point-range plot shows the estimated marginal means derived from the mixed-effects model and their 95% CI.

Latency of event production. The linear mixed-effects analysis on the latency of event production only revealed a main effect of the mode of production of events; directly produced events were associated with faster response times (estimated marginal mean = 4117 ms, *SE* =

204) than events that needed generative production (estimated marginal mean = 10785 ms, *SE* = 527). Results can be found in Table 1.

Table 1: *Results of the mixed-effects model on the latency of event production.*

Factors	*b*	*SE*	df	*t*	*p*
(Intercept)	7451	313	78.9	23.79	< .001
Manipulation	-97	626	78.9	-0.16	.877
Orientation	165	414	84.5	0.40	.690
Mode of production	6668	497	80.2	13.41	< .001
Manipulation ✻ Orientation	833	827	84.5	1.01	.316
Manipulation ✻ Mode of production	-467	994	80.2	-0.47	.640
Orientation ✻ Mode of production	-12	871	92.8	-0.01	.989
Manipulation ✻ Orientation ✻ Mode of production	1723	1743	92.8	0.99	.325

Note: Factors were coded using effects coding: manipulation (uncertainty = 0.5, control = -0.5), orientation (past = 0.5, future = -0.5), mode of production (generative = 0.5, direct = -0.5).

Event Ratings. The results of the mixed-effects models for each of the event ratings are shown in Table 2. The mixed-effects model examining belief in the occurrence of events revealed a main effect of manipulation, showing that participants in the uncertainty group believed less in the occurrence of events (estimated marginal mean = 6.27, *SE* = 0.07) than participants in the control group (estimated marginal mean = 6.49, *SE* = 0.07). In addition, there were main effects of temporal orientation and mode of production, as well as a signification interaction between these two factors. Post-hoc tests showed that, for past events, belief in occurrence did not significantly differ between directly (estimated marginal mean = 6.90, *SE* = 0.05) and generatively (estimated marginal mean = 6.79, *SE* = 0.07) produced events, $t(88.4) = 1.29$, $p = .201$, whereas for future events, belief in occurrence was higher for directly (estimated marginal mean = 6.37, *SE* = 0.09) than generatively (estimated marginal mean = 5.46, *SE* = 0.12) produced events, $t(87) = 6.59$, $p < .001$. All other interactions were not significant.

Regarding personal importance, there was a main effect of temporal orientation, showing that future events were rated as more important (estimated marginal mean = 3.86, *SE* = 0.10) than past events (estimated marginal mean = 3.09, *SE* = 0.10). Additionally, there was a main effect of the mode of production, showing that directly produced events were rated as more important (estimated marginal mean = 3.96, *SE* = 0.11) than generatively produced events (estimated marginal mean = 2.99, *SE* = 0.10). No other significant effects were observed.

For frequency of previous thoughts about the events, the analysis revealed several main effects. First, when uncertainty was induced, participants produced events that had been previously thought about to a greater extent (estimated marginal mean = 2.97, *SE* = 0.10) than in the control condition (estimated marginal mean = 2.62, *SE* = 0.10). Furthermore, a significant main effect of orientation was observed, indicating that future events (estimated marginal mean = 3.13, *SE* = 0.10) were previously thought about more frequently than past events (estimated marginal mean = 2.46, *SE* = 0.07). There was also a main effect of the mode of production, showing that directly produced events (estimated marginal mean = 3.22, *SE* = 0.09) had been thought about more frequently than generatively produced events (estimated marginal mean = 2.37, *SE* = 0.08). Finally, the manipulation by mode of production interaction was significant and post-hoc tests showed that directly produced events had been previously thought about more frequently in the uncertainty condition (estimated marginal mean = 3.50, *SE* = 0.13) than in the control condition (estimated marginal mean = 2.93, *SE* = 0.13), $t(87.9) = 2.99$, $p = .004$, whereas there was no significant difference between the two conditions for generatively produced events (estimated marginal means = 2.44 and 2.31, *SE* = 0.11 and 0.11, for the uncertainty and control conditions, respectively), $t(83.3) = 0.87$, $p = .38$.

Regarding emotional valence, significant main effects were observed for both orientation and mode of production. Future events (estimated marginal mean= 1.87, *SE* =

0.08) were rated as more positive than past events (estimated marginal mean = 1.08, *SE* = 0.08). Moreover, directly produced events (estimated marginal mean = 1.61, *SD* = 0.07) were rated as more positive than generatively produced events (estimated marginal mean = 1.34, *SD* = 0.08). There were no other significant effects.

Finally, for the temporal distance of events, there was a main effect of orientation, showing that past events were more distant in time (estimated marginal mean = 1388 days, *SE* = 183) than future events (estimated marginal mean = 276 days, *SE* = 69). No other main effects or interactions were observed.

Table 2: *Results of the mixed-effects models on event characteristics.*

Characteristic	Factors	*b*	*SE*	df	*t*	*p*
Belief in occurrence	(Intercept)	6.38	0.05	85.7	125.38	< .001
	Manipulation	-0.22	0.10	85.7	-2.16	.034
	Orientation	0.93	0.08	100.1	11.67	< .001
	Mode of production	-0.51	0.08	96.7	-6.41	< .001
	Manipulation ✻ Orientation	0.1	0.16	100.1	0.61	.541
	Manipulation ✻ Mode of production	-0.06	0.16	96.7	-0.36	.718
	Orientation ✻ Mode of production	0.8	0.16	91.7	4.93	< .001
	Manipulation ✻ Orientation ✻ Mode of production	-0.04	0.32	91.7	-0.13	.897
Personal importance	(Intercept)	3.48	0.09	89.3	39.45	< .001
	Manipulation	0.20	0.18	89.3	1.15	.253
	Orientation	-0.77	0.10	119.3	-7.45	< .001
	Mode of production	-0.98	0.11	217.3	-8.82	< .001
	Manipulation ✻ Orientation	-0.09	0.21	119.3	-0.43	.670
	Manipulation ✻ Mode of production	-0.16	0.22	217.3	-0.73	.466
	Orientation ✻ Mode of production	0.16	0.23	101.7	0.70	.483
	Manipulation ✻ Orientation ✻ Mode of production	-0.38	0.45	101.7	-0.83	.406
Frequency of previous thoughts	(Intercept)	2.79	0.07	88.7	38.27	< .001
	Manipulation	0.35	0.15	88.7	2.41	.018
	Orientation	-0.67	0.1	95.7	-7.02	< .001
	Mode of production	-0.84	0.09	151.4	-9.19	< .001
	Manipulation ✻ Orientation	-0.09	0.19	95.7	-0.49	.624
	Manipulation ✻ Mode of production	-0.43	0.18	151.4	-2.37	.019
	Orientation ✻ Mode of production	0.34	0.19	102.7	1.80	.074
	Manipulation ✻ Orientation ✻ Mode of production	-0.08	0.38	102.7	-0.21	.836
Emotional valence	(Intercept)	1.47	0.06	103	25.66	< .001
	Manipulation	-0.12	0.11	103	-1.09	.280
	Orientation	-0.80	0.11	120	-7.3	< .001
	Mode of production	-0.27	0.11	179	-2.49	.014
	Manipulation ✻ Orientation	-0.06	0.22	120	-0.26	.798
	Manipulation ✻ Mode of production	0.33	0.22	179	1.53	.127
	Orientation ✻ Mode of production	0.09	0.22	121	0.39	.698
	Manipulation ✻ Orientation ✻ Mode of production	0.68	0.45	121	1.52	.132
Temporal distance	(Intercept)	832	102	89.8	8.14	< .001
	Manipulation	219	204	89.8	1.07	.286
	Orientation	1113	187	91.3	5.96	< .001
	Mode of production	-114	118	127.9	-0.96	.338
	Manipulation ✻ Orientation	190	373	91.3	0.51	.612
	Manipulation ✻ Mode of production	-233	237	127.9	-0.98	.328
	Orientation ✻ Mode of production	-273	227	134.9	-1.20	.232
	Manipulation ✻ Orientation ✻ Mode of production	-307	454	134.9	-0.68	.501

Note: Factors were coded using effects coding: manipulation (uncertainty = 0.5, control = -0.5), orientation (past = 0.5, future = -0.5), mode of production (generative = 0.5, direct = -0.5).

Discussion

The results of Experiment 2 provide a deeper understanding of how uncertainty salience affects the production of episodic future thoughts. Following the induction of uncertainty, participants showed a significant decline in their ability to directly produce future events. Interestingly, this effect was specific to future events, as our experimental manipulation left the recall of past events largely unaffected. In addition, the examination of response latencies showed that the direct mode of event production was much faster than the generative mode, in line with previous studies (Jeunehomme & D'Argembeau, 2016; Uzer et al., 2012), but uncertainty did not affect response latencies. These results indicate that uncertainty salience reduces the probability of direct access to future events (and thus encourages a more generative thinking approach) but does not affect the process of direct event production per se (in which case response latencies should have been impacted). In fact, the direct activation of future thoughts relies mainly on the retrieval of imagined events previously stored in memory (Jeunehomme & D'Argembeau, 2016), so the reduced accessibility of directly produced future events following uncertainty induction might be attributed to a general decline in the perceived reliability and relevance of pre-existing thoughts about the future, rather than difficulties in the process of retrieving/accessing these thoughts.

In support of this interpretation, Experiment 2 also yielded some interesting insights concerning the effect of uncertainty on the characteristics of produced events. Notably, participants in the uncertainty condition had a lower belief in the occurrence of events compared to participants in the control group, in line with the idea that uncertainty makes future thoughts seem less reliable. The frequency of previous thoughts about the events was

also influenced by uncertainty, with participants reporting events that had been previously thought about to a greater extent when uncertainty was induced. This finding is consistent with the idea that uncertainty reduces the accessibility of future representations (Smith et al., 2014), so that only events that have been frequently rehearsed in the past are accessible.

Finally, the results of Experiment 2 replicated several previous findings regarding the characteristics of directly vs generatively produced events. Specifically, directly produced future events were rated as more important and had been thought about more frequently than generatively produced events, in line with the view that they mainly involve "memories of the future" (Jeunehomme & D'Argembeau, 2016).

General Discussion

We live in an age of uncertainty (Gould-Davie, 1997), but how this pervasive sense of uncertainty affects our ability to envision the future is not fully understood. To address this question, the present study aimed to examine the effects of uncertainty salience on the accessibility and mechanisms of construction of episodic future thoughts. The results of Experiment 1 suggest that uncertainty may reduce the accessibility of episodic future thoughts, as participants in the experimental group generated significantly fewer future events in a fluency task than did participants in the control group. Experiment 2 then provided a better understanding of the mechanisms of episodic future thought production that are affected by uncertainty. Specifically, the impact of uncertainty manifested as a shift from the direct to the generative mode of production of future thoughts, and the future events that were nonetheless directly accessed turned out to have been thought about more frequently in the past. These results suggest that uncertainty primarily reduces the accessibility of previously

formed future thoughts (i.e., memories of the future) rather than affecting the ability to generatively think about the future and construct events.

Uncertainty frequently emerges in our daily lives due to a scarcity of information or doubts about ourselves and our worldviews, which creates difficulties in making well-informed judgments (Kahneman et al., 1982; van den Bos, 2009). The present research demonstrates that such states of uncertainty have a significant impact on the ability to envision the future, especially by reducing direct access to future thoughts. To be useful in guiding our decisions and actions, future simulations must be stored in memory and later retrieved when relevant situations are encountered (Ingvar, 1985; Kvavilashvili & Rummel, 2020; Szpunar et al., 2013). Most episodic future thoughts that are directly produced refer to such previously simulated events, the rapid access to which can have significant adaptive value (Jeunehomme & D'Argembeau, 2016). An important function of episodic future thinking is to formulate intentions and mentally explore possible futures to guide decisions and behavior (Baumeister et al., 2016; Kvavilashvili & Rummel, 2020; Suddendorf & Corballis, 2007; Taylor et al., 1998). The ability to recall the content of anticipated events and plans may, in part, underpin successful goal pursuit (Ingvar, 1985; Szpunar et al., 2013). Rapid access to such mental representations could therefore help guide behavior more efficiently and effectively. Previous studies have shown that simulations of future events are better retained in memory when they are integrated with autobiographical knowledge (Jeunehomme & D'Argembeau, 2021). Such knowledge also plays an important role in shaping our belief that imagined events will or will not happen in the future (Ernst & D'Argembeau 2017; Ernst et al., 2019; Scoboria et al., 2020). Based on these results, we suggest that uncertainty salience may lead people to doubt the accuracy or reliability of their future-oriented autobiographical knowledge, as well as associated events and plans, thereby reducing the accessibility of previously constructed future scenarios.

Part of our autobiographical knowledge includes "possible selves," which refer to ideas about what one might become, would like to become, or is afraid of becoming in the future (Markus & Nurius, 1986). It could be that, in the present study, uncertainty cast doubt on participants' possible selves, in line with previous findings that uncertainty can reduce the accessibility of potential future identities (Smith et al., 2014). This may in turn affect episodic future thinking processes, given the role that future self-concepts play in the construction and organization of future scenarios (D'Argembeau et al., 2012; Rathbone et al., 2011). Thus, in times of uncertainty, our anticipated future identities may become blurred, leading to questioning and re-evaluation of potential future scenarios. To investigate this further, future studies could induce uncertainty specifically at the level of future self-concepts and explore potential implications for the accessibility of episodic future thoughts and their characteristics.

Another interesting result of our study is that uncertainty salience had distinct effects on past and future autobiographical thinking. Experiment 2 showed that memories of past events were less influenced by uncertainty induction, which could be attributed to their higher stability compared to future thoughts. However, although the accessibility of memories was less impacted, uncertainty salience nevertheless reduced belief in the occurrence of retrieved past events. Thus, uncertainty seems to have some general effect on autobiographical thinking, regardless of its temporal orientation. In addition, previous research has shown that when people experience uncertainty, they tend to distance themselves from adverse past experiences (Yang et al., 2020). In our study, we did not specify the emotional valence of events that participants were asked to produce, and it would be interesting in future studies to examine whether uncertainty has distinct effects on the accessibility of positive and negative past and future events. In fact, it has been proposed that, when faced with uncertainty, people tend to prioritize negative information in their mental simulations, which may be adaptive

given that the cost of missing a threat may be higher than the cost of missing a reward (Anderson et al., 2019).

An additional avenue for future research would be to determine the impact of different forms of uncertainty on episodic future thinking. An important distinction is between informational and personal uncertainty (van den Bos, 2009). Informational uncertainty arises when the available information is vague, ambiguous, or when the probability of a future event is unclear, leading individuals to question their existing knowledge (Han et al., 2011). Personal uncertainty introduces an affective dimension, characterized by subjective doubt and instability in self-views and worldviews, often accompanied by discomforting emotions (Hogg, 2007; van den Bos & Lind, 2002). In the present study, uncertainty was induced using a procedure developed by van den Bos and colleagues (e.g., van den Bos, 2001) to increase personal uncertainty, so it could be that the reduced accessibility of episodic future thoughts evidenced here is due to personal rather than informational uncertainty. However, our manipulation may also have induced some informational uncertainty, and from a theoretical perspective, it is clear that informational uncertainty could also affect future thinking (Anderson et al., 2019). Disentangling the respective effects of personal and informational uncertainty, and their possible interaction, is an important next step in understanding how uncertainty salience impacts future thinking.

A related question would be to identify the components of uncertainty that impact future thinking, along with the underlying mechanisms. One possibility is that the affective component of uncertainty plays an important role. Uncertainty is often associated with negative affect, particularly fear and anxiety (Anderson et al., 2019; Carleton, 2016). Consequently, the influence of uncertainty salience on future thinking could be partly due to these emotional states. Although we cannot exclude this possibility, it remains unclear to what extent our results could be explained by negative affect such as anxiety. Indeed, anxiety is

generally associated with an increased accessibility of negative future thoughts (MacLeod & Byrne, 1996), whereas we found that the accessibility of future thoughts decreased following uncertainty induction (although it should be noted that the valence of these thoughts was not assessed). Furthermore, a recent study suggests that the induction of state anxiety influences the elaboration of future thoughts (i.e., participants spent more time to imagine events in detail) but not the initial access to specific events (Zhou et al., 2024; see also Du et al., 2022), whereas we found that uncertainty salience did influence future thought accessibility. Thus, although this question remains to be investigated in detail, the available evidence suggests that uncertainty and anxiety may have dissociable effects on future thinking. Another possibility is that it is the cognitive dimension of uncertainty that impacts episodic future thinking. From a "Bayesian brain" perspective, we are constantly making predictions about current and future events based on our internal models of the world, while seeking to minimize prediction error (Friston, 2009). Uncertainty salience might decrease the precision and perceived accuracy of these model-based predictions (Kinley et al., 2022), reducing the accessibility of episodic future thoughts and the belief that the events envisaged will actually occur (see Brouillet & Friston, 2023, for a more in-depth discussion of how processing fluency relates to prediction accuracy).

In conclusion, the present study provides empirical evidence that uncertainty salience reduces the accessibility of episodic future thoughts, mainly by diminishing the direct access to previously imagined future events. These results shed light on the mechanisms by which uncertainty influences the ability project oneself into the future and pave the way to future research investigating the complex interplay between uncertainty, future thinking, and human decisions and behavior.

CRediT authorship contribution statement

Marianthi Terpini: Methodology, Data curation, Formal analysis, Visualization, Writing - original draft, Writing - review & editing.

Arnaud D'Argembeau: Conceptualization, Methodology, Funding acquisition, Visualization, Writing - original draft, Writing - review & editing.

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