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Effects of inhibitory control capacity and cognitive load on involuntary past and future thoughts: A laboratory study

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ABSTRACT

The present study focused on involuntary thoughts about personal past events (i.e., involuntary autobiographical memories; IAMs), and involuntary thoughts about future events and plans (i.e., involuntary future thoughts; IFTs). The frequency of these involuntary thoughts is influenced by cognitive demands of ongoing activities, but the exact underlying mechanism(s) has yet to be revealed. The present study tested two possible explanations: (1) the special inhibitory mechanism switches on when one is engaged in attentionally demanding activities; (2) different levels of cognitive load interfere with cue-noticing that act as triggers for IAMs and IFTs. We report a study with pre-selected groups of participants that differed in terms of their individual level of inhibitory control capacity (high vs. low), and completed both standard and attentionally demanding versions of a laboratory vigilance task with irrelevant cue-words to trigger IAMs and IFTs, and random thought-probes to measure their frequency. To examine the level of incidental cue-noticing, participants also completed an unexpected cue-recognition task. Despite large differences between groups in inhibitory control capacity, the number of IFTs and IAMs, reported in the attentionally demanding condition, was comparable. In addition, high cognitive load reduced the number of IAMs, but not IFTs. Finally, the recognition of incidental cues encountered in the vigilance task was reduced under high cognitive load condition, indicating that poor cue-noticing may be the main underlying mechanism of cognitive load effect rather than the lack of inhibitory resources needed to suppress involuntary retrieval. This and other possible mechanisms and avenues for future research are discussed.

1. Introduction

In a typical day, many different thoughts go through our mind while being engaged in daily activities. For instance, we may need to recall our personal past (e.g., *how and when exactly we initially heard about the spread of COVID-19 in Wuhan*) or envisage future events (e.g., *how getting a vaccine will change our daily life and routines*) that are important for us. These examples capture two main forms of voluntary and deliberate episodic mental time travel (Suddendorf, Addis, & Corballis, 2009) that have been studied extensively in the past decades (e.g., Wheeler, Stuss, & Tulving, 1997; D'Argembeau & Van der Linden, 2004). However, in everyday life, past and future

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[1] Rémi Radel passed away on 14 May 2019. He will be sorely and truly missed.

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thoughts may also pop into our mind unexpectedly without any preceding attempts to think about them (e.g., Berntsen, 1996; Berntsen & Jacobsen, 2008). For example, while listening to an online lecture, memories relating to our time in high school may come to mind, or we may spontaneously think of a birthday present for a family member that – although already chosen – has yet to be ordered online. Importantly, such spontaneous cognitive phenomena seem to occur quite frequently in daily life (e.g., Finnbogadóttir & Berntsen, 2013; Rasmussen et al., 2015) and often in response to incidental cues in one's environment or thoughts (e.g., Berntsen, 1998; Berntsen & Jacobsen, 2008; Mace, 2004; Schlagman et al. 2007). As a result, researchers have started to distinguish voluntary and involuntary forms of episodic mental time travel in terms of how they appear in a person's mind (i.e., intentionally or unintentionally). The main focus of the present paper is on such spontaneous thoughts; namely, the involuntary autobiographical memories (IAMs) and involuntary future thoughts (IFTs) that relate to our personal past or possible future events, respectively.

Over the years, IAMs and IFTs were studied separately from each other and there was only a handful of published studies on IFTs (for a review, see Berntsen, 2019). Recently, however, there has been a significant increase not only in research on IFTs (Cole & Kvavilashvili, 2019), but also in studying IAMs and IFTs within one unified framework of spontaneous cognition (e.g., Barzykowski et al., 2019, Barzykowski, Hajdas et al., 2021; Berntsen & Jacobsen, 2008; Cole, Staugaard, & Berntsen, 2016; Finnbogadóttir & Berntsen, 2013; Mazzoni, 2019; Plimpton, Patel & Kvavilashvili, 2015; Vannucci, Pelagatti, & Marchetti, 2017; Warden, Plimpton & Kvavilashvili, 2019). A clear advantage of such unified approach is the possibility of investigating similarities in their key characteristics and underlying cognitive mechanisms.

1.1. The cognitive inhibition dependency hypothesis of involuntary past- and future-oriented thoughts

One important cognitive mechanism, recently examined in the literature, concerns the role of inhibition in the occurrence of IAMs and IFTs in everyday life (e.g., Barzykowski et al., 2019, Barzykowski, Hajdas et al., 2021; Vannucci, Pelagatti, Hanczakowski, Mazzoni, & Paccani 2015). This idea is not new (for a review, see Barzykowski et al, 2019; Barzykowski, Hajdas et al., 2021) and was put forward by Conway and Pleydell-Pearce (2000) in their influential model of autobiographical memory (for later modifications of the model, see Conway, 2008, 2009; Conway & Jobson, 2012) and in the broader framework of inhibitory control proposed by Hasher and colleagues (see Hasher, Lustig, & Zacks, 2007, 1999; also, Friedman & Miyake, 2004). The main idea proposed in these models was that the occurrence of IAMs and IFTs can be explained by inefficient or sub-optimal functioning of the inhibitory control mechanism with the likelihood of experiencing IFTs and IAMs increasing with poorer inhibitory control in general (according to Conway et al.'s, model) and/or with the susceptibility to irrelevant stimuli in particular (according to Hasher et al.'s model). However, although the cognitive inhibition hypothesis is fairly straightforward, there are only a handful of published studies investigating the effects of inhibitory control on the occurrence of involuntary thoughts. For example, some correlational studies (e.g., Kamiya, 2014; Verwoerd & Wessel, 2007) provided initial but indirect support for the cognitive inhibition hypothesis by showing a significant relationship between the weak inhibitory control and the increased frequency of involuntary memories.

More recently, Barzykowski and colleagues (Barzykowski et al., 2019, Barzykowski, Hajdas et al., 2021) addressed this issue by experimentally manipulating levels of inhibitory control between participants (Barzykowski et al., 2019) or studying groups of participants characterized by different levels of inhibitory control (low, medium, high) (Barzykowski, Hajdas et al., 2021). In addition, Barzykowski, Hajdas et al. (2021) tested individuals with attentional deficit hyperactivity disorder (ADHD), which is characterized by low levels of inhibitory control. It was assumed that if the frequency of IAMs and IFTs was affected by inhibitory control, then they should be reported more frequently in conditions in which this inhibitory mechanism is impaired compared to conditions in which inhibitory control works optimally.

To test this idea, Barzykowski et al. (2019) used a well-established paradigm of depleting inhibitory control (Radel et al., 2015; Muraven & Baumeister, 2000; Hagger, Wood, Stiff, & Chatzisarantis, 2010), and assessed the number of reported IFTs and IAMs after the depletion manipulation. In particular, participants in the depleted inhibition condition performed a 60-min high-conflict Stroop task (i.e. requiring high levels of inhibitory control) before completing an undemanding vigilance task (i.e., detecting infrequent target stimuli) with irrelevant verbal cues and thought probes to measure the frequency of IFTs and IAMs. Participants in the intact inhibition condition performed a congruent version of the Stroop task that did not deplete inhibitory control and participants in the control condition completed the vigilance task only. Although participants' inhibitory resources were indeed depleted in the depletion condition compared to the intact inhibition condition, the two groups did not differ from each other and from the control group, in the number of reported IFTs and IAMs. The findings, therefore, did not provide support for the role of inhibitory control in the occurrence of IAMs and IFTs.

In the next study, Barzykowski, Hajdas, et al. (2021) tested the inhibitory control hypothesis using the individual differences approach, in which they assessed the frequency of IAMs and IFTs in a pre-selected pool of participants characterized by low, medium and high levels of inhibitory control capacity, and a group of adults with high scores on ADHD symptoms (Barkley, 1997). However, contrary to the inhibition hypothesis, all groups reported IAMs and IFTs with comparable frequency. Surprisingly, even individuals with ADHD spectrum symptoms did not report more spontaneous thoughts compared to other groups.

When discussing these findings and plausible alternative explanations, Barzykowski and colleagues (Barzykowski et al, 2019, Barzykowski, Hajdas, et al., 2021) suggested that these null results could be due to the fact that the inhibitory control mechanism switches on or is most effective only when one is engaged in attentionally very demanding activities (e.g., revising a paper), because these activities have been shown to be negatively affected by the occurrence of involuntary thoughts (for more details see section below). Indeed, both studies by Barzykowski et al. (2019); Barzykowski, Hajdas et al., 2021 used the vigilance task with a fairly low level of attentional demands. Therefore, they might have not been sensitive enough to examine this alternative explanation, which is related to the special role of the cognitive inhibition under high cognitive load in laboratory conditions. This idea relates directly to the cognitive load dependency view (e.g., Barzykowski & Niedźwieńska, 2018b; also cognitive load hypothesis by Mazzoni, 2019; Vannucci et al., 2015) of IAMs and IFTs, which considers available attentional resources as an important variable affecting the occurrence of involuntary cognitions.

1.2. Cognitive load dependency hypothesis of involuntary past- and future-oriented thoughts

Results of previous diary studies have shown that in everyday life, IAMs and IFTs are not only most likely to occur in response to incidental external and internal cues, but also when people are engaged in ongoing activities that are not attentionally demanding or difficult to carry out (e.g., Berntsen, 1998; Berntsen & Jacobsen, 2008; Finnbogadóttir & Berntsen, 2013).

When discussing possible effects of cognitive load on the frequency of IAMs and IFTs, Mandler (1994) suggested that the retrieval of spontaneous thoughts could depend on the same executive resources that are needed for controlling and carrying out cognitively-demanding activities (for a similar argument, see Berntsen, 2009, p. 97; Mazzoni, 2019). Alternatively, Kvavilashvili and Mandler (2004) argued that the cognitive dependency may result from limited working memory capacity that enables, at any given time, only a finite number of thoughts to occupy one's mind. Therefore, even if a particular IAM or IFT is ready to pop into one's mind in response to a given cue if, at that moment, one's mind is already attending to the environment or is engaged in other activities or thoughts, this may be sufficient to prevent this thought entering into one's mind.

As discussed in the previous section, Barzykowski et al. (2019), Barzykowski, Hajdas et al., (2021) proposed a possibility that optimal task performance during attentionally demanding tasks may activate inhibitory mechanism(s) that keeps any task-unrelated thoughts at bay and it enables to carry on with such cognitively-demanding activities uninterrupted. Finally, an alternative explanation was proposed by Kvavilashvili and Mandler (2004) who suggested that a diffuse state of attention, accompanying cognitively undemanding habitual activities, can increase the likelihood of noticing cues that may act as potential triggers for IAMs and IFTs. Thus, fewer involuntary thoughts experienced during attentionally demanding activity is a result of poor cue-noticing rather than of the cognitive resource dependency of involuntary retrieval *per se*.

So far, very few laboratory studies have investigated the cognitive load hypothesis of IAMs and IFTs by using well-controlled experimental conditions (e.g., Ball, 2007, Experiment 2; Barzykowski & Niedźwieńska, 2018b; Mazzoni, 2019; Vannucci et al., 2015, 2019). In most of these studies, the cognitive load was manipulated by using a dual-task paradigm (i.e., divided attention manipulation) (but see Vannucci et al., 2019). In general, this involves performing a main focal task (such as the vigilance task to measure the frequency of IAMs and IFTs) and an additional, relatively demanding parallel task. For example, Ball (2007, Study 2) who used a free-association task as a focal task, demonstrated that IAMs were retrieved faster under the low attention load than when participants were engaged in an additional parallel task.

All other studies conducted so far (Barzykowski & Niedźwieńska, 2018b; Mazzoni, 2019; Vannucci et al., 2015, 2019), have used slightly different variations of the same experimental procedure originally designed to elicit involuntary memories in the laboratory (Schlagman & Kvavilashvili, 2008). In this paradigm, participants perform an undemanding focal vigilance task (i.e., responding to a pattern of just a few vertical lines in a stream of horizontal lines) while being exposed to short verbal phrases in the centre of the screen, some of which may incidentally trigger involuntary memories (see also the method section below). Importantly, to measure the frequency of IAMs and/or IFTs, participants also report involuntary thoughts that come to mind during a vigilance task either themselves (i.e., self-caught probing method) or when stopped occasionally during the vigilance task (probe-caught method). Although these studies (i.e., Barzykowski & Niedźwieńska, 2018b; Mazzoni, 2019; Vannucci et al., 2015, 2019) differ in terms of how attentional load was manipulated,[2] findings consistently showed a significant decrease in the frequency of IAMs and IFTs as the cognitive demands increased. However, although all these findings unequivocally support the cognitive load dependency hypothesis, the exact mechanism(s) underlying this dependency still remains to be revealed (for a similar argument see also Vannucci et al., 2016, p. 1083).

1.3. The present study

In the present study we wanted to further test two possible mechanisms underlying the cognitive load dependency of IAMs and IFTs. The first possibility, as recently suggested by Barzykowski, Hajdas, et al. (2019, 2021), is a modification of the cognitive inhibition dependency hypothesis according to which the low frequency of IAMs and IFTs observed under cognitively demanding conditions is due to activation of the inhibitory control mechanism. Thus, it may be that when engaged in attentionally very demanding activities we are not negatively affected by the occurrence of involuntary thoughts simply because inhibitory control mechanism keeps them at bay allowing us to carry on with given activities uninterrupted. At the same time, such mechanism should not be activated to the same extent by a task with a rather low level of attentional demands.

To investigate this assumption, we selected two groups of participants differing from each other in terms of their individual levels of cognitive inhibitory control capacity (*cf.* Barzykowski, Hajdas, et al., 2021). These participants were invited to a two-session laboratory study assessing the frequency of IAMs and IFTs under different cognitive load conditions (low vs. high cognitive load), manipulated within subjects across the two sessions. By engaging participants with low and high inhibitory control capacity in a

[2] For example, while Vannucci et al. (2019) did not use the dual-task paradigm and manipulated attentional load by varying the complexity of patterns of vertical and horizontal lines, Barzykowski and Niedźwieńska (2018b) instructed participants to perform an additional demanding task (i.e., responding to additional stimuli presented on the screen).

vigilance task with either low or high cognitive load, we wanted to maximize the likelihood of observing a significant interaction between inhibitory control and cognitive load demands. First, in line with previous studies on cognitive load (e.g., Barzykowski & Niedźwieńska, 2018b; Mazzoni, 2019; Vannucci et al., 2015, 2019), we expected to replicate the main effect of cognitive load with fewer IAMs and IFTs reported in the high than low cognitive load condition. Second, and most important, we expected that this reduction in IAMs and IFTs under high cognitive load would be particularly noticeable in participants with high inhibitory control than those with low inhibitory control capacity. This is because inefficient or suboptimal functioning of the inhibitory control mechanism in participants with low inhibitory control capacity should lead to a higher number of IAMs and IFTs that cannot be efficiently and successfully inhibited under high cognitive task demands.

An alternative hypothesis about the possible mechanism underlying the powerful effect of cognitive load on IAMs and IFTs, as suggested by Kvavilashvili and Mandler (2004), is that the focused state of attention induced by high cognitive load simply decreases the likelihood of noticing cues that may act as potential triggers for IAMs and IFTs. As a result, lower frequency of IAMs and IFTs under cognitive load may not originate from the lack of available attentional resources necessary for their retrieval, but simply because of the impaired noticing of incidental cues. Surprisingly, no previous study has addressed directly this possibility in the context of studying IAMs and IFTs, and therefore it is still unknown whether the lower frequency of IAMs and IFTs is due to cognitive load *per se* or to the presumed differences in the level of cue-noticing between the conditions.

To address this important question, we used a modified version of the standard laboratory paradigm for studying involuntary thoughts that was originally developed by Schlagman and Kvavilashvili (2008). Unless otherwise specified, we strictly followed the same version of the vigilance task that was used by Barzykowski, Hajdas, et al. (2021). Participants had to complete a standard (easy) and more difficult version of the vigilance task across two experimental sessions. Both vigilance tasks involved detecting 15 infrequent target slides with vertical lines and ignoring non-target slides with patterns of horizontal lines (785 slides). In addition, participants were exposed to short verbal phrases (270 compared to 800 in Barzykowski, Hajdas, et al.'s 2021 study), some of which could incidentally trigger task-unrelated thoughts, including IFTs and IAMs. Throughout the vigilance tasks, participants were probed 18 times at random intervals to record their thoughts at the moment they were stopped (*cf.* Plimpton et al., 2015). On completion of the vigilance task, participants were given their thought descriptions and were asked to indicate whether their thoughts referred to past memories or future events. At the end of Session 2, participants were also provided with an unexpected cue-recognition task in which they were given a recognition memory test for cues displayed during the vigilance task. This allowed us to examine the possibility that different levels of cognitive load may interfere with external cue-noticing. Finally, at the end of each laboratory session, we assessed the levels of inhibitory control to ensure that the high and low inhibitory control groups were indeed different in terms of their inhibitory control capacity during the laboratory session.

In relation to assessing inhibitory control in participants, there is an ongoing debate about whether a general (i.e., unitary) response inhibition ability exists because of weak or non-significant correlations between tasks of inhibitory control reported in the literature (e.g., Draheim et al., 2020; Hedge et al., 2018, 2020; Friedman and Miyake, 2017; Rey-Mermet et al., 2018). Another potential issue is the stability and reliability of participants' scores on standard tasks measuring inhibition. While we do not postulate or advocate for the idea that the inhibitory control is a unitary cognitive construct, in the present study we decided to use two standard tasks, which according to previous research (e.g., Friedman & Miyake, 2004; Pettigrew & Martin, 2014; Stahl et al., 2014), relate to different aspects of inhibitory control, namely, the inhibition of the prepotent response (i.e., the Stroop task) and the resistance to distracter interference (i.e., the Flanker task). By combining these two types of tasks we wanted to measure a broadly understood phenomenon of inhibitory control while including its different aspects into a composite score (see also Barzykowski, Hajdas et al., 2021, p. 6). In addition, to ensure the reliability of participants' scores on the Stroop and Flanker tasks, we had participants perform these tasks at the end of each laboratory sessions. Although participants were pre-selected on the basis of their online scores on these tasks, obtaining these additional scores turned out to be useful as described at the beginning of Results section.

Finally, it is important to point out that, in the present study, participants were assigned to discrete groups based on their inhibition scores instead of examining the relationship between participants' inhibition scores and the number of reported involuntary cognitions in the entire online sample. Despite problems associated with the extreme groups design (for discussion see Fisher et al., 2020; Preacher et al., 2005), it has been fairly popular in several areas of cognitive psychology, particularly in research on individual differences in working memory (for a discussion see Conway et al., 2005, pp. 782–783) mainly because it is a cost-effective way of testing whether a given relationship does or does not exist irrespective of the strength of the relationship (Conway et al., 2005; Fisher et al., 2020; Preacher et al., 2005). Moreover, this approach is particularly appropriate in situations where there is little prior empirical research to guide theory development, and/or there are limited resources for testing very large samples (when the expected effect sizes are very small) (see Preacher et al. (2005). Since we wanted to verify whether the frequency of involuntary past and future thoughts depended on the putative inhibitory control mechanism, using discrete groups was the best possible solution for achieving this goal. If previous studies by Barzykowski and colleagues had found significant effects of inhibitory control capacity on the frequency of IAMs and IFTs (Barzykowski et al., 2019; Barzykowski, Hajdas, et al., 2021), the next logical step would have been to use the regression approach and/or linear mixed models treating inhibition scores as a continuous variable to assess the strength of the relationship.

2. Method

2.1. Design

A mixed-subjects design was used in which the level of inhibitory control capacity (low vs. high) was treated as a between-subjects variable and the cognitive load of the vigilance task (low vs. high) as a within-subjects variable. This allowed us to examine the effects of cognitive load and individual inhibitory control capacity in the retrieval of IAMs and IFTs.

2.2. Participants

The study consisted of two phases: an online pre-selection phase (also called the online session) and two laboratory-based experimental sessions (also called the low and high cognitive load conditions) (for an overview of the design, see Fig. 1).

Online pre-selection phase. This was part of a bigger project aimed at pre-selecting a pool of participants based on their individual inhibitory control capacity and is described in detail elsewhere (Barzykowski, Hajdas, et al., 2021, p. 11; Barzykowski, Wereszczyński et al., 2021). Briefly, the final pool consisted of 433 participants who engaged in online versions of two well-known and widely used tasks for assessing inhibition, such as the Stroop task (MacLeod, 1991; Chuderski, Taraday, Nęcka, & Smoleń, 2012) and the Eriksen flanker task (Eriksen & Eriksen, 1974). Based on their scores of these online tasks, participants were divided into three equal sized groups: low inhibitory control capacity (144 participants), medium inhibitory control capacity (144 participants), and high inhibitory control capacity (145 participants). The three groups were significantly different from each other in terms of individual inhibitory control capacity (all $p_s < 0.001$).

Laboratory-based experimental session. A total of 100 participants (26 males, $M_{age} = 24.65$, $SD = 4.53$, range 20–49 years; 14 participants did not indicate their age) were randomly recruited to the study from the online pool of participants who were classed into two groups with high and low inhibitory control capacity. Participants with medium level of inhibitory control capacity were not invited to take part. If an individual did not accept the invitation or was not able to take part, then a new participant was randomly selected (however, this happened very rarely). Therefore, the final sample consisted of 50 participants in the low inhibitory control capacity condition (12 males, $M_{age} = 24.00$, $SD = 2.72$, range 20–36 years; eight participants did not indicate their age) and 50 participants in the high inhibitory control capacity condition (14 males, $M_{age} = 25.28$, $SD = 5.72$, range 21–49 years; six participants did not indicate their age). Due to technical difficulties, two people (one in each group) did not finish the study and were excluded from the analyses, thus, resulting in 49 participants in each group. All participants in the laboratory-based session were compensated 50 PLN (ca. 14 USD) for each session (i.e., ca. a total of 30 USD for two sessions).

To ensure that our study had sufficient power, we performed a priori power analysis with G*POWER 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007). We based our power calculations on the effect size ($\eta_p^2 = 0.03$) obtained by Barzykowski, Niedźwieńska, et al. (2019) in a 3 condition (control, depleted inhibition, intact inhibition) × 2 temporal focus (past, future) mixed ANOVA that resulted in a non-significant main effect of condition. Using this effect size (f = 0.18), a correlation of r = -0.02 between the dependent variables obtained in that study, and assuming the minimum power of 0.80 with an alpha level of 0.05 and four measurements (i.e., IAMs-Low load, IAMs-High load, IFTs- Low load, IFTs-High load), 88 participants were necessary to find a statistically significant effect in the model. Therefore, a sample size of 100, used in the present study, allowed good power to detect small, medium to large size effects (0.18, 0.25 to 0.40).

2.3. Materials

2.3.1. The vigilance task

We used a fully computerized version of the vigilance task with 800 slides (trials), and was very similar to the procedure used by Plimpton et al. (2015) and Barzykowski, Hajdas, et al. (2021) to study IAMs and IFTs under laboratory conditions (adapted from Schlagman & Kvavilashvili, 2008).

The vigilance task involved detecting patterns of vertical lines (fifteen target slides) in a stream of 785 non-target slides with horizontal lines. Slides were presented for 2 s with short cue phrases (e.g., *driving a car*) displayed in the centre of some of the slides. There were equal numbers of neutral (N = 90; e.g., *buying a bread*), positive (N = 90; e.g., *a wonderful smile*) and negative (N = 90; e.g., *unpleasant conversation*) phrases, which constituted the final pool of 270 phrases used in previous studies (e.g., Barzykowski & Niedźwieńska, 2016; Barzykowski & Staugaard, 2016, 2018; Barzykowski, Niedźwieńska, & Mazzoni, 2019). Two sets of different cues were used during the first and second laboratory sessions. Thus, each time participants performed the vigilance task, they were provided with new cues for the first time. The cues were presented in two fixed pseudo-random orders and were counterbalanced across groups and conditions. They occurred at varying intervals consisting of a minimum of 1 (about 2 s) and a maximum of 7 (about 14 s) slides.

The mean interval between the cues was about 3 slides (i.e., 6 s). Similarly to our previous study (Barzykowski & Niedźwieńska, 2018a), a square (approximately 1.5 cm by 1.5 cm) containing a random number (ranging from 1 to 9) was presented on each trial (except the 15 target slides with vertical lines). In slides with no verbal cue, the square was presented in the centre of the screen. If there was a cue on a given slide, the square was presented below it. The number and colour of the square changed randomly with each slide (colours used: black, green, blue, orange).

During the presentation, the program stopped automatically 18 times, and the following message appeared on the screen: "*Please stop and record your concentration and thoughts now*". Participants provided a brief description of the content of their thoughts (by typing it into the computer program); they indicated how much they were concentrating on the task when stopped (1 = *Not at all*; 7 = *Fully concentrating*) and whether the thought occurred deliberately (they decided to think about it) or involuntarily (it simply popped into their mind). These thought probes were presented in a fixed pseudo-random order and occurred at intervals of between 42 (about 84 s) and 50 (about 100 s) slides (the mean was 88.78 s). These intervals between the stops were comparable to similar previous studies (e.g., Barzykowski, Hajdas, et al., 2021; Plimpton et al., 2015).

In summary, the main differences between the present task and Barzykowski, Hajdas, et al.'s (2021) design were as follows: (1) 270

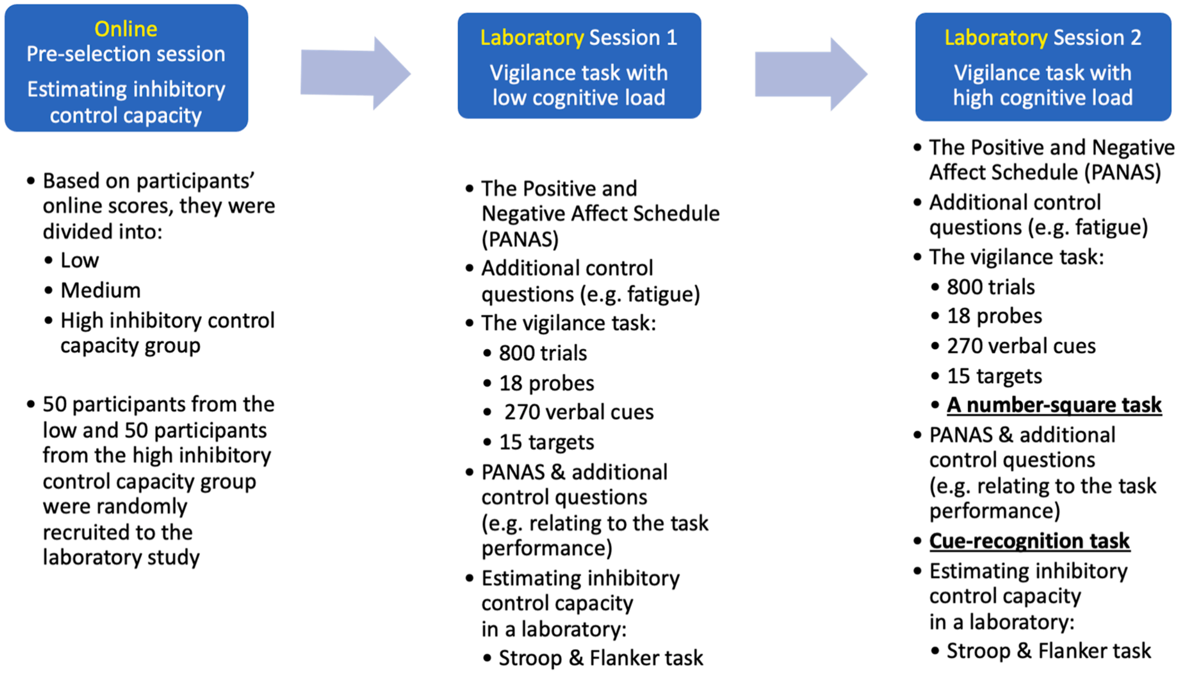

Fig. 1. An overview of the experimental procedure. The two laboratory sessions were identical except for different versions of the vigilance task, which were counterbalanced across participants, and a recognition task that was administered in Session 2 only. Study overview depicts the procedure for participants who completed the low cognitive load vigilance task in Session 1 and high cognitive load vigilance task in Session 2. **Note:** The order of laboratory conditions (i.e., low vs. high cognitive load) was counterbalanced between participants. The average distance between the first and the second laboratory session was 8.08 ± 3.92 days (range = 4 to 30 days; 81% of second sessions took place either on the 6th or 7th day after the first session).

verbal cues (90 positive, 90 neutral and 90 negative) were used instead of 800 cues, but we used all 800 slides;[3] (2) on each trial, a square and a random number were presented either below the verbal cue or in the centre of the screen (on trials without verbal cues) and, important, only participants in the cognitive load condition were instructed to perform a task related to the numbers displayed in the centre of the square.

Equivalence of cues. To assess the comparability of two sets of cues, used in the first and second experimental sessions, all 270 cues in both sets were rated for imagery, concreteness, and typicality on 7-point scales (1 = low to 7 = high) by 10 participants. For each cue, a mean was calculated (based on ratings of 10 participants) for these three dimensions. The mean ratings of 270 cues in each set were entered into three separate t-tests with the cue set as an independent variable and ratings of concreteness, imagery, and typicality as the dependent variable. There were no significant main effects of the cue set used (all $p_s > 0.44$). Therefore, any differences between the two cognitive load (low vs. high) conditions in terms of the number and characteristics of reported thoughts could not be due to different sets of verbal cue phrases used across the sessions.

2.3.2. *The cue-recognition task*

To further verify whether individual inhibitory control capacity and/or the level of cognitive load affected the noticing of word cues that could incidentally trigger IAMs and IFTs, the unexpected cue recognition task was presented to participants at the end of the second laboratory session.[4] Participants were presented with a total of 84 cues, half of which (i.e., 42 cues) were randomly selected from the pool of cues presented during the vigilance task in Session 2. The remaining 42 cues, which were the same for all participants, were presented for the first time and were randomly selected from the rest of the Polish pool of 800 cues. Importantly, there were equal numbers of neutral (N = 14), positive (N = 14) and negative (N = 14) phrases in each set of old and new cue phrases. Cues were

[3] We decided to use less cues for two main reasons. First, given the fact that participants performed the vigilance task twice during the study, we wanted to use different sets of cues across the two study sessions. However, the Polish pool of cues consists of only 800 cues that have been successfully validated in previous studies. Second, similar to previous studies (e.g., Vannucci et al., 2015; 2018), we used an infrequent number of cues, with 270 word cues over 800 slides (i.e., cues were presented on 1/3 of all slides), which should also increase the number of IAMs and IFTs. For example, in Vannucci et al. (2015), participants in the infrequent cue condition (cues were presented on 1/5 of all slides) reported more than twice the number of IAMs that were reported in the frequent cue condition (cues were presented on 2/3 of all slides). Therefore, using fewer cues allowed us to maximize the retrieval of both IAMs and IFTs while optimising the efficacy of the experimental design.

[4] We used the unexpected cue-recognition task only during the second and the last laboratory session to avoid focusing participants on verbal phrases, which would have occurred if the task had been used in the first session.

presented in two fixed pseudo-random orders and were counterbalanced across groups and conditions. Participants responded to each cue, presented on the screen, in a self-paced manner without any time restrictions.

To investigate the comparability of cues used in the cue-recognition task, we used the mean ratings for each phrase as a function of set used (presented in Set 1, Set 2, or not presented at all) and entered them into three separate between-subject ANOVAs with concreteness, imagery, and typicality as dependent variables. There were no significant main effects of the cue set used (all Fs < 1) of the cue-recognition type for any of the characteristics.

2.3.3. Tasks accessing individual differences in inhibitory control capacity

In line with Barzykowski, Hajdas, et al. (2021, p.14), we used the Stroop task (MacLeod, 1991; Chuderski, Taraday, Nęcka, & Smoleń, 2012) and the Eriksen flanker task (Eriksen & Eriksen, 1974) to measure participants' inhibitory control capacity. These tasks were created using Inquisit Web software (Millisecond software) and were used in both the online and laboratory-based sessions. While the Inquisit-web protocol is described in more detail in Barzykowski, Wereszczyński et al. (2021), we briefly describe it below.

The Stroop task consisted of four colour words (red, green, blue, and yellow) in Polish, displayed in one of these four colours (e.g., the word red could be displayed in red, green, blue or yellow). Participants were instructed to judge the colour of the 'ink' of the word as quickly as possible without paying attention to the meaning of the word by pressing a key corresponding to the colour of the ink. While the meaning of the word and the colour of the ink were the same in congruent trials, the meaning differed from the colour of the ink in incongruent trials. In total, there were 140 trials (70 congruent and 70 incongruent). Finally, for the practice trial, we used a short 14-trial version of the Stroop task that consisted of 50% congruent and 50% incongruent trials. The main task lasted up to 10 min.

In the Eriksen flanker task (Eriksen & Eriksen, 1974), participants had to press the arrow keys with either the left or right index finger according to the direction pointed to by the centre target arrow. This target arrow was surrounded by other arrows (flankers) that were to be ignored. In congruent trials, all targets (including flankers) indicated the same response (they pointed in the same direction). In incongruent trials, they indicated opposite directions, with flankers activating a wrong automatic response that was to be ignored and inhibited. In total, there were 140 trial blocks with 70 congruent and 70 incongruent trials. Additionally, before starting the main task, participants completed a practice task with 10 trials. The main flanker task with 140 trials lasted up to 10 min.

The inhibitory control capacity was calculated as the mean interference ratio for the Stroop-like task and the Eriksen flanker task. The standard interference effect is the difference between the mean response times of incongruent and congruent trials divided by the mean response time for congruent trials, which represents the time needed to inhibit the interference while controlling for individual processing speed (Chuderski et al., 2012). It is considered a reliable indicator of the efficacy of cognitive control (e.g., Van Den Wildenberg et al., 2010). Since the lower the interference (interference is resolved more quickly), the stronger the inhibitory capacity, we expected to observe differences between groups with the poorest and the strongest mean interference in the low and the high group, respectively.

2.3.4. The positive and negative affect schedule (PANAS; Brzozowski, 2010)

To test the comparability of participant groups with high and low inhibitory control capacity before and after the vigilance task in terms of participants' mood ratings, we used PANAS (30 items), which measures the strength of negative and positive current emotional states. Participants had to rate on a 5-point scale the extent to which given adjectives corresponded with their current state. The reliability coefficients (internal consistency and stability) of the Polish version of PANAS are high and range from 0.73 to 0.95 (Brzozowski, 2010).

2.4. Procedure

The Research Ethics Committee approved the study. Written consent for participation was obtained prior to data collection. Participants were informed that they were free to withdraw from the study at any point. A general overview of the procedure is presented in Fig. 1.

2.4.1. Online pre-selection session

Participants were recruited to the online pre-selection session via social-media, university advertisements and flyers. They were explicitly informed that, depending on their results in the online session, they might be invited to the main study consisting of two laboratory sessions. Participants were also instructed (a) to complete the online tasks in the environment free of noise and distractions, and (b) to perform the tasks to the best of their abilities. First, participants completed the practice version of the Stroop task, which was followed by the main Stroop task. Then, participants were provided with instructions for the Eriksen flanker task, which was followed by a brief practice task, and the main Eriksen flanker task. In total, the online session lasted for about 30–40 min (see also Barzykowski, Hajdas, et al., 2021; p. 5; and Barzykowski, Wereszczyński et al., 2021).

2.4.2. Laboratory-based experimental session

The order of experimental conditions (i.e., low cognitive load condition vs. high cognitive load condition) was counterbalanced in the low and the high inhibitory control capacity groups. The average distance between the first and second session was 8.08 ± 3.92 days (range $= 4$ to 30 days; 81% of second sessions took place either on the 6th or 7th day after the first session).

Low cognitive load condition (a standard version of the vigilance task). We used the same procedure as the one used in the control condition in the study by Barzykowski, Hajdas, et al. (2021, p. 7). First, participants rated their current level of physical and mental fatigue on 7-point scales (1 referred to not endorsing the item at all, 4 to medium endorsement, and 7 to highly endorsing the item; all points along the scales were clearly and explicitly labelled). Then, participants were verbally informed that the experiment examined how people concentrated on monotonous and boring tasks.

Next, participants were provided with detailed written instructions on how to perform the computerized vigilance task (see Fig. 2 for an overview of the vigilance task procedure). In particular, participants had to identify slides with vertical lines by pressing a red button ("m" on the keyboard). They were also informed that they would see other items on the screen such as word phrases and a square with a number in it, but they did not need to respond to these items, because the condition they were in involved focussing on and responding to line patterns, while participants in another condition had to focus on these items without responding to line patterns. Participants were informed that during the vigilance task they might experience different kinds of task-unrelated thoughts, and they were provided with examples of such thoughts. However, we did not put any particular emphasis on memories and future-oriented thoughts during the briefing. Participants were only informed that thoughts could be diverse (i.e., specific, general) and pertain either to the present, past or future. Importantly, they were assured that these thoughts could be about anything and that they could simply pop into their mind spontaneously or they could deliberately choose to think about them. It was explained that since the study was about people's attention and concentration, the program would occasionally stop, and they would be asked to record their concentration level and the content of their thoughts at the exact moment that the program stopped. Importantly, participants were encouraged to record the content of their thoughts at the exact moment they were stopped, regardless of what it was (see Appendix 1_SM in the Supplementary Materials for the written instructions provided to participants). Before the main vigilance task started, participants filled in the Positive and Negative Affect Schedule (PANAS; Brzozowski, 2010). Each time the program stopped, they were asked to provide a brief description of the content of their thoughts (by typing it into the program), rate their level of concentration (on a 7-point scale), and indicate if the thought occurred deliberately (they decided to think about it) or involuntarily (it simply popped into their mind). They also specified what triggered their thought (1 = *something in the program*, 2 = *something in my mind*, 3 = *something in the surroundings*, 4 = *nothing*).[5]

After completing the vigilance task, participants filled in PANAS and rated their current level of physical and mental fatigue for the second time. They responded also to additional manipulation-check questions by rating on a 7-point scale the extent to which they had been concentrating on the vigilance task (in general), on verbal phrases and on vertical lines, followed by rating the importance of performing the computer task as well as they could, the difficulty of the computer task, and the extent to which it was interesting. Finally, participants rated the extent to which involuntary thoughts and verbal phrases were experienced as interfering, and how much they suppressed involuntary thoughts or ignored verbal phrases during the vigilance task.

After completing these ratings, participants were provided with brief verbal instructions describing the nature of autobiographical memory (as, for example, in Schlagman, Kliegel, Schulz, & Kvavilashvili, 2009, p. 410) and future thoughts. Participants reviewed all the thoughts they had recorded during the vigilance task. They did this one at a time and in the same order as they had been recorded; they were instructed to decide whether each thought was an autobiographical memory, future-oriented thought, thought relating to the current situation or other type of thought by clicking the appropriately labelled button and described each entry in more detail. Once all the mental contents were reviewed, participants who were completing this standard (low cognitive load) vigilance task in the second session, received an unexpected cue-recognition task. It was explained to participants that they would be provided with verbal phrases and instructed to decide (Yes/No) whether each phrase had been presented to them during the vigilance task.

Once the task was finished, participants performed the Stroop task and the Eriksen flanker task in the same way as during the online session. Thus, we were able to obtain additional measures of individual inhibitory control capacity under well-controlled experimental conditions.

High cognitive load condition (vigilance task + a number-square task). This was the same as in a previous study (Study 2, Barzykowski & Niedźwieńska, 2018a; p. 125). More specifically, the only difference between the high and low cognitive load conditions was that participants were asked to perform a parallel cognitively demanding task. Every time the square in the centre of the screen turned green, participants had to decide whether the number in the centre of the green square was equal to the number of blue lines (range: 2–8) displayed on the screen. They pressed a green button for YES ("z" on the keyboard) or a black button for NO ("c"). One of the three hundred and sixty critical (target) trials appeared approximately every 4 s (i.e., approximately every 2 cards) and featured equal numbers of YES and NO trials.

3. Results

For all statistical analyses reported below, the level of significance was set at $p < .05$, and the effect size was measured by partial eta-squared (η_p^2). Before presenting the main findings on the number of IAMs and IFTs reported by participants as a function of their inhibitory control capacity and cognitive load of the vigilance task, we first describe findings in relation to participants' performance on inhibition tasks in the laboratory, followed by analyses comparing groups with low and high inhibitory control capacity for their ratings of several cognitive and emotion variables obtained before, during and after the vigilance task.

3.1. *Manipulation checks for inhibitory control capacity across the groups*

To ensure the reliability of online classification of participants into high and low inhibitory control groups, which took place several

[5] This question was used mainly for exploratory purposes and the results from this additional question will not be reported here.

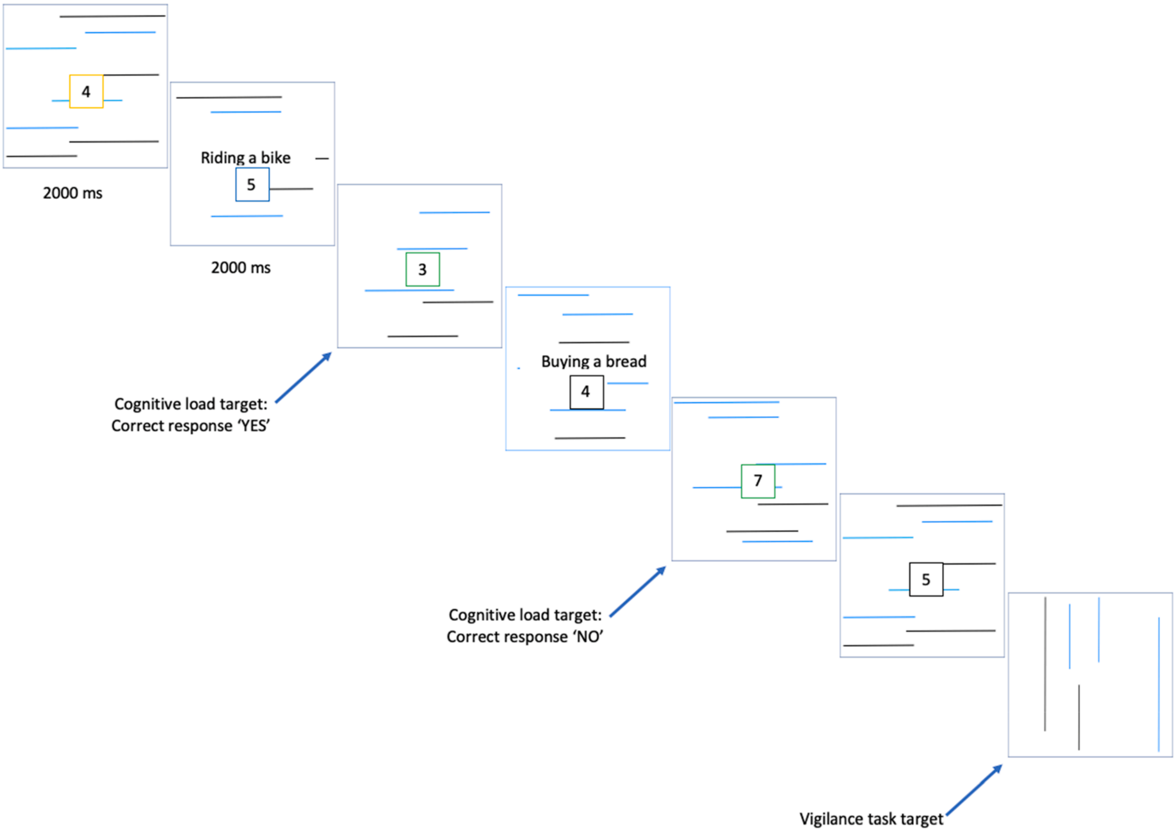

Fig. 2. An overview of the vigilance task procedure.

months before the laboratory-based study ($M = 13.88$ months, $SD = 0.96$; range 11–16 months), participants performed the inhibitory tasks again at the end of both laboratory sessions. This allowed us to compute the mean interference ratio for each participant by averaging their z-scores for the Stroop-like and the Eriksen flanker tasks across the two testing sessions. This composite score should be more reliable than the score obtained in a single online session with no control over participants' performance. Based on this new composite score of inhibitory control, participants were divided into two equally sized groups with the highest and the lowest z-transformed interference ratios. As a result, a sub-sample of participants changed their group membership (*cf.* Barzykowski, Hajdas et al., 2021, p. 8), with 15 participants who were originally in the low inhibitory control group and 15 participants who were in the high inhibitory control group being re-categorized into the high (N = 49) the low (N = 49) inhibitory control groups, respectively.[6]

The expected differences between these two newly created groups were verified by entering participants' mean interference scores (averaged across the Stroop and the Flanker task) (see Table 1) into a 2 inhibitory control (low vs. high) by 2 cognitive load (low vs. high) mixed ANOVA with repeated measures on the second factor.[7] While neither the main effect of cognitive load nor the group by cognitive load interaction were significant ($F < 1$), the main effect of group was significant with a very large effect size ($F(1, 96) = 131.23$, $p < 0.001$, $\eta_p^2 = 0.58$). As expected, participants in the low inhibitory control group were worse at inhibiting ($M = 0.14$, $SD = 0.04$) than those in the high inhibitory control group ($M = 0.07$, $SD = 0.02$).

3.2. Equivalence of experimental groups before, during and after the vigilance task

Table 1 shows the mean ratings of various cognitive and non-cognitive variables provided by participants before, during or after the

[6] Schuch et al. (2021, p. 24) suggested that Stroop-like effects may be "*well suited for assessing group-level effects of cognitive control*" but less "*suitable for reliably assessing interindividual differences*". This may be reflected by a discrepancy between measuring the inhibitory control at the group vs. interindividual level. Due to this discrepancy (i.e. low intraindividual stability), it was necessary to re-classify participants while ensuring sufficient group-level differences in inhibitory control.

[7] When dividing participants into groups, we used z-transformed ratios since we wanted to order participants alongside the strongest-poorest inhibitory control capacity dimension. However, when looking at the differences between groups in terms of the inhibitory control capacity, we used as a dependent variable the mean of interference ratio in the Stroop task and the Flanker Eriksen task that was not z-transformed because we were interested in the nominal not relative interference value.

Table 1
Means (standard deviations) for variables measuring mood, fatigue, concentration, motivation, and performance on the vigilance task as a function of individual inhibitory control capacity (low vs. high) and cognitive load condition (low vs. high), and the results of 2 (inhibitory control) × 2 (cognitive load) mixed ANOVAs with repeated measures on the last factor on these measures as dependent variables.

	Inhibitory Control Capacity						
	Participants with **low** inhibitory control capacity (N = 49)		Participants with **high** inhibitory control capacity (N = 49)				
	Cognitive Load of Vigilance Task						
	Low	High	Low	High	Effects of inhibitory control capacity (low vs. high) *Test:* $F(1,94)$	Effects of cognitive load (low vs. high)	Interaction
	M *(SD)*	*M* *(SD)*	*M* *(SD)*	*M* *(SD)*			
Individual inhibitory control capacity differences							
General inhibitory control capacity index (laboratory-based)	0.14 (0.06)	0.14 (0.05)	0.08 (0.03)	0.07 (0.03)	$F^1 = 131.23^*$ $p = .01, \eta_p^2 = 0.58$	$F < 1$ $p = .54, \eta_p^2 = 0.01,$	$F < 1$ $p = .48, \eta_p^2 = 0.01$
Mood before vigilance task							
PANAS: Positive affect	35.04 (12.86)	37.63 (14.43)	37.19 (12.73)	35.31 (11.49)	$F < 1$ $p = .97, \eta_p^2 = 0.01$	$F < 1$ $p = .79, \eta_p^2 = 0.01$	$F = 2.81$ $p = .10, \eta_p^2 = 0.03$
PANAS: Negative affect	20.83 (7.68)	20.83 (7.25)	19.35 (6.35)	19.25 (5.78)	$F = 1.65$ $p = .20, \eta_p^2 = 0.01$	$F < 1$ $p = .94, \eta_p^2 = 0.01$	$F < 1$ $p = .94, \eta_p^2 = 0.01$
Physical fatigue	3.23 (1.53)	3.29 (1.65)	3.50 (1.58)	3.40 (1.67)	$F < 1$ $p = .70, \eta 2 = 0.01$	$F < 1$ $p = .88, \eta_p^2 = 0.01$	$F < 1$ $p = .50, \eta_p^2 = 0.01$
Mental fatigue	3.89 (1.48)	3.89 (1.52)	3.98 (1.54)	3.96 (1.66)	$F < 1$ $p = .67, \eta_p^2 = 0.01$	$F < 1$ $p = .77, \eta_p^2 = 0.01$	$F < 1$ $p = .84, \eta_p^2 = 0.01$
Mood after vigilance task							
PANAS: Positive affect	32.73 (14.41)	31.04 (11.43)	34.48 (14.08)	35.65 (13.60)	$F = 1.65$ $p = .20, \eta_p^2 = 0.01$	$F < 1$ $p = .83, \eta_p^2 = 0.01$	$F = 1.45$ $p = .23, \eta_p^2 = 0.02$
PANAS: Negative affect	20.17 (6.50)	18.63 (4.57)	18.29 (5.07)	18.35 (5.29)	$F = 1.23$ $p = .27, \eta_p^2 = 0.01$	$F = 1.93$ $p = .17, \eta_p^2 = 0.02$	$F = 2.27$ $p = .14, \eta_p^2 = 0.02$
Physical fatigue	3.15 (1.50)	3.60 (1.67)	3.56 (1.61)	3.48 (1.61)	$F < 1$ $p = .49, \eta_p^2 = 0.01$	$F < 1$ $p = .82, \eta_p^2 = 0.01$	$F = 1.34$ $p = .25, \eta_p^2 = 0.01$
Mental fatigue	3.87 (1.31)	4.36 (1.21)	4.29 (1.62)	4.23 (1.72)	$F < 1$ $p = .46, \eta_p^2 = 0.01$	$F < 1$ $p = .71, \eta_p^2 = 0.01$	$F < 1$ $p = .61, \eta_p^2 = 0.01$
Performance on vigilance task (self-reporting)							
Concentration on the task	4.27 (1.28)	4.96 (1.17)	4.06 (1.55)	5.13 (1.10)	$F < 1$ $p = .93, \eta_p^2 = 0.01$	$F = 41.34^*$ $p = .01, \eta_p^2 = 0.31$	$F = 1.90$ $p = .17, \eta_p^2 = 0.02$
Concentration on vertical lines	4.90 (1.42)	4.50 (1.86)	4.88 (1.72)	4.46 (1.84)	$F < 1$ $p = .92, \eta_p^2 = 0.01$	$F = 4.42^*$ $p = .04, \eta_p^2 = 0.04$	$F < 1$ $p = .96, \eta_p^2 = 0.01$
Concentration on phrases	3.88 (1.54)	3.48 (1.61)	3.54 (1.25)	3.56 (1.51)	$F < 1$ $p = .61, \eta_p^2 = 0.01$	$F = 1.04$ $p = .31, \eta_p^2 = 0.01$	$F = 1.29$ $p = .26, \eta_p^2 = 0.01$
Importance of performing the task well	5.33 (1.14)	5.54 (0.85)	5.27 (1.40)	5.77 (1.13)	$F < 1$ $p = .68, \eta_p^2 = 0.01$	$F = 8.85^*$ $p = .01, \eta_p^2 = 0.09$	$F = 1.50$ $p = .22, \eta_p^2 = 0.02$
Perceived task difficulty	2.50 (1.17)	3.21 (1.18)	2.27 (1.28)	3.40 (1.25)	$F < 1$ $p = .91, \eta_p^2 = 0.01$	$F = 26.78^*$ $p = .01, \eta_p^2 = 0.22$	$F = 1.38$ $p = .24, \eta_p^2 = 0.01$
How interesting was the task	3.10 (1.24)	3.37 (1.10)	2.88 (1.41)	3.33 (1.40)	$F < 1$ $p = .55, \eta_p^2 = 0.01$	$F = 7.43^*$ $p = .01, \eta_p^2 = 0.07$	$F < 1$ $p = .49, \eta_p^2 = 0.01$

	Inhibitory Control Capacity	
	Participants with **low**	Participants with **high**

(*continued on next page*)

Table 1 (*continued*)

	Inhibitory Control Capacity						
	inhibitory control capacity (N = 49)		inhibitory control capacity (N = 49)				
	Cognitive Load of Vigilance Task						
	Low	High	Low	High	Effects of inhibitory control capacity (low vs. high)	Effects of cognitive load (low vs. high)	Interaction
	M *(SD)*	*M* *(SD)*	*M* *(SD)*	*M* *(SD)*	*Test*		
Performance on vigilance task (self-reporting): $F(1, 94)$							
How much did involuntary thoughts interfere with the vigilance task	2.75 (1.45)	3.33 (1.45)	2.60 (1.58)	2.94 (1.28)	$F = 1.20$	$F = 8.23$*	$F < 1$
					$p = .28$, $\eta2 = 0.01$	$p = .01$, $\eta2 = 0.08$	$p = .44$, $\eta2 = 0.01$
How much did verbal phrases	2.17 (1.43)	2.40 (1.41)	2.02 (1.31)	2.52 (1.54)	$F < 1$	$F = 5.59$*	$F < 1$
interfere with the vigilance task					$p = .97$, $\eta2 = 0.01$	$p = .02$, $\eta2 = 0.01$	$p = .38$, $\eta2 = 0.01$
How much were involuntary thoughts being suppressed	2.81 (1.86)	3.04 (1.75)	2.81 (1.47)	3.15 (1.58)	$F < 1$	$F = 3.62$*	$F < 1$
					$p = .87$, $\eta2 = 0.01$	$p = .06$, $\eta2 = 0.04$	$p = .73$, $\eta2 = 0.01$
How much were verbal phrases ignored	2.90 (1.64)	3.29 (1.73)	3.84 (1.88)	3.40 (1.81)	$F = 2.87$	$F < 1$	$F = 4.88$*
					$p = .09$, $\eta2 = 0.03$	$p = .91$, $\eta2 = 0.01$	$p = .03$, $\eta2 = 0.05$
Performance on vigilance task (objective indicators): $F(1, 96)$							
Proportion of targets detected	0.92 (0.12)	0.88 (0.17)	0.90 (0.18)	0.92 (0.08)	$F < 1$	$F < 1$	$F = 2.91$
					$p = .58$, $\eta2 = 0.01$	$p = .63$, $\eta2 = 0.01$	$p = .09$, $\eta2 = 0.03$
Correct response reaction time (in sec.) to vigilance task targets	0.76 (0.17)	0.88 (0.17)	0.71 (0.17)	0.87 (0.19)	$F = 1.20$	$F = 58.10$*	$F = 1.65$
					$p = .28$, $\eta2 = 0.01$	$p = .01$, $\eta2 = 0.38$	$p = .20$, $\eta2 = 0.02$
Concentration rating	3.51 (1.47)	4.41 (0.98)	3.28 (1.53)	4.50 (1.12)	$F < 1$	$F = 69.47$*	$F = 1.62$
					$p = .76$, $\eta2 = 0.01$	$p = .01$, $\eta2 = 0.42$	$p = .21$, $\eta2 = 0.02$
Proportion of right decisions		0.84 (0.13)		0.86 (0.09)	$t(96) = 1.1$, $p = .29$, $d = 0.18$		
Correct decision response time		1.11 (0.12)		1.10 (0.11)	$t(96) = 0.30$, $p = .80$, $d = 0.09$		
Successful cue-recognition	0.65 (0.09)	0.60 (0.05)	0.64 (0.10)	0.59 (0.06)	$F < 1$	$F^1 = 11.26$*	$F < 1$
					$p = .39$, $\eta2 = 0.01$	$p = .01$, $\eta2 = 0.11$	$p = .87$, $\eta2 = 0.01$

Note. * $p < .050$; * $p = .060$; All questions except PANAS were rated on 7-point scales (1 = low to 7 = high). The mean inhibitory control capacity index was the mean of the interference effects (measured by subtracting the reaction times of incongruent and congruent trials, divided by the mean response time for congruent trials) in the Stoop task and the Eriksen flanker task performed in the laboratory. The stronger the cognitive inhibitory capacity, the lower the index (i.e., the faster an individual responded to incongruent trials). [1]$F(1, 96)$.

vigilance task and the results of 2 inhibitory control capacity (low vs. high) by 2 cognitive load (low vs. high load) mixed ANOVAs with repeated measures on the second factor. Results of these ANOVAs showed that the main effect of inhibitory control capacity was not significant and it did not interact with the cognitive load variable, suggesting that any possible differences between high and low inhibitory control capacity groups in the frequency of involuntary past and future thoughts could not be due to group differences in the ratings of mood, concentration, motivation and fatigue, or the way participants interacted with the vigilance task and its stimuli. It is interesting, however, that significant main effects of cognitive load were obtained for several variables showing that the cognitively demanding version of the vigilance task was rated as more difficult, concentration demanding and engaging, and thoughts accompanying this condition were also perceived as more interfering.

Finally, to control for possible differences in the duration of the experiment, the overall durations of the laboratory session in minutes were entered into a 2 inhibitory control capacity (low vs. high) by 2 cognitive load (low vs. high load) mixed ANOVAs with repeated measures on the second factor. The groups did not significantly differ from each other in this regard (all $F_s < 3.47, p_s < 0.065$).

3.3. Performance on the vigilance task

All participants successfully completed the vigilance task. The results are presented in Table 1. There were no significant differences between the inhibitory control capacity groups in terms of the proportion of targets detected. However, we observed the main effect of cognitive load condition for response times to targets and reported levels of concentration. In particular, participants in the high cognitive load condition were more focused on the task and responded more slowly than in the low cognitive load condition, which might have reflected engagement in the additional parallel task. Finally, we did not observe any differences between the high and the low inhibitory control capacity groups in terms of performance on the additional number-square task both for the proportions of targets detected ($p = 0.29$) and response times ($p = 0.80$).

3.4. Frequency and type of recorded thoughts

All recorded thoughts were independently coded by the first and second author as either task-related or task-unrelated (*cf.* Plimpton et al., 2015; Smallwood et al., 2003; Smallwood, Obonsawin, & Reid, 2003). Out of all 3,316 valid thoughts, 2,252 (68%) were coded as task-unrelated thoughts (e.g., *riding a bike*), while 198 (6%) and 866 (26%) were classed as task-related (*don't forget to push the button*) or task-related interference thoughts (*this is so boring, I am tired*), respectively, and were removed from further analysis. The agreement between the raters was 95%. Disagreements were solved by discussion. Out of 2,252 task-unrelated thoughts, 310 (14%) were classed by participants as occurring deliberately rather than involuntarily, and were excluded from further analyses, resulting in 1,942 (86%) spontaneous task-unrelated thoughts (*cf.* Plimpton et al., 2015).

To examine the effects of inhibitory control capacity and cognitive load on the total number of involuntary task-unrelated thoughts (ITUTs) reported during the vigilance task, the number of these thoughts was entered into a 2 inhibitory control capacity (low vs. high) by 2 cognitive load (low vs. high) mixed ANOVA with repeated measures on the last factor (see Table 2). Neither the main effects of inhibitory control capacity nor the inhibitory control by cognitive load interaction were significant ($Fs < 1$). However, the main effect of cognitive load was significant with more ITUTs reported in the low ($M = 10.63$, $SD = 0.43$) than in the high cognitive load condition ($M = 9.18$, $SD = 0.43$).

3.5. Temporal focus of thoughts

After completing the vigilance task, participants were asked to decide whether each reported thought was a memory of a past event, a future-oriented thought, or something else. Because participants could not change their response if they made an error when choosing a response option (e.g., pressed a 'future thought' option for '*the first time I kissed a girl*'), all 1942 thought descriptions were also coded independently by the first and the second author (for a similar procedure see Barzykowski & Niedźwieńska 2018a, p. 123; Barzykowski et al. 2019, p. 676; Barzykowski, Hajdas et al., 2021). The aim of this coding was to ensure that all past and future thoughts were coded by participants as IAMs and IFTs, and that all thoughts coded by participants as 'current thoughts' or 'other' did not actually refer to past or future. This additional coding resulted in 241 entries being re-coded by coders, which represented 12% of all involuntary TUTs provided by participants. These re-evaluated entries (e.g., '*the first time I kissed a girl' being re-coded by judges as a past memory*) were only included in the analysis if there was 100% agreement between the judges.

The number of IAMs and IFTs was then entered into two separate mixed factorial ANOVAs with inhibitory control capacity (low vs. high) as between subjects variable and cognitive load (low vs. high) as a within subjects factor (for means, see Table 2). Only the main effect of cognitive load condition on the number of IAMs was significant (see Table 2): more memories were reported in the low cognitive load than in the high cognitive load condition.[8]

For the sake of completeness, we repeated the analyses on the number of IAMs and IFTs on a sub-sample of participants whose laboratory inhibition scores were consistent with their online scores in terms of them being assigned to the low ($n = 34$) and the high ($n = 34$) inhibitory control capacity groups. The main effect of cognitive load condition for IAMs was again significant, with more IAMs in the low than in the high cognitive load condition ($F(1, 65) = 6.48$, $p = .013$, $\eta_p^2 = 0.09$), while neither the main effect of inhibitory control capacity nor the capacity by cognitive load interaction were significant ($Fs < 1.92$, $ps > 0.171$). At the same time, no significant effects were obtained for IFTs ($Fs < 1.63$, $ps > 0.21$).

3.6. Cue-recognition ratio across participants and conditions

Finally, we analysed cue recognition-ratios by entering them into 2 inhibitory control (low vs. high) $\times$ 2 cognitive load (low vs. high) $\times$ 3 cue type (positive, neutral, negative) mixed ANOVA with repeated measures on the last factor. Because participants

[8] We also conducted 2 inhibitory control capacity (low, high) by 2 cognitive load (low, high) by 2 thought type (past thoughts, future thoughts) mixed ANOVA with repeated measure on the last two factors. This analysis resulted in a significant main effect of cognitive load ($F(1, 95) = 10.37$, $p = 0.002$, $\eta_p^2 = 0.10$) with more involuntary thoughts reported in the low cognitive load than high cognitive load condition. At the same time, the main effects of the thought type and the cognitive load by thought type interaction were close to statistical significance, $F(1, 95) = 2.89$, $p = 0.093$, $\eta_p^2 = 0.03$, and $F(1, 95) = 3.64$, $p = 0.059$, $\eta_p^2 = 0.04$, respectively. Specifically, there was a tendency towards higher frequency of memories than future thoughts, which replicates findings by Plimpton et al. (2015) and Barzykowski, Hajdas et al. (2021). In addition, the interaction showed that effect of load mainly influenced the number of IAMs leaving the number of IFTs constant across cognitive load conditions.

Table 2
Means (standard deviations) for the number of involuntary task-unrelated thoughts, involuntary autobiographical memories and future-oriented thoughts as a function of inhibitory control capacity (low vs. high) and cognitive load of the vigilance task (low vs. high), and the results of 2 (inhibitory control) × 2 (cognitive load) mixed ANOVAs with repeated measures on the last factor on these measures as dependent variables.

	Inhibitory Control Capacity						
	Participants with **low** inhibitory control capacity (N = 49)		Participants with **high** inhibitory control capacity (N = 49)				
	Cognitive Load of Vigilance Task						
	Low	High	Low	High	Effects of inhibitory control capacity (low vs. high)	Effects of cognitive load (low vs. high)	Interaction
	M *(SD)*	*M* *(SD)*	*M* *(SD)*	*M* *(SD)*	*Test:* $F(1, 95)$		
Involuntary task-unrelated thoughts	10.80 (4.67)	9.51 (4.27)	10.47 (3.79)	8.86 (4.18)	$F < 1$ $p = .53$, $\eta 2 = 0.01$	$F^1 = 15.76^*$ $p = .01$, $\eta 2 = 0.14$	$F < 1$ $p = .66$, $\eta 2 = 0.01$
Involuntary autobiographical memories	3.82 (3.35)	3.22 (2.40)	4.31 (2.23)	3.02 (2.41)	$F < 1$ $p = .75$, $\eta 2 = 0.01$	$F = 11.51^*$ $p = .01$, $\eta 2 = 0.11$	$F = 1.59$ $p = .21$, $\eta 2 = 0.02$
Involuntary future-oriented thoughts	3.16 (2.92)	2.92 (2.29)	3.04 (2.69)	3.15 (2.99)	$F < 1$ $p = .91$, $\eta 2 = 0.01$	$F < 1$ $p = .80$, $\eta 2 = 0.01$	$F < 1$ $p = .53$, $\eta 2 = 0.01$

Note. * $p < .05$; [1]$F(1, 96)$.

completed the cue-recognition task only during the second laboratory session, the cognitive load was a between subjects variable. The analysis revealed a significant main effect of condition (with a higher recognition ratio in the low than in the high cognitive load condition, $F(1, 94) = 11.82$, $p < 0.001$, $\eta_p^2 = 0.11$). The main effect of cue type was also significant, $F(2, 188) = 28.93$, $p < 0.001$, $\eta_p^2 = 0.24$. Post hoc tests revealed that significantly fewer neutral cues ($M = 0.35$; $SD = 0.02$) were recognised than positive cues ($M = 0.49$; $SD = 0.02$) ($p = 0.001$) and negative cues ($M = 0.48$; $SD = 0.02$) ($p = 0.001$), which did not differ from each other ($p = 0.86$) (see Table 1 for means as a function of inhibitory capacity and cognitive load conditions). None of the other main and interaction effects were significant ($Fs < 1.26$, $ps > 0.26$).

It is also interesting that the recognition ratio was positively and significantly correlated with the number of IAMs ($r(97) = 0.32$, p $= 0.001$), but not IFTs ($p = 0.41$), indicating that participants who recognised more cues correctly (presumably because they were noticed during the vigilance task) were also reporting higher number of IAMs than participants who recognised fewer cues presented in the vigilance task.

4. Discussion

In the present study, we examined possible mechanisms of involuntary past- and future-oriented thoughts by studying the effects of inhibition and cognitive load on the number of reported IAMs and IFTs. We selected individuals with high or low inhibitory control capacity and asked them to perform easy (low cognitive load condition) and cognitively demanding (high cognitive load condition) versions of the vigilance task. It was expected that if the inhibitory control mechanism switched on only during cognitively demanding activities, as suggested by Barzykowski and colleagues (Barzykowski et al, 2019, Barzykowski, Hajdas, et al., 2021), then individuals with low levels of inhibitory control would report more IAMs and IFTs in the ongoing task with high cognitive load than participants with high inhibitory control capacity. In addition, we also expected that if cognitive load impairs the noticing of incidental cues, the recognition of such cues should be worse in the high cognitive load than in the low cognitive load condition.

Contrary to predictions, but in line with previous studies by Barzykowski et al. (2019), and Barzykowski, Hajdas, et al.(2021), our results did not demonstrate any significant effects of inhibitory control capacity on the number of spontaneous task-unrelated thoughts in general, and the number of reported IFTs and IAMs, in particular. In other words, although participants in the two inhibitory control capacity groups differed significantly from each other in terms of their inhibitory control capacity (high vs. low), we did not observe any differences across the groups in the number of spontaneous thoughts in either the standard or cognitively demanding vigilance task conditions (low vs. high cognitive load conditions, respectively).

By contrast, a significant and interesting pattern of findings emerged for the manipulation of cognitive load. In line with previous studies (e.g., Barzykowski & Niedźwieńska, 2018a; Mazzoni, 2019; Vannucci et al., 2015), participants were generally more likely to report spontaneous task-unrelated thoughts in the low than the high cognitive load condition. However, results also showed that while this effect of cognitive load was present for past-oriented thoughts (i.e., IAMs), the number of future-oriented thoughts was stable across the two cognitive load conditions. Finally, as expected, irrelevant cues presented in the low cognitive load condition were recognized significantly better than cues presented in the high cognitive load condition (0.65 and 0.59, respectively).

Below, we will first discuss the implications that these findings have for our understanding of the nature and underlying mechanisms of IAMs and IFTs, and then discuss possible limitations of the study as well as avenues for future research.

4.1. Theoretical implications

The overriding goal of the present paper was to study the cognitive processes and mechanisms involved in the occurrence of IAMs and IFTs while being engaged in (focal) ongoing tasks. Previous research on the frequency of IAMs and IFTs in everyday life has demonstrated that they often occur in response to incidental external and internal cues, and when individuals are engaged in automatic daily activities with low attentional demands (e.g., Berntsen & Jacobsen, 2008; Finnbogadóttir & Berntsen, 2013). As a result, cognitive psychologists have been asking important general questions, such as “why are we not constantly flooded by these thoughts in daily life?”, or “what keeps these spontaneous mental occurrences at bay and enables us to carry on with our daily activities uninterrupted?” (e.g., Ball, 2007; Barzykowski & Niedźwieńska, 2018a, Barzykowski et al., 2019, 2021, Mazzoni, 2019; Vannucci et al., 2015, 2019).

The research that has tried to address these interesting questions has primarily focussed on two main approaches which were not necessarily mutually exclusive. The research testing the cognitive load dependency hypothesis, examined mainly how the occurrence of IAMs and IFTs depended on the extent of cognitive resources needed to carry out various ongoing (vigilance) tasks (e.g., Barzykowski & Niedźwieńska, 2018a; Mazzoni, 2019; Vannucci et al., 2015, 2019). By contrast, research on the cognitive inhibition dependency hypothesis (e.g., Barzykowski et al., 2019, 2021) was motivated by theory-driven explanations related to the special inhibitory control mechanism in the recall of IAMs and task-unrelated thoughts (e.g., Conway and Pleydell-Pearce, 2000; Conway, 2008, 2009; Conway & Jobson, 2012; Hasher, Lustig, & Zacks, 2007; Hasher, Zacks, & May 1999). The novel aspect of the present study is that we tested the cognitive inhibition hypothesis while manipulating the levels of attentional task demands, which resulted in several theoretically important findings about the mechanisms of IAMs and IFTs.

4.1.1. The role of inhibitory control in the retrieval of involuntary thoughts

In relation to the cognitive inhibition hypothesis, the present study is the third in a series of studies by Barzykowski and colleagues (Barzykowski et al., 2019; Barzykowski, Hajdas et al., 2021) designed to assess the relationship between the cognitive control mechanism and the retrieval of IAMs and IFTs. Contrary to the inhibition dependency hypothesis, but in line with the previous two studies, the findings did not provide any support for the existence of a ubiquitous control mechanism that protects us from experiencing a constant stream of task irrelevant thoughts in response to incidental environmental cues. All the null effects that were consistently observed using different pools of participants and different approaches such as experimental manipulation of the inhibitory control capacity (Barzykowski et al., 2019), individual differences approach (Barzykowski, Hadjas et al., 2021), or a combination of these two, as was the case in the present study, lead us unambiguously to a single outcome in relation to this important theoretical question. In particular, findings appear to suggest that the retrieval of IAMs and IFTs has nothing exclusively to do with inhibition. In a broader sense, this also suggests that the putative suppression mechanism that we discussed in the present paper – if it exists – seems not to be switched on all the time, but might only be switched on intermittently, similarly to proactive and retroactive cognitive control (for a review, see Braver, 2012). However, there is still a need to find the circumstances in which such a mechanism may be observed.

One possible alternative explanation that has not yet been explored is that the IAMs and IFTs studied in previous research were not activated strongly enough to break down the inhibitory control, thus they were easily inhibited by participants even with poor inhibitory control (e.g., in the present study and in Barzykowski, Hajdas et al., 2021) and in depleted inhibition conditions (Barzykowski et al., 2019). In line with this reasoning, one may argue that if inhibitory control did matter – even if in a rather limited and narrow sub-class of circumstances – then it should predominantly matter in relation to intrusive memories and thoughts. As suggested by Kvavilashvili (2014), intrusive memories and flashbacks should be treated as a separate sub-category of involuntarily retrieved autobiographical memories (but see Berntsen & Nielsen, 2021). Briefly, Kvavilashvili (2014) proposed a continuum with IAMs and trauma re-experiencing in the form of flashbacks at opposite poles and intrusive memories in the middle. While all these memories are spontaneously retrieved, they may also be treated as different from each other. For instance, IAMs can be positive, negative or neutral, and they cause no or minimal avoidance, disruption, and distress; intrusive memories, which are typical for normal and clinical populations, can be positive or negative and cause moderate to high or very high avoidance, disruption, and distress; flashbacks, which are restricted to the PTSD population only, can only be negative and cause high to extreme avoidance, disruption and distress. As a result, while inhibitory control may not underlie the occurrence of typical examples of IAMs and IFTs, it still may be important for retrieval in the case of extreme levels of activation. Thus, although cognitive inhibitory control was impaired (or at least functioned inefficiently) in the present and previous studies, it might still work efficiently enough to keep these typical and not very highly intrusive spontaneous thoughts at bay. However, it may still be possible that extremely intrusive and highly activated memories break down cognitive control, and only strong and efficient inhibitory control could limit their frequency. Clearly, this may be an important avenue for future research, especially with clinical samples. Finally, it may be possible that inhibitory control is more oriented towards the content of IAMs and IFTs rather than their occurrence *per se*. Thus, future studies could also manipulate and/or analyse the consistency of the content of IAMs and IFTs with current self-goals (e.g., task requirements, current concerns, e.g., Cole & Berntsen, 2016; Krans, 2013) to verify the idea that only IAMs and IFTs that are consistent with and/or reflect people’s goals may indeed get through this inhibitory control mechanism and reach awareness (Conway & Playdel-Pearce, 2000).

Taken together, it appears that several variables may actually influence the occurrence of IFTs and IAMs in addition to, or instead of, the putative inhibitory control mechanism. The results of the studies, conducted so far, show that the role of the inhibitory mechanism is perhaps not as strong as suggested by the inhibitory control dependency hypothesis, and there may be other cognitive mechanisms that underlie retrieval of IAMs and IFTs (see for example, Barzykowski & Mazzoni, 2022; Barzykowski & Staugaard, 2016, 2018; Barzykowski, Staugaard, & Mazzoni, 2021; Barzykowski and Niedźwieńska, 2018b; Barzykowski, Niedźwieńska, & Mazzoni, 2019).

4.1.2. The role of cognitive load on the retrieval of involuntary thoughts

In relation to the cognitive load dependency hypothesis of involuntary thoughts (e.g., Barzykowski & Niedźwieńska, 2018a; Mazzoni, 2019; Vannucci et al., 2015, 2019), our results replicated and extended those observed in some of the previous studies by showing that the higher frequency of both involuntary task-unrelated thoughts in general (ITUTs) and IAMs, in particular, was reported in the low than in the high cognitive load condition. Overall, our findings clearly show that the frequency of IAMs decreases as cognitive load increases. Therefore, the next important question relates to the possible mechanism(s) involved in cognitive load dependency of IAMs. While there may be several possible effects of cognitive load on the frequency of IAMs as discussed in the introduction (for a comprehensive review, see also Barzykowski & Niedźwieńska, 2018a; Mazzoni, 2019; Vannucci et al., 2015, 2019), our findings most directly corroborate the possibility suggested by Kvavilashvili and Mandler (2004) that the focused attention simply hampers the likelihood of noticing and (most likely) processing cues that act as potential triggers for IAMs and IFTs. Thus, the related idea is that cognitive load taxes not the retrieval of IAMs *per se,* but the extent to which an individual can attend to and/or process cues that may incidentally trigger IAMs. The present study provides strong initial support for this idea. Thus, participants were better at recognizing cues presented during the vigilance task in the low than in the high cognitive load condition (see Table 2). Although participants were not instructed to pay any special attention to irrelevant cues on the screen, the extent to which they were able to recognize a cue as presented or not presented during the vigilance task may be interpreted as an indirect measure of the level of cue-noticing. Thus, higher scores on the cue recognition task may be indicative of participants having been able to notice and/or process more incidental cues during the standard (easy) version of the vigilance task. In addition, participants with a higher cue recognition-ratio tended to report more IAMs during the thought probes, independently of the load condition. Interestingly, neutral cues were least well recognised, which may suggest that they were less likely to attract participants' attention compared to positive and negative cues. This novel finding may therefore explain the underlying mechanisms of cognitive load dependency of IAMs by suggesting that the effect of cognitive load may be more related to cue-noticing than cognitive resources *per se*.

The reduced cue-noticing in the high cognitive load condition was also reflected in longer reaction times to vigilance task targets in the high versus low cognitive load condition. This idea accords well with Sörqvist and Marsh (2015) who suggested that high levels of on-task concentration significantly reduce the chances of noticing background information and thus make participants less susceptible to the irrelevant (distracter) stimuli presented in the background. Interestingly, since we did not observe any cognitive-load effect on the frequency of IFTs, our study also indirectly suggests that the occurrence of IFTs is less dependent on noticing external cues. These are interesting possibilities that we discuss in more detail below.

Surprisingly (and in contrast to findings of Mazzoni, 2019), in the present study the frequency of IFTs was not affected at all by the level of cognitive load (see Table 2). This interesting result suggests that retrieval of IFTs is affected by an additional parallel task to a lesser degree than IAMs. This discrepant pattern of findings may be due to some methodological differences between the present study and the study by Mazzoni (2019). As discussed by Barzykowski and Niedźwieńska (2018a, p. 121), although Mazzoni (2019, p. 691, also Vannucci et al., 2015) exposed participants to simple arithmetic operations (e.g., $2 + 5 = 7$) in the cognitively demanding condition, they "*were told that they were not supposed to do anything with these items*". However, as typically happens with verbal cues, it was still assumed that participants would automatically read these formulas and would episodically check their validity, thereby increasing cognitive load. While we may agree with this reasoning, it is unknown to what extent participants were indeed checking the validity of the arithmetic operations. By contrast, in the present study, we actually engaged participants in an attentionally demanding secondary task. In addition, we were able to measure the level of performance on the additional task to control for the extent to which participants were actually engaged in performing it. Therefore, we were able to examine whether their engagement was high enough to increase cognitive load. Finally, we also compared the low and high cognitive load conditions in terms of how participants perceived the difficulty of the task. Therefore, we were able to determine whether the presumed differences in the level of cognitive load between the conditions were reflected in subjective ratings.

In addition, some differences in study design, such as the length of the main vigilance task, might have also affected the observed patterns of IFT frequency. In particular, in the present study, we used four times as many trials (i.e., 800 compared to 200 in study by Mazzoni, 2019) and up to six times as many verbal cues (i.e., 270 cues compared to 100 cues in the frequent condition, and 50 cues in the infrequent conditions in Mazzoni's study, 2019). In addition, we provided participants with 18 thought probes compared to 13 probes in the study by Mazzoni (2019). Therefore, our participants were involved in a relatively long (at least compared to the study by Mazzoni, 2019) version of the vigilance task, which allowed us to observe the frequency of IAMs and IFTs over a fairly long period of time.[9]

Bearing this in mind and based on the results related to weaker cue-recognition in the high cognitive load condition, it may be hypothesized that future-oriented thoughts may be less dependent on external cues and more likely to be triggered by internal cues or no cues at all (see Kvavilashvili & Rummel, 2020; Warden et al., 2019). For instance, it may be suggested that because involuntary memories relate to actually experienced events (e.g., *eating spaghetti in a nice Italian restaurant*), incidental external or internal cues may

[9] Moreover, in the present study, during the first 200 trials participants were probed for their ongoing thoughts approximately five times (compared to 13 probes in the study by Mazzoni, 2019) with a mean number of 44 trials between the probes (88 s, compared to 15 trials and 23s in Mazzoni's study). Therefore, we cannot directly compare our results with the study by Mazzoni (2019).

overlap much more easily with key features of the memory content than with some future scenarios or plans that have not yet been directly/personally experienced (e.g., *imagine having spaghetti with a significant other, as was depicted in the Lady and the Tramp cartoon movie*). Consequently, reduced cue-noticing in the high cognitive load condition, would result in fewer IAMs, but this drop in cue attendance would not affect the occurrence of IFTs as was observed in the present study (Table 1 shows that the observed successful cue-recognition ratio ranged from 0.59 to 0.65, which is still relatively high since it reflects incidental noticing of cues presented during the vigilance task). The idea of differential cue dependency in IAMs and IFTs seems to be a potentially interesting avenue for future experimental research on involuntary thoughts.

4.2. Some limitations, design considerations and avenues for future research

When considering the results of the present study, some limitations and possible improvements may be taken into account. For example, it may be argued that when comparing the low and high load conditions the observed differences in the number of thoughts might have been mostly due to qualitative differences between these two conditions other than the pure effect of cognitive load. Interestingly, this issue was also discussed by Barzykowski & Niedźwieńska (2018a). Specifically, they argued that as the cognitive load manipulation usually requires performing an additional, relatively demanding task, and, crucially, as participants in the low load condition do not have to spend time performing the second task, the differences in the number of reported thoughts between conditions may reflect a cumulative effect of both presumed cognitive load dependency and those differences between conditions. However, using a dual task method to increase cognitive load of an ongoing task is a fairly standard procedure that has been often used in different fields of cognitive psychology (e.g., Ball, 2007; Dixon & Li, 2013; Harrison et al., 2014; Guynn & McDaniel, 2007). Moreover, in the present study the additional task of monitoring the colour of a square occurred in the same (visual) modality and importantly, squares were presented in the center of the screen rather than in the periphery, which reduced the necessity for switching attention between stimuli in the high cognitive load condition.

Furthermore, even if the reduced frequency of thoughts in the high load condition was a direct consequence of the qualitative differences between the low (no-load) and high (dual-task) load conditions, by examining the cue recognition-ratio, we still were able to demonstrate that the underlying mechanism of the cognitive load dependency potentially resulted from other factors than that of cognitive load per se. An interesting avenue for future research is to manipulate the level of cognitive load (none, low, high) and the presentation of cognitive load task-items and cue phrases simultaneously versus sequentially or separately from each other. We are currently exploring some of these possibilities in follow-up studies (Barzykowski, Ilczuk, & Kvavilashvili, 2022), and believe that this research may ultimately provide interesting insights into cognitive mechanisms of involuntary past and future thinking.

Finally, as discussed by Barzykowski, Hajdas et al. (2021), although performance scores on well-known inhibitory control tasks, used in the present study, have been shown to predict performance in multiple cognitive tasks and behaviours such as in unintentional stereotyping (e.g., Payne, 2005), or bilingual spoken word processing (especially in relation to within- and cross-language competition; Abutalebi & Green, 2007; Mercier, Pivneva, & Titone, 2014), the spontaneous past and future thoughts do not seem to be predicted by them. For this reason, future studies may benefit from using different inhibitory control tasks, especially those requiring the inhibition of memory representations as used by, for example, Friedman and Miyake (2004).

4.3. Final conclusions and future directions

In the present study, we investigated the cognitive inhibition hypothesis under low and high cognitive load conditions. First of all, the findings of the present study and the studies by Barzykowski et al. (2019, 2021) provide little support for the idea that the involuntary occurrence of mental contents relies heavily on the special inhibitory control mechanism. By contrast, our findings demonstrate that an important and somewhat overlooked mechanism underlying the cognitive load effect on the frequency of involuntary memories may be actually reduced cue-noticing. This opens up potentially interesting avenues for research that will further address the cognitive load dependency of IAMs while separating the effects of cognitive load from different aspects of memory retrieval (e.g., noticing cues vs. forming or retrieving a memory representation in response to a cue). For instance, it is still not clear to what extent the retrieval of IAMs, which relates to forming and developing of an autobiographical memory, depends on the cognitive resources especially when the level of cue-noticing influenced by the cognitive load manipulation is kept under the strict control. Another potentially interesting avenue for research is to manipulate different types of load (e.g., visual, auditory, perceptual) to further investigate the cognitive load dependency of IAMs. We hope that these research avenues may ultimately provide important insights into cognitive mechanisms of involuntary cognitions. Finally, it is worth pointing out that our findings about the occurrence of IFTs being less dependent on external cues are in line with recent findings from the naturalistic experience sampling study by Warden et al. (2019), which showed that IFTs, in general, and involuntary thoughts about upcoming prospective memory task, in particular, may be so highly activated that they can pop into mind with no further need for any external or internal triggers or cues. Therefore, to gain further insights into the precise mechanisms of spontaneous cognition, future studies will need to examine the dependence of IAMs and IFTs on external cues by manipulating the presence/absence and the focality of cues (centrally vs. peripherally presented), in vigilance tasks with high and low cognitive load.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Disclosure statement

The authors declare no conflict of interest.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.concog.2022.103353.

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