Memory

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

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To cite this article: J. M. E. Kuiling, F. Klaassen & M. A. Hagenaars (2019) The role of tonic immobility and control in the development of intrusive memories after experimental trauma, Memory, 27:6, 772-779, DOI: 10.1080/09658211.2018.1564331

To link to this article: https://doi.org/10.1080/09658211.2018.1564331

Published online: 12 Feb 2019.

MEMORY
2019, VOL. 27, NO. 6, 772–779
https://doi.org/10.1080/09658211.2018.1564331

Routledge
Taylor & Francis Group

The role of tonic immobility and control in the development of intrusive memories after experimental trauma

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ABSTRACT

Tonic immobility (TI; state of motor inhibition during threat) has been implicated in the onset of intrusive trauma memories, while controllability was associated with reduced anxiety. The present study investigated the interaction between TI and control in the development of intrusive memories of an analogue trauma. Sixty-four participants watched negative pictures while being allowed to close their eyes (InControl) or not (NoControl). They completed measures for spontaneous TI afterwards and recorded intrusive memories of the pictures in a diary in the subsequent week. Bayesian analyses were used to test informative hypotheses. Spontaneous TI during picture viewing was positively associated with increased intrusion frequency. Intrusion frequency did not differ for InControl versus NoControl. Moderation (control x TI) and non-moderation (main effect of TI only) were both adequate models, with no preference. Our results confirm the importance of TI in PTSD development. Implications of the findings regarding control merit more research.

ARTICLE HISTORY
Received 20 June 2018
Accepted 17 December 2018

KEYWORDS
Tonic immobility; control; intrusions; intrusive memories; posttraumatic stress disorder

Tonic immobility (TI) is a response to threat characterised by profound motor inhibition, muscular rigidity, and suppressed vocal behaviour (Gallup, 1974; Hagenaars, Oitzl, & Roelofs, 2014). In animals, TI may occur when freezing, fight or flight are no longer options for survival, for example, when there is physical contact with the predator. This distinguishes TI from freezing, which occurs at post-encounter, when the predator is detected and risks assessment takes place. TI increases survival chances because many predators lose interest in the seemingly dead prey animal (Bracha, 2004; Gallup, 1977; Marx, Forsyth, Gallup, Fusé, & Lexington, 2008). Humans were found to display TI too, with similar symptoms (Galliano, Noble, Travis, & Puechl, 1993). Moreover, human TI was found to have negative consequences. That is, TI during trauma was associated with the development of posttraumatic stress disorder (PTSD) in cross-sectional studies, even after controlling for trauma severity or fear (Bovin, Jager-Hyman, Gold, Marx, & Sloan, 2008; Hagenaars, 2016; Heidt, Marx, & Forsyth, 2005; Rocha-Rego et al., 2009). Proposed working mechanisms of TI are increased self-blame or blame by others (Bovin et al., 2014; McCaul, Veltum, Boyechko, & Crawford, 1990) and enhanced sensory intake, leading to sensory-rich trauma memories (Bradley, Codispoti, Cuthbert, & Lang, 2001; Hagenaars & Putman, 2011; Hagenaars, Van Minnen, Holmes, Brewin, & Hoogduin, 2008). Decreased controllability has also been put forward, given its key role in PTSD as well as TI (Bovin et al., 2008; Hagenaars & Putman, 2011; Maser & Gallup, 1974). If so, then providing control should buffer against the effects of TI (see below).

Watching aversive material (e.g., negative films or pictures) is frequently used as an analogue for trauma for a more controlled investigation of PTSD predictors (Holmes & Bourne, 2008; James et al., 2016; Krans, Langner, Reinecke, & Pearson, 2013; Pearson, Ross, & Webster, 2012). Intrusive memories of the aversive material are typically used as representations for re-experiencing symptoms (Hall & Berntsen, 2008; James et al., 2016; Krans et al., 2013). Using such an analogue setup, non-movement manipulations (mimicking TI-inductions in animals) led to more intrusive memories of an aversive film in the subsequent week (Hagenaars, Brewin, van Minnen, Holmes, & Hoogduin, 2010; Hagenaars et al., 2008). Hagenaars and Putman (2011) found that spontaneous, self-reported TI (measured by the Tonic Immobility Scale; TIS; Fusé, Forsyth, Marx, Gallup, & Weaver, 2007) during an aversive film predicted higher levels of intrusive memories.

Interestingly, in the latter study, TI was related with intrusive memories in participants with low but not in those with high attentional control, suggesting that attentional control buffers against intrusion development

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(Hagenaars & Putman, 2011). The question remains whether actual *behavioural* control would have the same moderating effect. Behavioural control is defined as the availability of a behavioural response that can prevent or terminate a stimulus (Foa, Zinbarg, & Rothbaum, 1992; Thompson, 1981). It may reduce stress responses during threat anticipation, threat impact, and post-threat, and has thereby implicated as a major factor in the etiology of PTSD (Mineka & Zinbarg, 2006). However, although behavioural control was quite consistently found to be related to lower stress responses in the anticipation period (Houston, 1972; Lovibond, Saunders, Weidemann, & Mitchell, 2008; Szpiler & Epstein, 1976), findings are less consistent for the impact period, and to our knowledge, only a few studies examined effects on a long-term post-threat period. Regarding impact, some studies reported reduced arousal during threat (e.g., Bjorkstrand, 1973), some found no effect of control (e.g., Bowers, 1968), and others even found increased arousal (Gatchel & Proctor, 1976). Most studies used a shock or pain-inducing stimulus as threat. Interestingly, Geer and Maisel (1972) applied an affective picture viewing paradigm to study the impact of control, operationalised as the possibility to terminate picture viewing by button press. Having control indeed resulted in reduced skin conductance responses to the negative pictures. Vogeltanz and Hecker (1999) applied a similar design with pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1997) and found no differences between those with and without control on physiological (skin conductance responses) or subjective arousal measures. However, in the latter study, the anticipation of completing a memory test afterwards may have distracted participants from the emotional impact of the pictures, increasing their focus on cognitively remembering the picture-content (Laposa & Alden, 2006). Also, physiological responses were measured during the inter-trial intervals and not during picture viewing, and may therefore be associated with recovery rather than impact (Norris, Larsen, & Cacioppo, 2007).

In conclusion, it is not clear whether behavioural control has a direct effect on the emotional impact of a stressor. Contradictory findings may point towards a more complex role, for example with control acting as a moderator (see also Hagenaars & Putman, 2011). In addition, its effects on long-term stress-symptoms are not well known. Finally, effects of *actual* behavioural control should be distinguished from *perceived* control (perceptions of control over the nature of situational factors and events), which is considered to be involved in the etiology of anxiety disorders (Gallagher, Bentley, & Barlow, 2014; Sanderson, Rapee, & Barlow, 1989). We aim to contribute to these hiats by examining main and moderating effects of behavioural control during analogue trauma on subsequent stress symptoms (intrusive memories). An affective picture viewing paradigm was used to allow eye closure for the duration of specific stimuli. We expected that: (1) spontaneous TI during picture viewing would be associated with more intrusive memories in the subsequent week, (2) participants would develop fewer intrusive memories of the pictures if they had control over watching them relative to those who did not have control, and (3) having control would buffer against the effects of spontaneous TI. Thus, the TI-intrusion association was expected to be larger in the group without control than in the group with control. These expectations were translated into informative hypotheses, i.e., hypotheses that include specific orderings or (in)equalities between the parameters (Klugkist, Laudy, & Hoijtink, 2005), rather than formulating a non-directional "difference" which is done in a frequentist approach. These informative hypotheses were evaluated using Bayes factors in order to test their relative evidence (see also Hagenaars, Holmes, Klaassen, & Elzinga, 2017). Bayes factors allow for quantification of evidence for null hypotheses (e.g., Wagenmakers, Wetzels, Borsboom, & van der Maas, 2011), which is relevant in this study, because some hypotheses of interest are null hypotheses (H2 and H4; see below and Table 1). In addition, Bayesian testing of informative hypotheses (like H1, H3 and H5-H7; see below and Table 1) allows for a direct evaluation of hypotheses (rather than via post-hoc testing; e.g., Klugkist, van Wesel, & Bullens, 2011), and a direct comparison of competing theories (to each other rather than to a null hypothesis).

Method

Participants

Group size is typically about 20 participants per group for this method (range ~15–30 participants; James et al., 2016; Krans et al., 2013; Pearson et al., 2012). We aimed for a relatively high sample size in the present study, reducing type I errors. Participants were undergraduate students from the Radboud University Nijmegen ($N = 65$). Students were excluded in case of blood phobia or ongoing treatment for psychiatric disorders. One participant was excluded from analysis because of noncompliance to the task instructions. A total of 64 participants (47 females) were randomly assigned to either the group with control (InControl; $n = 32$) or the group without control (NoControl; $n = 32$). Age ranged from 18 to 28 with the mean age of 20.69 (SD = 2.20). All participants gave written informed consent. They received course credits after completion.

Materials and measures

Neuroticism. Neuroticism was related to PTSD in several studies (Engelhard, van den Hout, & Lommen, 2009) and therefore included to check for baseline differences between groups. Neuroticism was assessed with the neuroticism scale of the Eysenck Personality Questionnaire-Revised, short version (EPQ-RSS-N; Eysenck & Eysenck,

1991; Sanderman, Arrindell, Ranchor, Eysenck, & Eysenck, 2012), which consists of 12 dichotomous items (yes/no). The reliability of the EPQ-RRS-N is high (Cronbach's α = .81−.84; Sanderman et al., 2012).

Tonic Immobility. The Tonic Immobility subscale of the Tonic Immobility Scale (TIS-TI; Fusé et al., 2007) was used to measure immobility reactions during picture viewing. The TIS-TI subscale contains 7 self-report items which are scored on a 7-point Likert scale, ranging from 0 (not at all) to 6 (extremely/very much). An example item is "Rate the degree to which you were unable to move even though not restrained". Internal consistency was moderate to strong for TIS-TI (Cronbach's α = .65 to .94; Bados, Toribio, & García-Grau, 2008; Fusé et al., 2007; Hagenaars, 2016). The original TIS was adapted to match the experimental setup so that items referred to immobility responses during picture viewing (see also Hagenaars & Putman, 2011).

Intrusive memories. Participants recorded intrusive memories they had in the subsequent week in an intrusion diary (see also Brewin & Saunders, 2001; Davies & Clark, 1998; James et al., 2016). Verbal and written instructions were given about keeping the diary. Intrusions were defined as spontaneously occurring involuntary memories related to the pictures in the affective viewing task. Deliberate recollections should not be recorded. Participants specified whether it was an image or a thought, described the content of the intrusion and the situation in which it had occurred, and indicated how spontaneously it came up on a scale ranging from 0 (totally not) to 100 (extremely), in order to check whether the memory was indeed intrusive and related to the pictures. Following previous studies, the total number of intrusive memories were obtained by adding up all image-based intrusive memories (Hagenaars et al., 2010; Holmes, Brewin, & Hennessy, 2004).

Mood ratings. Mood ratings were used to check whether the affective viewing task-induced negative affect. Participants rated fear, horror, anger, sadness, helplessness and subjective control before and after the affective viewing task on an 11-point Likert scale ranging from 0 (not at all) to 10 (extremely) (Hagenaars et al., 2008; Holmes et al., 2004). The mood ratings of helplessness and subjective control were included as indicators of perceived control (Weems & Silverman, 2006).

Eye closure. After the affective viewing task participants in both experimental groups indicated whether they closed their eyes and if so, they estimated how many times.

Visual stimuli. A total of 40 pictures were used in the affective viewing task, all selected from the IAPS (Center for the Study of Emotion and Attention, 1999). There were two sets: 10 neutral pictures (neutral object such as a cup or a chair) and 30 negative pictures (mutilation and threat).[1] The neutral set was presented first to allow InControl participants to practice with the timing of eye closure. The negative pictures served as experimental trauma. Such a procedure has been used before and proved adequate for inducing intrusive recollections (Hall & Berntsen, 2008; Pearson et al., 2012) and immobility responses (Hagenaars, Stins, & Roelofs, 2012) in a non-clinical sample. Each picture was shown 3 s with a 1-s intertrial interval, which would facilitate accurate eye closure. In total, the affective viewing task took 159 s. Pictures were presented on a BenQ XL2420Z 24-inch screen monitor at eye height in a 30 × 40 format.

Procedure

Participants completed mood ratings and EPQ-RSS-N, after which standardised (written) instructions were provided on how to watch the pictures. NoControl participants received a usual affective viewing instruction: They had to watch the pictures carefully and had to imagine they were present at the scene. They had to keep looking at the screen throughout the task, without looking away or closing their eyes. InControl participants were given control during picture viewing: They were allowed to close their eyes for the duration of one picture if they did not want to see that picture. They could do this at any time during the affective viewing task and as many times as they wanted. The affective viewing task was started after these instructions. After the affective viewing task had ended, participants completed the second mood ratings, TIS-TI and eye closure questions. Finally, the intrusion diary was explained. Participants returned to the lab 7 days later when the diary was handed in and course credits were given.

Analyses

Hypotheses. We had three research questions: (1) Is spontaneous TI associated with higher intrusion frequency? (2) What is the effect of control over picture viewing on intrusion frequency? (3) Does control over picture viewing moderate the effect of spontaneous TI on intrusion frequency? The expectations for each research question were formulated in two competing informative hypotheses (see Table 1 for formulas and descriptions of the hypotheses). Per research question, each set of hypotheses was evaluated using Bayes factors (see next section) to determine whether one of the hypotheses was clearly preferred over the other.

For the third research question (moderation) a conditional plan was adopted: Analyses would depend on the findings for the first two research questions. H5 would be compared to H6 if TI had a positive effect (H1 is preferred over H2), because then, it was unlikely that in both conditions TI would not be related to intrusion frequency (H7). On the other hand, H5 would be compared to H7 if TI was not related to intrusion frequency (H2 is preferred over H1), because then, it was unlikely that in both conditions TI would be positively related to intrusion frequency (H6).

Finally, exploratively, helplessness and subjective control (indicators of perceived control) would be analysed as mediating factors in case there was a main effect of

Table 1 . A priori formulated hypotheses and Bayes factors describing the relative evidence for each set of hypotheses (per research question).

Hypotheses[a]	Description	BF	BFxu[b]
Main effect of TI[c]			
H1 $\beta_{TI} > 0$	TI is related to higher intrusion frequencies	BF12 = 8	2
H2 $\beta_{TI} = 0$	TI is not related to intrusion frequencies		.25
Main effect of Control[d]			
H3 $\mu_{NoControl} > \mu_{InControl}$	Intrusion frequency is higher for NoControl than for InControl.	BF34 = .32 (BF43 = 3.12)	1
H4 $\mu_{NoControl} = \mu_{InControl}$	Intrusion frequency is the same for NoControl and InControl.		3.12
Presence and direction of a TI x Control interaction			
H5 $\beta_{TIxNoControl} > 0$ & $\beta_{TIxNoControl} > \beta_{TIxInControl}$	There is a TI x Control interaction: TI is related to higher intrusion frequencies in the NoControl condition, and less so in the InControl condition (a main effect of TI is no prerequisite).	BF56 = .66 (BF65 = 1.53)	2.19
H6[e] $\beta_{TIxNoControl} > 0$ & $\beta_{TIxNoControl} = \beta_{TIxInControl}$	There is a main effect of TI (TI is related to higher intrusion frequencies in both conditions), but no TI x Control interaction.		3.34
H7[f] $\beta_{TIxNoControl} = 0$ & $\beta_{TIxNoControl} = \beta_{TIxInControl}$	There is no main effect of TI, nor a TI x Control interaction: for both conditions TI is not related to intrusion frequency.	N/A	N/A
Posthoc analyses			
$H_{posthoc}$ $\beta_{TIxNoControl} > 0$ & $\beta_{TIxInControl} > 0$ & $\beta_{TIxNoControl} > \beta_{TIxInControl}$	There is a main effect of TI and a TI x Control interaction: TI is related to higher intrusion frequencies in both conditions, but this relation is stronger in the NoControl condition.	$BF5_{posthoc}$ = 1.29 $BF6_{posthoc}$ = .84	2.85

[a]Dependent variable = intrusion frequency.
[b]Bayes factor for testing the hypothesis against the unconstrained hypothesis (Hu).
[c]The hypothesis that TI is related to lower intrusion frequencies is not likely based on theory and empirical evidence and therefore not included.
[d]The hypothesis that intrusion frequency is lower for NoControl than InControl participants is not likely based on theory and empirical evidence and therefore not included.
[e]Excluded if H2 is preferred over H1.
[f]Excluded if H1 is preferred over H2.
[g]These analyses will be executed if H5 is preferred over H6 or H7, otherwise mediation is not possible.

Control or a TI x Control interaction effect (i.e., evidence for H3 or H5 versus H4 and H6/H7).

Bayes factor and BIEMS. Bayes factors were used to evaluate the competing hypotheses. When comparing informative hypotheses, a Bayes factor describes the support in the data for one hypothesis relative to another. For example, if BF12 = 10, H1 is 10 times more supported by the data than H2, and if BF12 = .5 (or BF21 = 2), H2 is 2 times more supported by the data than H1. The Bayes factor provides a continuous relative measure of evidence for hypotheses. For interpretation, Bayes factors between 3 and 10 have been proposed to reflect moderate evidence (Kass & Raftery, 1995). Bayes factors should be interpreted on a continuous scale, though, and these guidelines should not be used as "cutoff" criteria.

In addition to testing competitive hypotheses against each other, we also compared their quality. That is, when comparing 2 hypotheses, one (Hx) can be clearly preferred over the other (Hy), but this is *relative* evidence and does not necessarily mean that Hx is a good model and Hy is a poor model. Hx and Hy can both be good or poor models. Therefore, we also calculated the Bayes factor against the unconstrained hypothesis (Hu: all other hypotheses), which imposes no constraints on the parameters in the model. Hu testing serves as a posthoc test for the fit of the tested model with the data. Here we checked whether there was more evidence for Hx than for Hu (so, BFxu > 1). This indicates that there is more evidence for Hx, than for no model at all, i.e., the model is at least a reasonable description of the data. Thus, BFxu < 1 indicates that model x may not be a good model, while BFxu > 1 confirms that model x is an adequate model. Although the interpretation for BFxu is not different to the interpretation of BFxy, BFxu factors with no equality constraints have a maximum value (depending on their complexity; e.g., Morey & Wagenmakers, 2014).

The analyses were executed in BIEMS (Mulder, Hoijtink, & de Leeuw, 2012). In BIEMS, the data is used to compute a conjugate prior distribution, which allows for the computation of Bayes factors.

Results

Two participants were identified as outliers on intrusion frequency, scoring more than four SDs above the mean. Those scores were changed into one unit smaller than the most extreme score in the data set (Tabachnick & Fidell, 1996).

Baseline descriptives and manipulation checks

Sample descriptives (means and SDs) and BFs for testing the null hypotheses (groups are equal) are listed in Table 2. InControl and NoControl participants did not differ on age, gender and neuroticism. Participants in the

Table 2 . Means (SDs) of descriptive and experimental variables.

	InCo ($n = 32$) *M (SD)*	NoCo ($n = 32$) *M (SD)*	BFxu[a]
Age	20.59 (2.21)	20.78 (2.21)	2.69
Gender (*n* female [%])	23 (72%)	24 (75%)	3.91
EPQ-RSS-N	4.28 (2.61)	3.97 (2.50)	2.67
Frequency eye closure [range]	1.97 (3.91) [0–15]	0.50 (0.98) [0–3]	**.43**
Anxiety			2.87[b]
Pre	1.19 (1.26)	.97 (.93)	
Post	2.41 (2.41)	2.06 (2.05)	
Horror			.89
Pre	.19 (.54)	.38 (.83)	
Post	4.97 (2.34)	4.16 (2.50)	
Sadness			2.65
Pre	1.94 (2.45)	1.69 (2.13)	
Post	3.34 (2.04)	3.19 (2.04)	
Anger			2.63
Pre	.44 (1.19)	.22 (.49)	
Post	1.88 (2.03)	1.66 (1.93)	
Helplessness			**.56**
Pre	.53 (1.52)	.72 (.99)	
Post	1.28 (1.76)	2.19 (2.15)	
Control[c]			2.37
Pre	6.94 (1.70)	6.78 (1.96)	
Post	6.03 (1.98)	5.72 (2.25)	
TIS-TI	9.53 (6.09)	11.88 (7.09)	1.27
Number of intrusions	1.53 (2.17)	1.53 (2.44)	2.73

Note: InCo = InControl; NoCo = NoControl; EPQ-RSS-N = neuroticism subscale of the Eysenck Personality Questionnaire; TIS-TI = Tonic Immobility subscale of the Tonic Immobility Scale.

[a]Bayes factor for testing the hypothesis (no differences between conditions) against the unconstrained hypothesis (Hu). Higher Bayes factors indicate higher probabilities that the groups do not differ.

[b]A pre to post change score was used as dependent variable for all mood ratings.

[c]Higher scores indicate more feelings of control.

InControl group closed their eyes more frequently than those in the NoControl group (BF = .43, thus, a difference between InControl and NoControl is 2.3 times more likely than no difference). For InControl, 21 participants never closed their eyes (while 11 participants did), and for NoControl, 25 participants never closed their eyes (while 7 participants did).

The pictures successfully elicited negative affect, as indicated by increases in mood ratings from pre to post picture viewing (all BFxu > 1.98),[2] see also Table 2. Like in trauma film research, especially horror was increased (see, e.g., Hagenaars, 2012). Interestingly, feelings of control did not differ between groups. However, helplessness seemed to increase more in NoControl than InControl participants, although the effect was weak (BF = .56, thus, a difference between NoControl and InControl is 1.8 times more likely than no difference). There were no differences between the groups on the other mood ratings.

Hypotheses testing

Table 1 displays the results of the Bayesian evaluation of the hypotheses. The first set of hypotheses concerns the relationship between spontaneous TI and intrusion frequency across conditions. H1 was 8 times more supported by the data than H2. Thus, spontaneous TI during watching the pictures was related to intrusion development. In addition to being a better model than H2, we also tested whether H1 was an adequate model. The data provided 2 times more support for H1 than for Hu (BF1u = 2),[3] indicating that H1 is a good model. To clarify the relationship between spontaneous TI and intrusion frequency, a bivariate correlation was calculated, which was $r = .32$.

The second set of hypotheses concerned a difference in intrusion frequency between InControl and NoControl. H4 was approximately 3 times more supported by the data than H3 (see Table 1). Thus, there is more evidence that NoControl and InControl had similar intrusion frequencies, than that NoControl led to higher intrusion frequencies than InControl. Furthermore, H4 seems a reasonable model, because there is more evidence in the data for H4 than for Hu (BF4u = 3.12).[4]

The final comparison of hypotheses concerns the interaction between spontaneous TI and control over picture viewing. We excluded H7 (no main effect of TI, no moderation) from the analyses, because H1 (main effect of TI) was preferred over H2. Thus, we compared H5 (moderation) to H6 (main effect of TI, no moderation). Based on the data, H5 and H6 cannot be distinguished (see Table 1 for BFs). Thus, we cannot be sure whether the effect of spontaneous TI on intrusion frequency is moderated by control over picture viewing (H5) or not (H6). Both hypotheses receive more evidence than Hu (BF5u = 2.19; BF6u = 3.34). Thus, both the moderation and the TI-main effect model are adequate, but there is no clearly best hypothesis. In other words, it is indecisive if spontaneous TI is directly associated with increased intrusion frequency without moderation of control (H6: main effect of TI, no moderation), or if having control buffers against the effects of TI (H5: moderation). Bivariate correlations between spontaneous TI and intrusion frequency were $r = .19$ in InControl and $r = .42$ in NoControl.

A possible explanation for the inability to differentiate between H5 (moderation, with no necessary TI main effect) and H6 (main effect of TI only) could be that both a main effect and an interaction effect are present. Therefore, we tested the posthoc hypothesis ($H_{posthoc}$), which included a main effect of TI (in both groups) as well as a TI x Control interaction (i.e., a stronger effect of TI on intrusion frequency for NoControl). However, when comparing $H_{posthoc}$ with H5 and H6, none of these 3 models could be easily differentiated (see Table 1). $H_{posthoc}$ received more evidence than Hu ($BF_{posthoc}u = 2.85$), indicating that this too is an adequate model. However, because there is no clearly best hypothesis when comparing $H_{posthoc}$, H5 and H6, we cannot conclude whether there is a main effect of TI, a TI x Control interaction, or both.[5]

Finally, because the results suggest there is no effect of condition (H3), and it is uncertain whether control moderated the effects of TI (H5), the exploratory analyses were not executed.

Discussion

The present study investigated the role of spontaneous TI and behavioural control during analogue trauma in subsequent intrusion development. We found that spontaneous TI was related to higher intrusion frequencies. Participants with and without control over picture viewing showed similar intrusion frequencies. The results were inconclusive regarding the moderating effect of control: both the moderation hypothesis (control attenuates the TI-intrusion relationship) as well as the main effect hypothesis (main effect for TI, but no moderation by control) were adequate models.

Our results regarding spontaneous TI are in line with several retrospective cross-sectional studies in which TI was found to be associated with PTSD development (Bovin et al., 2008; Hagenaars, 2016; Heidt et al., 2005; Humphreys, Sauder, Martin, & Marx, 2010). Together with the findings of one prospective study (Maia et al., 2015) and replicating one experimental study (Hagenaars & Putman, 2011), our findings suggest that spontaneous TI during (analogue) trauma contributes to the development of intrusive trauma memories and PTSD. Moreover, the overall association between TI and intrusion frequency in our study was similar to the correlation reported by Hagenaars and Putman (2011). Future studies may explore whether TI also affects voluntary memory. For example, a previous study found different effects on vividness and emotionality of voluntary recollections but not on the frequency of involuntary intrusive memories (Cuperus, Klaassen, Hagenaars, & Engelhard, 2017).

Having behavioural control during analogue trauma did not directly affect the development of intrusions in our study. Rather, we found evidence for control *not* affecting intrusion development directly. Although this may seem surprising at first, note that it is actually in line with several studies that found no effects of behavioural control on threat impact (Bowers, 1968; Vogeltanz & Hecker, 1999). Regarding long-term effects of control, behavioural control (escapable shock in a fear conditioning task) prevented return of fear 14 days later in rats (Baratta et al., 2007), possibly pointing out a difference the effects of being able to completely prevent (escape a shock) or temporary escape (eye closure) an aversive event. Previous findings suggest an important association between anxiety (disorders) and *perceived* control (Mineka & Zinbarg, 2006). Post hoc analyses indeed showed that helplessness (an indicator of perceived control; Geer, Davison, & Gatchel, 1970; Weems & Silverman, 2006) was associated with increased intrusion frequency ($r = .26$). Thus, behavioural control may have had an indirect effect, by increasing helplessness, which was higher in participants without control.

Alternatively, behavioural control may rather have a moderating than a direct effect. In our sample, behavioural control during analogue trauma moderating the association between spontaneous TI and intrusion frequency was a reasonable model indeed, although spontaneous TI being associated with intrusion frequency without a moderating effect of control was a reasonable model as well. Interestingly, correlations between spontaneous TI and intrusions in participants with and without control were similar to those reported by Hagenaars and Putman (2011). These authors found a moderation effect of attentional control on the relationship between TI and intrusion development and also did not find a main effect of (attentional) control either. Future research may test the moderation and non-moderation hypotheses against each other to examine which is the strongest model. A Bayesian approach may be fruitful, as it allows direct comparisons and incorporating previous findings in the statistical model, thereby building cumulative evidence. Accumulating findings using minor variations to the design (for example a different manipulation of behavioural control) may also stabilise the evidence. Future research may also delineate the effects of different types of control (e.g., attentional control, behavioural control, perceived control) and examine its specific impact regarding period (anticipation, impact, post-threat) and symptoms (e.g., subjective mood, symptomatology).

Our study was limited by the use of aversive stimuli as an analogue for trauma. This enhanced a controlled examination of causality, but decreased ecological validity. Also, the manipulation of control may have been inadequate. The stimuli were presented brief and continuously, which may have interfered with eliciting a sense of control (i.e., opening one's eyes immediately resulted in threat exposure). In addition, many InControl participants did not close their eyes and subjective control did not differ between conditions. On the other hand, the results were similar when controlling for encoding-time (i.e., exclusion of participants who closed their eyes), suggesting that variations in visual exposure did not interfere with the operationalisation of control. Also, the number of eye closures may not be a good indicator of control (increased control may result in higher distress tolerance and thus reduced need for eye closure; Thompson, 1981). Also, two findings suggest that the manipulation may have been successful, i.e., participants with control experienced less helplessness (associated with uncontrollability; Glass & Singer, 1972), and we found some evidence for a moderation effect. However, there may be a floor effect in healthy populations, in whom (perceived) control may be high anyway (in our study possibly indicated by eye closure in NoControl participants), and even increased by using predictable stimuli as in our study. Future research may thus reduce control rather than increase it.

In conclusion, this study found higher intrusion frequencies after negative picture viewing for participants who experienced more spontaneous TI, confirming the importance of TI in the development of intrusive trauma memories. Controlling picture viewing time by means of eye closure did not affect intrusion frequencies directly. We found evidence for a moderation hypothesis, but also for

a hypothesis with TI as main effect without moderation. The test between these informative hypotheses was inconclusive. Our findings stress the importance of directly comparing two models.

Notes

1. Neutral pictures: 7000, 7004, 7006, 7009, 7010, 7020, 7030, 7031, 7040 and 7050.
   Negative pictures: 1050, 1120, 1201, 1205, 1300, 1302, 1525, 1930, 1932, 3000, 3010, 3016, 3053, 3060, 3061, 3100, 3101, 3102, 3110, 3130, 3140, 3261, 8480, 8485, 9040, 9230, 9635.1, 9903, 9921 and 9925.
2. Note that the maximum is 2 for all pre-post comparisons (no equality constraints), so the maximum level of evidence possible has been achieved for most mood ratings.
3. Note that the maximum of BF1u is 2 (this hypothesis has no equality constraints), so the maximum level of evidence possible has been achieved.
4. The results were similar (although less strong) after exclusion of participants who closed their eyes, i.e., when controlling for encoding-time (BF34 = .60).
5. All analyses were re-run without participants that closed their eyes, and also with Neuroticism included as a covariate. The effects were similar as those reported here.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was supported the Netherlands Organisation for Scientific Research (NWO) with a grant for innovative research awarded to Muriel Hagenaars (VENI #451-09-018) and a talent grant awarded to Fayette Klaassen (#406.12.001). NWO was not involved in any part of this study.

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