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Randomness increases self-reported anxiety and neurophysiological correlates of performance monitoring

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Several prominent theories spanning clinical, social and developmental psychology suggest that people are motivated to see the world as a sensible orderly place. These theories presuppose that randomness is aversive because it is associated with unpredictability. If this is the case, thinking that the world is random should lead to increased anxiety and heightened monitoring of one's actions and their consequences. Here, we conduct experimental tests of both of these ideas. Participants read one of three passages: (i) comprehensible order, (ii) incomprehensible order and (iii) randomness. In Study 1, we examined the effects of these passages on self-reported anxiety. In Study 2, we examined the effects of the same manipulation on the error-related negativity (ERN), an event-related brain potential associated with performance monitoring. We found that messages about randomness increased self-reported anxiety and ERN amplitude relative to comprehensible order, whereas incomprehensible order had intermediate effects. These results lend support to the theoretically important idea that randomness is unsettling because it implies that the world is unpredictable.

Keywords: meaning; performance monitoring; anxiety; ERN

Every year a new generation of physics students learns what should be a profoundly confusing truth; they learn, through the study of quantum entanglement, that the observation of one particle can 'instantaneously' influence another particle that is some distance away (Schrödinger, 1935). Many students are not sufficiently bothered by this information, at least according to Niels Bohr, who famously stated 'Anyone who is not shocked by quantum theory has not understood it' (Bohr, 1998). Bohr's comment speaks to a remarkable aspect of human nature: people are consistently able to come to terms with even the most puzzling truths about the world.

A number of theorists have taken note of this phenomenon and have suggested that people are adept at dealing with information that does not make sense. Constructs like effectance motivation (White, 1959), need for cognition (Cohen *et al.*, 1955) and belief in a just world (Lerner, 1980) are intended to capture people's motivation to impose order on the environment. Cognitive dissonance theory (Festinger, 1957), terror-management theory (Greenberg *et al.*, 1986), the meaning maintenance model (Heine *et al.*, 2006; Proulx and Inzlicht, 2012) and the compensatory control model (Kay *et al.*, 2009) all propose that when people are faced with observations that are incoherent or otherwise violate their sense of order they use strategies that serve to restore it. Traumatic events can have long-term detrimental effects on psychological health, in part because people struggle to assimilate these experiences with previous assumptions about the world (Janoff-Bulman, 1989).

Theories of sense-making suggest that order is comforting because it is associated with predictability, and thus allows people to confidently pursue goals and interact with their environment (Harmon-Jones and Harmon-Jones, 2002; McGregor *et al.*, 2009). Recent research has demonstrated that reminding people of the structure that exists in the environment increases people's willingness to engage in goal pursuit (Kay *et al.*, 2014). The appeal of structure is also evident in people's stubborn insistence on explaining everything, even when the end result is clearly a fabrication. In his pioneering work with split-brain patients, Gazzaniga (1995) observed that when information is available only to the right side of the brain, the 'left-brain interpreter' creates a plausible, but false, explanation for how that information affected their behavior. Similarly, experiments have shown that people will make up sensible but demonstrably incorrect stories about how they solved intuitive problems (Maier, 1931), how they rationally developed their moral convictions (Haidt, 2001) and how they evaluated the pleasantness of pictographs (Payne *et al.*, 2005). Behaviors like these have been taken as evidence that people have 'a need to understand and make reasonable the experiential world' (Cohen *et al.*, 1955, p. 291).

RANDOMNESS AND ANXIETY

These theories all imply, directly or indirectly, that randomness can be aversive because it prevents people from anticipating what will happen next (Peterson, 1999; Inzlicht and Tullett, 2010; Tullett *et al.*, 2011; Hirsh *et al.*, 2012; Proulx *et al.*, 2012). Support for this possibility comes from studies comparing the effects of predictable and unpredictable negative outcomes. People show increased anxiety (Monat *et al.*, 1972), a potentiated startle reflex (Grillon and Davis, 1997; Grillon *et al.*, 2004) and greater avoidance (Abbott and Badia, 1979) when the occurrence of aversive stimuli is unpredictable or random. These ideas seem to be echoed, albeit indirectly, in some areas of clinical research. For instance, researchers have postulated that anxiety disorders, such as post-traumatic stress disorder and panic disorder, are particularly aversive because of the unpredictable nature of their symptoms (Foa *et al.*, 1992; Craske *et al.*, 1995). These ideas give rise to *Hypothesis 1*: randomness should lead to increased anxiety when compared with order.

RANDOMNESS AND PERFORMANCE MONITORING

If randomness is aversive because it makes the course of action unclear, an adaptive response to randomness should include heightened performance monitoring (Shackman *et al.*, 2011)—a process involving the comparison of actual with intended action outcomes, and the initiation of compensatory action when discrepancies are detected (Carter *et al.*, 1998; Holroyd and Coles, 2002). In an environment that is highly ordered—insofar as this order can be understood by the individual—monitoring one's actions should be relatively unnecessary because their outcomes can be easily predicted ahead of time. In contrast,

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increasing levels of randomness should necessitate increasing levels of monitoring due to the unpredictability of the consequences of one's actions.

Researchers have documented psychophysiological and behavioral manifestations of performance monitoring, including faster reaction times (Rabbitt 1966, 1967), post-error slowing (Hajcak *et al.*, 2003; Kerns *et al.*, 2004) and increased neural responses to conflict (Carter *et al.*, 1998; Botvinick *et al.*, 2001). These changes, along with the phenomenological experience of anxiety, are thought to facilitate adaptive responses to unpredictability by increasing an organism's vigilance to its actions and their consequences.

Several decades of research has demonstrated that the anterior cingulate cortex (ACC) plays a role in performance monitoring (Botvinick *et al.*, 2001). Specifically, researchers have proposed that the ACC may be involved in monitoring the consistency between predictions and outcomes, and in driving behavior aimed at reducing discrepancies (Holroyd and Coles, 2002; Brown, 2013). Recent results suggest that ACC activity is also associated with anxiety and negative affect (Benkelfat *et al.*, 1995; Critchley *et al.*, 2003). With evidence that the ACC is involved in both performance monitoring and negative affect (Inzlicht and Al-Khindi, 2012; Spunt *et al.*, 2012), theorists have proposed that these roles may be complementary and that negative emotion may contribute to adjustments in performance (Carver and Scheier, 1990; Shackman *et al.*, 2011; Schmeichel and Inzlicht, 2013).

Electroencephalographic (EEG) studies have demonstrated that ACC activity is associated with an event-related potential called the error-related negativity (ERN) that occurs within 100 ms of making a mistake (Falkenstein *et al.*, 1990; Gehring *et al.*, 1993). The amplitude of the ERN is greater when demands for performance monitoring are heighted, as when the consequences of errors are greater or when the outcomes of one's actions are less predictable (Brown and Braver, 2005; Hajcak *et al.*, 2005). Recent research suggests that the ERN is also associated with anxiety and defensive reactions (Johannes *et al.*, 2001; Hajcak *et al.*, 2003; Hajcak and Foti, 2008; Inzlicht and Al-Khindi, 2012).

If randomness is aversive because it makes it harder to anticipate what will happen next, we should expect it to be associated with elevated performance monitoring. Past work has shown that increasing the salience of one's ideology (Amodio *et al.*, 2007) and religion (Inzlicht and Tullett, 2010) can reduce ERN amplitude, perhaps because these belief systems suggest that the world is an orderly and comprehensible place (Kay *et al.*, 2009; Inzlicht *et al.*, 2011). This reasoning, then, leads to *Hypothesis 2*: thinking the world is random should lead to increases in performance monitoring—as evidenced by an enhanced ERN—as a way to manage the unpredictability in the environment.

THE IMPORTANCE OF COMPREHENSIBILITY

If it is the case that order has these effects because it affords a sense of predictability—that is, of comprehending the causal relations present in the environment—then order that is 'incomprehensible' should have weaker effects on anxiety and performance monitoring. The importance of both order and comprehensibility become clear when you consider how goal-pursuit could proceed without them. Imagine, for example, trying to get a promotion in a company where you suspected that employee evaluations were completely random. Now imagine a slightly improved scenario where you suspected that evaluations were based on a system, but that the system was mostly inscrutable. Finally, consider pursuing the same goal in a company that had a transparent system for employee evaluation. These three scenarios exemplify what we will call randomness, incomprehensible order and comprehensible order, respectively. Theoretical models of sense-making suggest that comprehensible order should be most desirable because it suggests that predictability and controllability are attainable, whereas randomness should be most aversive because it suggests the opposite (White, 1959; McGregor *et al.*, 2009; Kay et al., 2009; Hirsh *et al.*, 2012; Proulx *et al.*, 2012).

Whereas some researchers suggest that order is comforting 'solely' because it affords comprehensibility, other researchers have maintained that people are drawn to order even when it remains mysterious (Kay *et al.*, 2009). In other words, although there may be some types of order that are better than others, all types should be better than randomness. Consistent with this line of thinking, people feel less anxious if they think that someone or something is in control of what happens, even when that control lies outside of the individual (Kay *et al.*, 2008; Laurin *et al.*, 2008). Here, as an ancillary hypothesis, we aim to see whether incomprehensible order has intermediate effects compared with comprehensible order and randomness.

Table 1 Demographic variables by condition in studies 1 and 2

	Age		Gender	
	M	s.d.	N_{female}	N_{male}
Study 1				
CO	33.38	12.58	56	71
IO	30.81	11.13	61	68
R	33.73	12.97	70	55
Study 2				
CO	21.67	6.53	6	9
IO	19.23	2.20	8	5
R	20.25	2.09	5	7

Note: CO = comprehensible order, IO = incomprehensible order, R = randomness. For Study 1, data is for included participants only.

STUDY 1

Our goal in Study 1 was to compare the effects of comprehensible order, incomprehensible order and randomness, on state anxiety. To accomplish this, we created three articles intended to prime each of these types of beliefs and examined their impact on people's self-reported feelings of anxiety. If order is more appealing when it is comprehensible, state anxiety should be lowest for comprehensible order, moderate for incomprehensible order and highest for randomness.

Method

Participants

Participants were recruited using Amazon's online crowdsourcing system Mechanical Turk (MTurk). A total of 487 participants (229 females, 218 males, 40 unspecified, $M_{age} = 31.86$ years, $s.d._{age} = 11.95$ years; Table 1) completed the experiment online for monetary compensation. We added 263 observations after analyzing the first 224 (from 300 and 250 MTurk slots, respectively). Data from 106 participants were excluded from analyses because the participant failed to complete the experiment ($N = 24$), failed an instructional manipulation check ($N = 54$; Oppenheimer *et al.*, 2009) or completed the experiment multiple times ($N = 28$). In cases where participants completed the experiment twice, only the data from the first completion was retained for analysis. This amount of data exclusion is not atypical for MTurk studies (Goodman *et al.*, 2012), but does present one limitation in establishing the generalizability of our findings.

Procedure

Participants were randomly assigned to read one of three articles: comprehensible order ($n = 127$), incomprehensible order ($n = 129$) or randomness ($n = 125$). The randomness article was intended to convey the idea that the world is 'neither' orderly nor comprehensible. The incomprehensible order article differed in that it suggested that the world is orderly, but beyond comprehension. Finally, the comprehensible order article was intended to convey that the world is 'both' orderly and comprehensible (Appendix A). After reading one of the three articles, participants completed the state version of the State-Trait Anxiety Inventory (STAI; Spielberger, 1983), which includes items like 'I am jittery' and 'I feel calm' (reverse-scored). Participants were instructed to use a 4-point scale (1 = 'not at all', 4 = 'very much so') to indicate how they feel '"right now", that is, "at this moment"'. Participants also completed a one-item measure of self-reported affect in which they used a sliding scale to indicate a value between 1 and 100 (higher numbers correspond to greater positivity). We report all data exclusions, all manipulations and all measures[1] in the study.

Pilot data with a separate sample of participants ($N = 88$) demonstrated that our manipulations were effective in temporarily influencing people's beliefs. Participants read one of the three articles and answered four questions about order (e.g. 'most events make sense in the grand scheme of things') and four questions about comprehensibility (e.g. 'humans are on their way to fully comprehending the world'). Reading the randomness article led people to report that the world was significantly less orderly ($M = 3.76$, s.d. = 0.92) compared with the other articles ($M = 4.42$, s.d. = 1.17), $t(87) = 2.62$, $P = 0.01$, $d = 0.56$. In addition, reading the comprehensible order article led people to report that the world was significantly more comprehensible ($M = 3.39$, s.d. = 1.29) compared with the other articles ($M = 2.87$, s.d. = 0.97), $t(87) = 2.12$, $P = 0.04$, $d = 0.45$. Thus, the two order articles appear to convey the idea that the world is orderly, and the comprehensible order article appears to convey the additional idea that the world is comprehensible.

Results and discussion

We hypothesized that STAI scores would be highest in the randomness condition, lowest in the comprehensible order condition and intermediate in the incomprehensible order condition. We made no specific predictions about whether incomprehensible order should differ from the other two conditions; rather, we anticipated that randomness and comprehensible order should be different, and incomprehensible order should fall between the two. In other words, we predicted a linear pattern across conditions. We conducted a regression predicting state anxiety from condition (coded using linear coefficients: randomness = −1, incomprehensible order = 0, comprehensible order = 1). The linear trend was significant, $\beta = -0.10$, $P = 0.04$. The quadratic effect of condition on state anxiety was not significant, $\beta = -0.04$, $P = 0.39$. We then looked at simple effects of condition (dummy coded), which revealed that randomness was associated with heightened state anxiety ($M = 1.91$, s.d. = 0.55) compared with comprehensible order ($M = 1.76$, s.d. = 0.53), $\beta = -0.12$, $P = 0.04$, $d = 0.28$. Incomprehensible order was associated with marginally increased state anxiety ($M = 1.89$, s.d. = 0.59) compared with comprehensible order, $\beta = -0.10$, $P = 0.08$, $d = 0.23$. Incomprehensible order was not significantly different from randomness, $\beta = -0.02$, $P = 0.78$, $d = 0.04$. These results suggest that reading about randomness increases anxiety relative to reading about comprehensible order. Furthermore, the observation that messages about incomprehensible order had an intermediate effect suggests that order has its palliative effects in part because it helps people understand the world.[2]

We conducted to the same linear regression to examine the effect of condition on self-reported affect. This analysis revealed a positive non-significant linear trend across the three conditions, $\beta = 0.07$, $P = 0.13$. The direction of this effect is consistent with that observed for the STAI, but it may be the case that measures of general negative affect are less effective at capturing people's response to the articles than are measures that specifically target anxiety.

STUDY 2

In Study 1, we observed that the comprehensible order condition led to decreased state anxiety relative to the randomness condition, with the incomprehensible order condition having an intermediate effect. In Study 2, we sought to extend this finding by examining whether these manipulations had a corollary effect on performance monitoring. To do so, we examined how the three articles used in Study 1 influenced participants' ERN amplitude during the multi-source interference task (MSIT; Bush and Shin, 2006). We expected to observe the same linear trend as in Study 1 (i.e. randomness > incomprehensible order > comprehensible order).

Method

Participants

Sixty-two introductory psychology students (19 females, 21 males, 15 unspecified) at the University of Toronto Scarborough ($M_{age} = 20.45$, $s.d._{age} = 4.37$) participated for course credit. We determined sample size by deciding to collect data until the end of the semester, provided that we had reached at least $N = 60$. Data from six participants were excluded from analyses because of experimenter error ($n = 2$), technical issues during the experiment ($n = 3$) or excessive artifacts identified before data analysis ($n = 1$). This left 20 participants in the comprehensible order condition, 18 participants in the incomprehensible order condition and 18 participants in the randomness condition.

Procedure

Participants were randomly assigned to read one of the three articles used in Study 1. To allow us to control for baseline ERN amplitude, participants completed the MSIT both before and after reading the article. For each trial on the MSIT, three numbers appeared on the screen and participants were asked to press a button that corresponded to the unique number. Participants responded using three buttons labeled 1, 2 and 3 from left to right. For control trials, the position of the unique number was aligned with the position of the button (i.e. 2 2 3), whereas for interference trials, the position of the unique number did not align with the position of the button (i.e. 2 2 1). A trial consisted of a fixation cross ('+') presented for 500 ms, followed by the number-string presented for 150 ms with an unlimited response window. For each administration of the task, participants completed five blocks, each comprised of 30 control trials and 15 interference trials.

EEG during both administrations of the MSIT was recorded using a stretch Lycra cap embedded with 32 tin electrodes. Recordings were digitized at 512 Hz using ASA acquisition software (Advanced Neuro Technology B.V., Enschede, the Netherlands) with a digital-average-ear reference. Data were then analyzed offline using ASA analysis software (Advanced Neuro Technology B.V., Enschede, the Netherlands). EEG was corrected for vertical electro-oculogram artifacts (Gratton *et al.*, 1983)

[1] In Study 1, we also assessed self-reported reactions to a fabricated news article, an individual difference measure of personal need for structure (Neuberg and Newsom, 1993). For the sake of brevity and because our main focus was state anxiety, we do not discuss these other measures further. Data from these measures are available on request from the first author.

[2] If we conduct the same analysis including the 54 participants who failed the instructional manipulation check we see the same linear trend, $\beta = -0.11$, $P = 0.02$. If we conduct the same analysis using only the first 224 participants we see a similar, but non-significant, linear trend, $\beta = -0.11$, $P = 0.18$.

and digitally filtered between 0.1 and 15 Hz. The period between 200 and 100 ms before keypress was used for baseline correction. Artifacts were automatically detected with −75 and +75 μV thresholds. For each artifact-free trial, an epoch was defined between 200 ms before and 800 ms after the response. Data for these epochs were averaged within participants independently for correct and incorrect trials but collapsed across control and interference trials. These data were then grand-averaged within the three experimental conditions. The ERN was defined as the peak minimum deflection at electrode-site FCz between 50 ms before and 150 ms after the keypress. ERNs were based on no fewer than six artifact-free trials (Olvet and Hajcak, 2009). In an effort to most effectively isolate the component of interest, we follow the recommendation of Luck (2005) and report ERN amplitudes as difference scores (error–correct). Finally, participants completed one item assessing anxiety (‘anxious’), as well as five items assessing negative affect (‘angry’, ‘irritated’, ‘annoyed’, ‘distressed’, ‘bored’) and three items assessing positive affect (‘relaxed’, ‘calm’, ‘content’). We report how we determined our sample size, all data exclusions, all manipulations and all measures[3] in the study.

Results and discussion

ERN amplitude

Our main prediction was that after controlling for baseline ERN amplitude, post-manipulation ERN amplitude would be largest in the randomness condition, intermediate in the incomprehensible order condition and smallest in the comprehensible order condition (see Table 2 for descriptive statistics). This result would indicate that the manipulation has comparable effects on self-reported state anxiety and ERN amplitude. To test the linear trend, we conducted a regression predicting post-manipulation ERN amplitude from condition (coded using linear coefficients: randomness = −1, incomprehensible order = 0, comprehensible order = 1) and pre-manipulation ERN amplitude (centered). The linear trend was significant, $\beta = 0.31$, $P = 0.01$. The quadratic effect of condition on ERN amplitude was not significant, $\beta = 0.08$, $P = 0.50$. We then looked at simple effects of condition (dummy coded), which revealed that randomness was associated with increased ERN amplitude ($M = -3.23$, s.d. = 3.07) compared with comprehensible order ($M = -1.95$, s.d. = 2.78), $\beta = 0.36$, $P = 0.01$, $d = 0.44$. Incomprehensible order was associated with marginally greater ERN amplitude ($M = -2.77$, s.d. = 3.10) compared with comprehensible order, $\beta = 0.25$, $P = 0.07$, $d = 0.28$. Incomprehensible order was not significantly different from randomness, $\beta = 0.10$, $P = 0.46$, $d = 0.15$ (Figure 1). Pre-manipulation ERN amplitude was a significant predictor of post-manipulation ERN amplitude, $\beta = 0.72$, $P = 0.02$, but did not interact with condition, $\beta s < 0.2$, $Ps > 0.4$. Thus, the pattern of results for ERN amplitude was similar to that for self-reported anxiety (Figure 2).[4]

Table 2 Peak and mean ERN amplitude

	Pre-manipulation				Post-manipulation			
	Error		Correct		Error		Correct	
	M	s.d.	*M*	s.d.	*M*	s.d.	*M*	s.d.
Peaks								
CO	−5.21	4.19	−.80	2.15	−2.90	2.59	−.95	1.78
IO	−4.22	3.74	−1.39	1.87	−3.61	3.60	−.84	2.21
R	−4.09	2.89	−1.55	2.15	−4.65	2.86	−1.42	2.27
Means								
CO	−0.53	0.63	0.14	0.37	−0.11	0.40	0.16	0.40
IO	−0.31	0.48	0.00	0.34	−0.21	0.56	0.14	0.47
R	−0.35	0.39	−0.01	0.43	−0.35	0.46	0.09	0.44

Note: Data are displayed for peak and mean amplitude between 50 and 150 ms after keypress. CO = comprehensible order, IO = incomprehensible order, R = randomness.

MSIT performance

There were no significant effects of condition on either error-rates or reaction times for correct trials, $Fs < 1.0$, $Ps > 0.4$ (see Table 3 for descriptive statistics). In addition, the linear effect of condition on ERN amplitude remained significant when controlling for overall error-rate and overall reaction time for correct trials, $\beta = 0.30$, $P = 0.01$, suggesting that the manipulation influenced ERN amplitude independently of effects on actual performance (Yeung, 2004). Although some researchers have suggested that there should be a link between ERN amplitude and performance (Carter *et al.*, 1998; Holroyd and Coles, 2002), there is also substantial evidence of a dissociation between these two measures (Weinberg *et al.*, 2012). In light of these latter results, it may not be surprising that our manipulation affects the ERN without influencing performance.

Self-reported affect

The linear trend for state anxiety was $\beta = 0.18$, $P = 0.28$, while for negative affect it was $\beta = 0.12$, $P = 0.45$, and for positive affect it was $\beta = -0.28$, $P = 0.08$. Although non-significant, the trends for self-reported affect are in the opposite direction of that observed in Study 1. We expect that this discrepancy occurred for one of two reasons. First, in Study 1 state affect was measured immediately after reading the article, whereas in Study 2 it was measured after participants completed the MSIT, thus leaving time for participants' affect to by influenced by things other than the article. Second, Study 1 had substantially higher power than Study 2, allowing us to obtain more precise estimates of effect size.

GENERAL DISCUSSION

Our results demonstrate that randomness increases self-reported anxiety and ERN amplitude compared with comprehensible order. We interpret this as converging evidence that randomness may evoke an aversive state characterized by increased anxiety and heightened performance monitoring. People who were told that the world is orderly but incomprehensible showed marginal increases in anxiety and ERN amplitude compared with those who read about comprehensible order, suggesting that order in and of itself may not be enough to dispel such aversive reactions completely. Thus, these results lend empirical support to a basic tenet of theoretical accounts of the aversiveness of inconsistency (Festinger, 1957), mortality (Greenberg *et al.* 1986),

[3] In Study 2 we also included individual difference measures of pain threshold, tolerance, religious and scientific belief, awe (Adler and Fagley, 2005), coping with uncertainty (Greco and Roger, 2001), personal need for structure (Neuberg and Newsom, 1993) and the big five inventory (John and Srivastava, 1999; John et al., 2008). For the sake of brevity and because our focus here is ERN amplitude and MSIT performance we do not discuss these other measures further. Data from these measures are available on request from the first author.

[4] Conducting the same analysis using the mean amplitude between 50 and 150 ms after keypress revealed the same linear trend, $\beta = 0.16$, $P = 0.04$. Another way to analyze these data is to conduct a 2 (response type: error *vs* correct) × 2 (task version: pre-manipulation *vs* post-manipulation) × 3 (condition: comprehensible order *vs* incomprehensible order *vs* randomness) mixed analysis of variance (ANOVA). Performing this analysis with peak amplitude as the dependent measure revealed a main effect of response type such that ERN amplitude was larger for correct responses than for errors, $F(1, 53) = 59.44$, $P < 0.001$. We also observed a main effect of task version such that ERN amplitude was larger for the pre-manipulation MSIT compared with the post-manipulation MSIT, $F(1, 53) = 4.74$, $P = 0.03$. Finally, we observed the predicted three-way interaction $F(2, 53) = 5.72$, $P = 0.006$. Examining the simple effects suggested that this interaction was driven by a significant decrease in ERN amplitude from pre-manipulation to post-manipulation MSIT for error trials in the comprehensible order condition, $F(1, 53) = 12.19$, $P = 0.001$, and also a significant (but smaller) decrease in ERN amplitude from pre-manipulation to post-manipulation MSIT for correct trials in the incomprehensible order condition, $F(1, 53) = 4.28$, $P = 0.04$. Conducting this same three-way ANOVA with mean amplitudes gave the same significant three-way interaction, $F(2, 53) = 4.79$, $P = 0.01$, and the same pattern of simple effects.

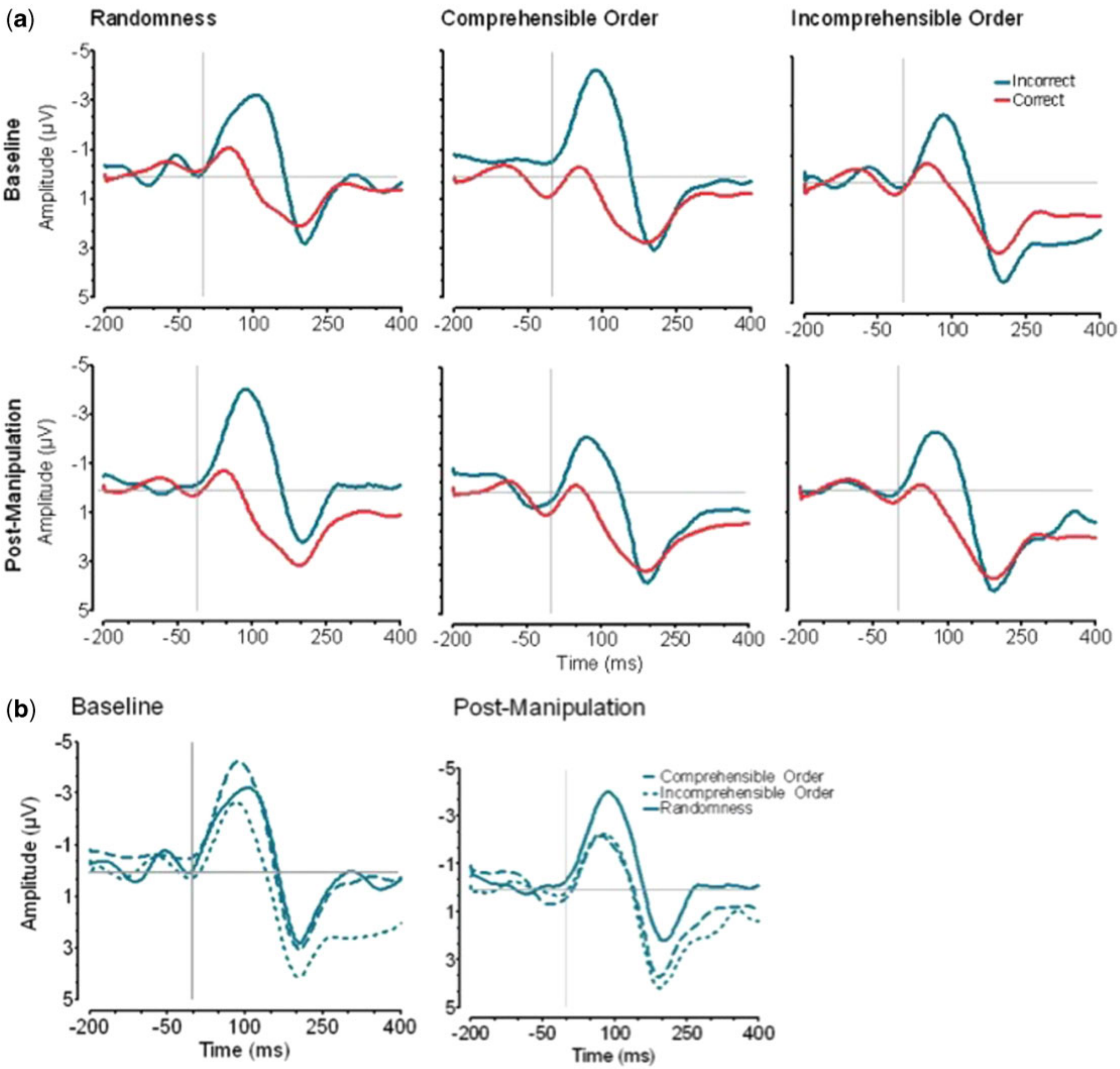

Fig. 1 (**a**) Pre- and post-manipulation event-related brain potential waveforms for all response types and conditions. (**b**) Pre- and post-manipulation event-related brain potential waveforms for incorrect trials only. Negative amplitudes are plotted upward.

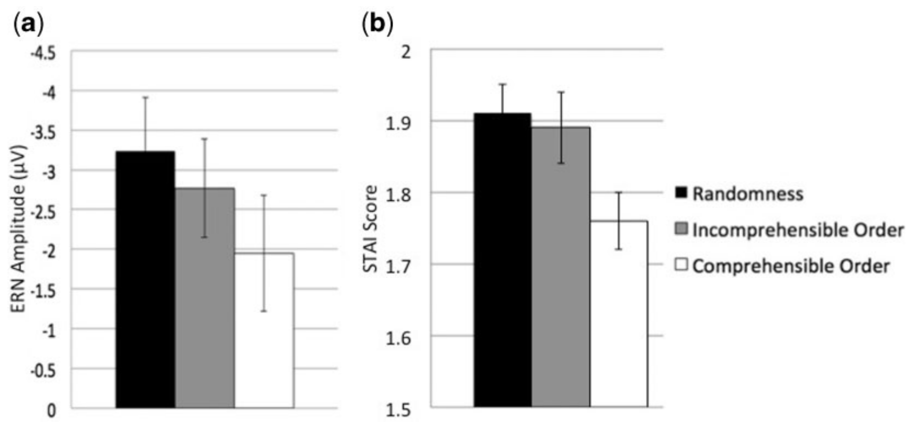

Fig. 2 Effect of condition on (**a**) ERN amplitude (negative amplitudes are plotted upward) and (**b**) STAI score.

Table 3 Performance data for the MSIT

	Pre-manipulation				Post-manipulation			
	Control		Interference		Control		Interference	
	M	s.d.	*M*	s.d.	*M*	s.d.	*M*	s.d.
Error rates (# errors/# trials)								
CO	0.01	0.01	0.22	0.12	0.01	0.01	0.20	0.14
IO	0.02	0.01	0.29	0.15	0.01	0.01	0.22	0.15
R	0.02	0.02	0.28	0.21	0.01	0.02	0.16	0.16
Reaction times for correct responses (ms)								
CO	435	60	732	112	414	55	681	119
IO	480	91	784	146	440	58	747	145
R	456	68	779	191	422	47	722	148
Reaction times for incorrect responses (ms)								
CO	420	85	641	150	2376	6061	550	85
IO	480	213	673	120	1647	3019	1085	1593
R	478	61	660	116	1669	2479	876	861

Note: CO = comprehensible order, IO = incomprehensible order, R = randomness. *N*s for reaction times for incorrect responses vary between 30 (post-manipulation control trials) and 61 (pre-manipulation interference trials) due to the exclusion of participants who made no errors.

meaninglessness (Heine *et al.*, 2006), lack of control (Kay *et al.*, 2009, 2014), injustice (Lerner, 1980) and trauma (Janoff-Bulman, 1989).

The effects that we observe in these two studies emerged as a result of relatively minimal changes in wording that were specifically relevant to orderliness and comprehensibility (Appendix A). Nevertheless, reading this type of content could influence anxiety and neural indices of performance monitoring through multiple potential avenues. One possibility is that it could temporarily shift people's beliefs to be more in line with the content expressed in the article. This is the interpretation we find most plausible, and is consistent with participants' responses in our pilot study. An alternative possibility is that reading these types of articles could introduce demand characteristics that lead participants to report changes in belief (accounting for our pilot study results), and to exhibit greater anxiety and heightened ERN amplitude. While it is plausible that the pilot study items could be at least partially accounted for by a demand explanation, it seems less likely that this would explain our results in Studies 1 and 2. Because we did not assess post-manipulation beliefs in Study 1 or Study 2 we cannot directly test whether these changes in belief mediated our effects. Taking the results of the two studies and the pilot study together, however, suggests that a temporary change in beliefs is the most parsimonious explanation for our effects.

In Study 2, the pattern of ERN results may appear to be at odds with previous findings, showing that violations of predictability are associated with increased neural indices of performance monitoring (Yasuda *et al.*, 2004; Oliveira *et al.*, 2007). In other words, one might expect violations of order (which plausibly include errors) to be particularly salient when the orderliness of the world has just been emphasized. This account is based on the idea that errors should be more unexpected and thus associated with larger ERNs, when participants read about comprehensible order. Indeed, there is no way to rule out this possibility in the current paradigm, as we do not assess people's performance expectations and thus cannot directly evaluate the influence of the comprehensible order prime on error expectation.

One alternative possibility, consistent with the findings reported here, is that rather than affecting participants' 'expectations' regarding errors, the manipulation influences their 'state of mind' on making such errors. Presumably, when people are told that the world they live in is largely random, this should increase vigilance and anxiety and enhance reactivity to errors as a consequence. This interpretation is consistent with our observation that the comprehensible order condition decreases self-reported anxiety. It would be informative for future research to directly examine these two possible accounts.

Although we found a similar pattern of results for both self-report and psychophysiological dependent variables, the size of the effects that we observed varied considerably across the two studies. When comparing the randomness and comprehensible order conditions the observed effect size was considerably larger for the ERN ($d = 0.44$) than for the STAI ($d = 0.28$). This could be an indication that the ERN is more sensitive to subtle changes in motivational state than measures, like the STAI, that require the ability to consciously detect, recall and report such changes. Because physiological and experiential measures of emotion are not always highly correlated (Mauss *et al.*, 2005), it could be informative for future research to investigate how these measures differentially relate to important outcomes.

In our paradigm, the pattern of means suggests that comprehensible order may have stronger effects on anxiety and ERN amplitude than incomprehensible order. Although the robustness of this finding is still unclear, it is consistent with the idea that order is more comforting when it can be understood (White, 1959; Kay *et al.*, 2009; McGregor *et al.*, 2009; Proulx *et al.*, 2012). Conceivably, however, there could be situations in which incomprehensible order would be particularly appealing. When living in highly uncertain environments, people might be willing, or even eager, to give up the burden of understanding without abandoning a belief in order (Inzlicht *et al.*, 2011). Indeed, religious beliefs, which often emphasize the existence of incomprehensible phenomena, are more prominent in times of uncertainty (Pargament *et al.*, 2005). Furthermore, belief systems that offer order without promising predictability or comprehensibility have the advantage of being less likely to be challenged or falsified by observed events (Inzlicht *et al.*, 2011).

According to our interpretation of these findings, people who read that world is random exhibit heightened anxiety and an enhanced ERN because randomness implies that the world is less predictable. Theoretically, however, one might expect that if the world were completely random, anxiety and performance monitoring would 'not' be adaptive responses because they would serve no function; anxiety and performance monitoring should have no adaptive benefit in a world where outcomes are literally impossible to predict. This hypothesis is conceptually interesting, but we expect that in practice it is very rare for people to wholly embrace the idea that events are truly random, in part because there is substantial evidence to the contrary, and in part because even in deliberately contrived scenarios people have trouble accepting and understanding random events (Tversky and Kahneman, 1971; Gilovich *et al.*, 1985).

It seems apparent that human beings are driven to make sense of the world around them. People exhibit a curiosity about the way things work—from the nature of particles to the behavior of people—that goes beyond practicality. The research presented here demonstrates that people find the idea of randomness aversive. Furthermore, it suggests that belief systems that reinforce the orderliness and comprehensibility of the world can act as buffers against that anxiety. Understanding this phenomenon may shed light on why people generate explanations for even the most complicated events and why they are resistant to changing them.

Conflict of Interest

None declared.

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APPENDIX A

Comprehensible order article

Every year, philosophers and scientists from around the world commune for a week-long conference at Harvard University to discuss one of the questions that has fascinated and frustrated the human species for centuries: Is there a meaning, a greater purpose or order, to the events that make up our lives? According to conference organizer Kenneth Burton, this year the various research projects and theories are beginning to converge on a strong theme. It is becoming more and more apparent that 'there is an underlying order, or meaning', to all of the events that happen in our lives, large or small. Whether we see this 'as a divine plan' or not, it is becoming clear that 'the events in our lives are not random, but are part of a large and complicated order'. We should remember, notes Burton, 'the human mind is almost unlimited in its ability to comprehend great complexity. We have the capacity to understand how everything makes sense within the grand scheme of things—we just need to utilize this ability to its fullest'.

Incomprehensible order article

Every year, philosophers and scientists from around the world commune for a week-long conference at Harvard University to discuss one of the questions that has fascinated and frustrated the human species for centuries: Is there a meaning, a greater purpose or order, to the events that make up our lives? According to conference organizer Kenneth Burton, this year the various research projects and theories are beginning to converge on a strong theme. It is becoming more and more apparent that 'there is an underlying order, or meaning', to all of the events that happen in our lives, large or small. Whether we see this 'as a divine plan' or not, it is becoming clear that 'the events in our lives are not random, but are part of a large and complicated order'. We should remember, notes Burton, that 'our perspective as humans is very limited and will always be overwhelmed by the complexity of the world. We will never be able to understand how everything makes sense within the grand scheme of things; we just need to trust that it does'.

Randomness article

Every year, philosophers and scientists from around the world commune for a week-long conference at Harvard University to discuss one of the questions that has fascinated and frustrated the human species for centuries: Is there a meaning, a greater purpose or order, to the events that make up our lives? According to conference organizer Kenneth Burton, this year the various research projects and theories are beginning to converge on a strong theme. It is becoming more and more apparent that 'there is no underlying order, or meaning', to all of the events that happen in our lives, large or small. Whether we see this 'as evidence against a divine plan' or not, it is becoming clear that 'the events in our lives are largely random, and not part of some large and complicated order'. We should remember, notes Burton, that 'this means it doesn't matter how advanced our understanding of the world becomes. It is pointless to make sense out of everything that happens; there might not always be any sense to make'.