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The fatigue illusion: the physical effects of mindlessness

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Attitudes that are blindly adopted, termed premature cognitive commitments, can place unnecessary limitations on how we perceive and engage in the world around us, including how we perceive fatigue. Fatigue is still widely treated as a somatic reaction, caused by physical limitations. In contrast to this, our hypothesis, based on Langer's mind/body unity theory, states that people perceive fatigue at proportional milestones during a task, regardless of how long it is, how strenuous it is, or whether it is physical or cognitive, and that fatigue can be manipulated psychologically. Five studies were designed to investigate (a) whether or not proportional perceptions of fatigue, or fatigue milestones, exists, rendering fatigue an illusion and (b) whether perceptions of fatigue are malleable by way of Langerian mindfulness, offering individuals control in the management of fatigue. Study 1 introduced a fatigue scale and used retrospective perceptions about travel-fatigue. Study 2 added an objective measure of physical fatigue in a cognitive task. Study 3 tested the illusion of fatigue on an athlete population in a physical task. Study 4 included the Langer Mindfulness Scale to further study subjective perceptions of fatigue in physical tasks. Study 5 tested mindful interventions on fatigue. The findings indicate that (a) an illusion of fatigue exists, with proportional set-in and peak milestones, what we label the fatigue illusion and (b) constructs of Langerian mindfulness offer individuals control over the timing, amount, and even the experience of fatigue.

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Introduction

"An alternate view of the world … one that recognizes how much of our reality is socially constructed, may actually afford more personal control" (Langer, 1989).

Individual perceptions are tightly yoked with the adopted understanding that the world is limited and fixed, an understanding that in many cases "narrows our sense of what is possible" (Langer, 1989: p. 33). When we think of our own potentials, we are invariably met with the concept of limited resources. Individuals mindlessly accept the absolute categories they adopt, including mind/body duality, or the segregation of physical and mental properties (Langer, 1989; Vogeley and Seitz, 1995). In contrast, the mind/body unity framework suggests that individuals have active mental control over physical ability to surpass dubious boundaries of potential (Carson and Langer, 2006; Grossman et al., 2003; Liu et al., 2012), one such boundary being fatigue.

Fatigue has been explored as a conscious feeling, arising in response to physiological changes, such as increased physical activity (Langer, 1989; St. Clair Gibson et al., 2003). This can be explained by processes that bind past experiences stored in memory with motivation and emotional states, as well as pre-experiential beliefs, to forecast estimations of reserves and tolerance about challenging tasks, also known as tele-oanticipation (Hampson et al., 2001). What we have titled the fatigue illusion refers to this process, namely that assumptions, either devised consciously or mindlessly accepted, based on learned and blindly adopted information, can limit individual potential. St. Clair Gibson et al. (2003) have theorized that differences in states during physical activity are mapped against a "proto-Self," and that the experience of increasing deviations from the proto-Self produces an increased conscious feeling of fatigue. While much research has focused on how the sensation of fatigue is manifested, and how perceptions function as a separate operation to physiological exertion (a dualistic mind/body approach; Hampson et al., 2001; St. Clair Gibson et al., 2003), we know of little research that has looked at how these assumptions of fatigue can be manipulated—how individuals can depart from their adopted understanding of fatigue and its limiting forces to operate in tandem with physiological exertion (a monistic mind/body approach). In this investigation, we use the theory of Mindfulness, as proposed by Langer's (1989) socio-cognitive definition, to explore how fatigue is mindlessly learned and adopted, and whether mindful approaches can postpone or even eliminate fatigue. Using previous evidence of fatigue milestones (Langer, 1989), where individuals perceived fatigue to set-in (FS) and peak (FP) at certain points during fatiguing tasks, even when not indicative of true energy reserves, we suggest that there exists a fatigue illusion that inhibits potential. Previous research concerned with exertion perceptions has likened this to a "perceptual barrier" (Hampson et al., 2001), which is often accepted as a fixed physiological operation. The antithesis to accepting anything as fixed, *Langerian Mindfulness* is the act of challenging our adopted forecasts, creating novelty, and requires the "continual creation of new [categories]" (Langer, 1989). It has been used to challenge adopted norms of aging (Levy et al., 2001), disease (Park et al., 2016), and mental health (Carson and Langer, 2006). This "reconfiguration of assumptions" (Levinthal and Rerup, 2006; as cited in Pirson et al., 2012: p. 5) that assists in altering experiences and lends individuals active control in how events are perceived, is how we propose individuals can influence their own fatigue and the fatigue illusion. As research shows that perceptions can indeed be shaped (Chanowitz and Langer, 1981; Stróżak, 2008), we suggest that fatigue, generally considered uncontrollable and adverse, may actually be managed to suit one's own will when approached with mindfulness.

Our multi-study investigation proposes that mindful techniques based on Langer's socio-cognitive definition can be used to postpone or eliminate fatigue milestones, and even the experience of fatigue itself. To examine this hypothesis, five studies were designed to examine (a) whether or not proportional perceptions of fatigue, or fatigue milestones, exists (e.g., regardless of length or complexity of the task), thus rendering fatigue an illusion and (b) whether perceptions of fatigue are malleable by way of mindfulness, offering individuals control in their own potentialities. The five studies were necessary in helping us generalize our findings (e.g., we used non-athlete and athlete populations and examined fatigue in a number of physical and non-physical tasks), and to investigate potential confounders and causal mechanisms. We formulated our conclusions from the assumption that proportionality of subjective perceptions of fatigue, in a variety of challenging tasks, would support the fatigue illusion, and not reflect actual energy reserves. Uncovering this proportionality of fatigue also adds to the literature by way of providing a useful metric of fatigue expression that can be appropriated in mindfulness intervention research, and provides further relevance in using duration of fatigue as a fatigue measure, an often-neglected dimension in the study of fatigue (DeLuca, 2005). Ultimately, the precise proportion when fatigue sets in or peaks, whether one-half or two-thirds or three-quarters of the way through, can vary from person to person or from task to task. The crucial insight is that fatigue sets in at a relative scale, proportional to the task—in other words, if the task is long, fatigue sets in much later. Thus, we propose that fatigue must be a psychological illusion, and therefore potentially malleable by way of mindfulness interventions.

Study 1: Self-reports of Long-Distance Travel

Consider the following situation:

> One day, I had to drive by myself from Boston to New York, which usually takes me about four hours. I began to feel tired mid-way to New York after driving for two hours. I grew increasingly tired over the next hour, however, as I approached New York, I suddenly felt increasingly less tired until I arrived at my destination. A few weeks later, I had to drive twelve hours from Boston to a city in Canada. Again, I started to experience fatigue after I drove for about six hours, and I experienced the most fatigue after driving for nine hours. My experience of fatigue gradually decreased after the nine-hour mark, as I got closer to my destination in Canada. On both car trips, I did not experience fatigue until I perceived I was around halfway through the travel distance, regardless of how much time I had spent in the car.

Based on the individual experience presented here, we began our investigation into the fatigue illusion by examining perceptions of fatigue as a result of travel duration, expecting that experiences of fatigue would set-in and peak at coinciding milestones, as a percentage of the way through different travel periods. Travel time provided an accessible first step in examining whether perceived FS and FP truly varies as a result of energy expenditures, or length of travel in this case, or if fatigue remains constant within standardized milestones, suggesting that fatigue is an illusion, and not indicative of energy costs.

Methods

Participants. Thirty-one college students of a private business school in the northeastern United States participated in the study for extra credit. Four participants were excluded from the data analysis because they had either reported to have not traveled long-distance (more than 3 h) within the past 3 months, or to have experienced no fatigue. Twenty-eight participants (60.7% female, 39.3% male; $M_{\text{age}} = 19.07$, SD = 0.54) were included in the data analysis. The data were collected in accordance with ethical standards for the treatment of human subjects. The survey lasted ~15 min.

Measures. All participants followed instructions on a computer using Qualtrics survey software to administer a brief questionnaire including the informed consent form, questions about their physical and mental ability to proceed with the task, as well as the task itself.

Procedure. We recruited participants in September, when they were more likely to have returned to school from the summer break involving long-distance travel within the past 3 months. Participants were asked to recall their experiences of long-distance travel (more than 3 h) within the past 3 months, by typing their total time of travel as a numerical number. For instance, if a 6-h road trip was the longest time of travel over the summer, then participants were instructed to type the number "6" in the provided slot. Participants were also asked to indicate whether the trip was by car, plane, both, or other, with the opportunity to name the other mode of transportation in a provided slot, and to indicate whether they were the driver, passenger, or both. Finally, participants were instructed to use a self-constructed sliding scale representing 0% (*time when the travel began*) to 100% (*time when the travel ended*) to indicate their FS and FP during their time of travel, and to indicate their level of fatigue for the moments of FS and FP on a self-constructed 10-point scale (1 = *no fatigue at all* to 10 = *extreme fatigue*).

The data that support the findings of this study have been deposited in the Harvard Dataverse, with the identifier [https://doi.org/10.7910/DVN/CBOYWO].

Results

Participants were placed in one of three travel-time categories according to the length of their long-distance travel within the past 3 months: 3- to 5-h, 6- to 10-h, and 11-or-more-hours. Descriptive statistics for main results of perceived FS and FP are presented in Fig. 1. Participants in the 3- to 5-h group reported that they started experiencing fatigue 51% (SD = 27.94%) of the way through their travel and experienced the most fatigue at 73.8% (SD = 25.6%) of the way through. Participants in the 6- to 10-h group reported that they started experiencing fatigue at 48.1% (SD = 40.2%) of the way through their travel and experienced the most fatigue at 72.2% (SD = 41.26%) of the way through. Participants in the 11-or-more-hours group reported they started experiencing fatigue at 53.09% (SD = 54.38%) of the way through their travel, and experienced the most fatigue at 82.2% (SD = 29.62%) of the way through.

One-way analyses of variance indicated there was no statistically significant difference among means of the three conditions for both dependent variables (FS and FP), $F(2, 25) = 0.11$, $p = 0.90$ and $F(2, 25) = 0.50$, $p = 0.61$, respectively. Furthermore, participants' reported levels of fatigue were also not significantly different across the three conditions for both FS(3–5 h: $M = 4.6$, 6–10 h: $M = 4.6$, and 11+: $M = 4.8$) and FP(3–5 h: $M = 5.9$, 6–10 h: $M = 7.2$, and 11+: $M = 7.7$), $F(2, 25) = 0.04$, $p = 0.96$ and $F(2, 25) = 1.55$, $p = 0.23$, respectively.

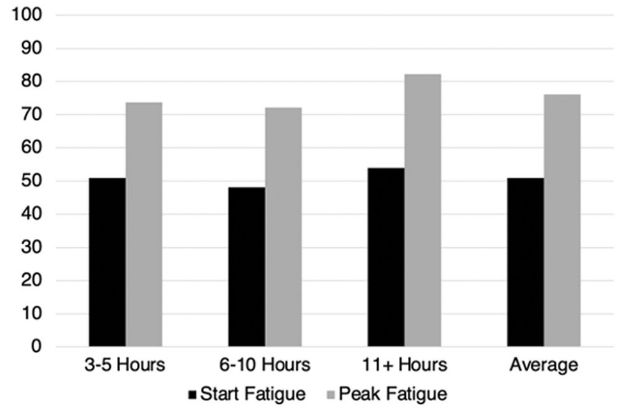

Fig. 1 Mean FS and FP for conditions. Start and peak fatigue are represented as a percentage of total travel duration for each condition. Differences in reported FS and FP between conditions were not significant.

Summary. Based on self-reports, participants indicated that they, on average, started experiencing fatigue about half-way through their travel and experienced the most fatigue around three-quarters-way through their travel, regardless of the actual duration of their travel. This finding displays that fatigue does not seem to be an absolute feeling, where we would expect it to arise after a certain time regardless of travel duration, but as a relative feeling, dependent on travel time. Non-significant differences in levels of fatigue for the conditions were also indicative that perceptions of fatigue were universally felt. Although these findings suggest that fatigue sets in and peaks at the same points in a task, in this case, long-distance travel, it could be that mitigating factors associated with a mentally fatiguing task impact FS and FP. We also concede that the method used here may induce retrospective survey bias. As mental tedium may vary with long-distance travel, and to mitigate retrospective survey bias, our next study had experimental conditions that varied the mental load of the task, while holding task-type and length constant, and surveyed participants immediately after the task.

Study 2: Counting Task

Whereas Study 1 provided evidence for a verifiable line of inquiry into the fatigue illusion, namely that self-reports of various long-distance travel had proportional fatigue milestones regardless of travel length, our next study sought to explore the mind/body connection; how perceptions about fatigue and physiology interact, by including an objective measure of fatigue. We designed a counting task, to explore the fatigue illusion on cognitive fatigue, with three conditions of varying task difficulty (holding time constant). Cognitively demanding tasks require extended and excessive use of executive resources, with research revealing that these tasks can deplete energy reserves (Aitken and MacMahon, 2019). We assumed that if fatigue follows pure energy consumption, participants in the higher cognitive load tasks would report earlier FSs and FPs. If fatigue follows the fatigue illusion, then we would expect no difference in perceived FS and FP between groups. Furthermore, because of existing research that has found evidence for diverging outcomes in the subjective experience of fatigue and observed evidence of fatigue (Cockshell and Mathias, 2013; Völker et al., 2015), we included an objective physiological measure of fatigue using Electroencephalography (EEG) waves to compare with self-reports of FS and FP. EEG waves often reflect brain cortex electric signals that aid in conveying physical responses to fatigue (Käthner et al., 2014). Amplitude analyses of Alpha-waves (8–12 Hz) reflect brain activity related to normal wakeful states—waves that are in contrast to Beta EEG, present when an individual is actively thinking and attentive (Kirstein, 2007). Käthner et al. (2014) reported that Alpha-waves were most sensitive in EEG outputs during cognitively demanding tasks, leading to our hypothesis that Alpha frequency bands would increase in activity as a response to fatiguing periods and decrease in activity in response to cognitive stimulation in the counting task. Furthermore, entropy analyses, which examine wave frequencies on spatial and temporal scales, provides information by quantifying uncertainty in wave patterns (Subramaniyam, 2018). Considering research (Aminoff, 2012) showing that Alpha frequencies wane during transitions to alert states, and that entropy levels decrease during periods of wave-length regularity (e.g., during administration of anesthesia; Subramaniyam, 2018), we expected less stability of wave patterns as participants fought to stay focused, and break out of fatigue, revealing higher entropy during periods of fatigue.

Lastly, in order to increase face validity of our self-constructed perceptions of the timing of fatigue scale, we added measures to capture perceptions about the timing at which participants believed they made the most mistakes, whether or not they wanted to stop the task, and, if so, when they wanted to stop the task. We hypothesized that participants' perceptions about when they believed they made the most mistakes and when they wanted to stop the task would be reported at consistent times as their self-reports of FP because this would be the point when participants would *feel* furthest from their proto-Self (St. Clair Gibson et al., 2003).

Methods

Participants. We recruited three hundred and one college students from the same private business school in the northeastern United States as Study 1 to participate in the study for extra credit. Seven participants were excluded from the data analysis because they did not complete the task. The data of the 294 participants (43.9% female, 53.5% male; $M_{\text{age}} = 19.54$, $\text{SD} = 1.78$) were used for the data analysis. The data were collected in accordance with ethical standards for the treatment of human subjects. The survey lasted ~35 min.

Measures. Qualtrics survey software was used to administer a brief survey including the informed consent form, questions about the participants' mental and physical ability to proceed with the task, as well as the task itself.

Headsets by Neurosky Mindwave were worn by participants during the entire counting task to record EEG wave data from the forehead (frontal cortex area). The Neurosky device has become well regarded by researchers in neuroscience because of its non-invasive applicability and relative low cost (Aboalayon and Faezipour, 2019). The device is electrode-based, consisting of a head band, ear clip, and forehead sensor. The raw data sampling rate of the headsets is 512 Hz and the eSense data rate is 1 Hz, which provided the calculated frequency bands (Alpha, Beta, Gamma and Theta waves). These signals were transmitted wirelessly (over radio frequency signals through serial ports) to the data collection laptop computer.

Procedure. When participants came to our laboratory, we seated them in front of a computer, placed the Neurosky Mindwave EEG headset on their head, and instructed them to follow the instructions on the computer screen. They were then randomly assigned to one of the three experimental groups: (a) 200-integer counting task, (b) 400-integer counting task, or (c) 600-integer counting task. The increase by 200 integers between groups was considered by the research team to (a) increase cognitive load, while (b) maintaining feasibility within the consistent time frames. In the 200ct task, participants were given a sheet with 200 randomly generated integers between 1 and 80. They were instructed to count the number of multiples of 3 within a string of 200 numbers and to use a pencil to mark each number that was a multiple of 3. In the other two conditions, the instructions and procedures were the same, except that there were 400 randomly generated integers between 1 and 80 for the 400ct task, and 600 randomly generated integers between 1 and 80 for the 600ct task. Participants in all three conditions were told that they had 15 min to complete the task. Thus, in Study 2, we varied the mental load of the task without varying the length of the task, as we had done in Study 1.

Immediately after the counting task, we asked the participants to use the same self-constructed sliding scale as in Study 1 representing 0–100% to report their FS and FP during the counting task (0% = *when participants started the counting task* and 100% = *when participants finished the counting task*). We also asked them to recall the level of fatigue on the same self-constructed 10-point scale (1 = *no fatigue at all* and 10 = *extreme fatigue*) used in Study 1 at the moments of FS and FP. Level of fatigue allowed us to evaluate our manipulation for cognitive load between groups (which we expected to increase correspondingly with increases in cognitive load) that we could compare with timing of fatigue (which we did not expect to fluctuate). In addition to perceptions about time and level of fatigue, we also asked participants to use an identical self-constructed sliding scale as for timing of fatigue, representing 0–100%, to report when in the task participants perceived that they made the most mistakes (0% = *when participants started the counting task* and 100% = *when participants finished the counting task*). Participants indicated whether they wanted to give up or not, and then used one more identical self-constructed sliding scale (0–100%) to indicate when in the task they wanted to give up (0% = *when participants started the counting task* and 100% = *when participants finished the counting task*). We recoded these last two sliding scale variables into quintiles (0–20% = 1, 21–40% = 2, 41–60% = 3, 61–80% = 4, 81–100% = 5), to examine whether perceptions landed, for instance, around the third quintile (~50%, where participants in Study 1 reported a universal FS) or the fourth quintile (~75%, where participants in Study 1 reported a universal FP), that we could compare with the reports of FS and FP in this study.

Finally, we used an electroencephalogram (EEG) to record participants' brain signals. Participants wore the Neurosky Mindwave headset throughout the entire duration of the task, and the EEG data acquisition was recorded from a computer over wireless transmission.

The data that support the findings of this study have been deposited in the Harvard Dataverse with the identifier [https://doi.org/10.7910/DVN/CBOYWO].

Results

Self-reports of Fatigue. Table 1 shows descriptive statistics for the self-reported FS and FP, and the level of fatigue for all three experimental conditions.

On average, participants reported a FS at 55.6% (SD = 29.31%) of the way into their task period, and a FP at 70.9% (SD = 27.39%) of the way into their task period. To test whether participants perceived a significant difference between FS and FP, we conducted paired sample (within-subject) *t*-tests. Results indicated that participants' perceived FS ($M = 55.6\%$) was

Table 1 Mean self-reports of FS and FP.

Condition	Fatigue start	Fatigue start level	Fatigue peak	Fatigue peak level
200 CT				
Mean	57.66	3.83	72.18	5.1
N	136	136	136	136
SD	30.34	2.42	28.81	2.87
400 CT				
Mean	53.98	4.16	69.52	5.65
N	81	81	81	81
SD	28.51	2.53	27.08	2.69
600 CT				
Mean	53.83	4.64	70.03	6.08
N	77	77	77	77
SD	28.43	2.43	25.31	2.57

significantly earlier in the counting task than their perceived FP ($M = 70.9\%$): $t(293) = -9.92$, $p < 0.001$; Cohen's $d = -0.58$, suggesting that participants' perceptions of the onset of fatigue was significantly earlier than when they perceived fatigue to peak. A one-way analysis of variance for the means between conditions, showed no significant difference for FS ($F(2,291) = 0.60$, $p = 0.55$, $\eta^2 = 0.004$) or FP ($F(2,291) = 0.29$, $p = 0.75$, $\eta^2 = 0.002$), indicating that participants reported a universal FS around 56% of the way through the task (in the third quintile) and a FP about 71% of the way through the task (in the fourth quintile) regardless of the mental load of the task.

Participants' self-reported level of fatigue when they first started experiencing fatigue was not significantly different across the experimental conditions, $F(2, 291) = 2.66$, $p = 0.079$, $\eta^2 = 0.018$. In contrast, participants' self-reported level of fatigue when they experienced the most fatigue *was* significantly different across the three experimental conditions, $F(2, 291) = 3.26$, $p = 0.04$, $\eta^2 = 0.022$, with post hoc tests indicating that the 600ct condition experienced the highest level of fatigue ($M = 6.08$, SD = 2.57), the 400ct condition experienced the next highest level of fatigue ($M = 5.65$, SD = 2.69), and the 200ct condition experienced the lowest level of fatigue ($M = 5.1$, SD = 2.87). This last finding demonstrates that the three conditions differed significantly in difficulty, serving as a manipulation check for our experimental group conditions.

Self-reports of Mistakes and Discontinuation of the Task. We first compared the standardized means of where in the task participants perceived they made the most mistakes among the three experimental groups: (a) 200ct ($M = 55\%$, SD = 25.3%), (b) 400ct ($M = 63\%$, SD = 23.1%), and (c) 600ct ($M = 53\%$, SD = 26.2). A one-way analysis of variance showed that, overall, there was no significant difference in standardized means for where in the task participants perceived they made the most mistakes for the conditions ($F(2,171) = 2.54$, $p = 0.082$, $\eta p^2 = 0.029$), however post hoc tests revealed that participants in the 400ct condition reported that they made the most mistakes significantly later in the task than the 600ct condition ($p = 0.036$). After running a within-subjects one-way analysis of variance (mean FS, mean FP, and mean point in task for most mistakes), results displayed that participants' mean FS (56%) and mean point-in-task for most mistakes (57%) differed significantly from participants' mean FP (71%; $F(2,582) = 36.67$, $p < 0.001$, $\eta p^2 = 0.112$), however there was no significant between-group effect for condition ($F(2,291) = 0.560$, $p = 0.572$, $\eta p^2 = 0.004$).

To further examine where in the task participants reported making the most mistakes, we broke the task into quintiles. Figure 2 shows the percentages of participants reporting mistakes in a specific quintile of task time for all three conditions, with findings

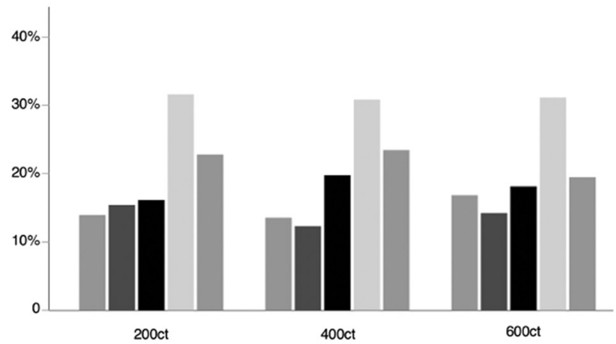

Fig. 2 Perceived mistakes. Duration of task is divided into quintiles for the three conditions displaying when in the task participants perceived they made the most mistakes. The *y*-axis displays the percentage of participants that reported mistakes for a given quintile in each condition.

clearly demonstrating that more participants perceived making more mistakes in the 4th quintile (about 61–80% through the task) than at other times in the task for all of the three conditions. Interestingly, these patterns were consistent across the three conditions, $X^2(8) = 1.437$, $p = 0.99$; the pattern of perceived mistakes by participants across the five quintiles was the same for all three conditions, regardless of the actual mental load of each task.

Out of the 294 participants, 59.2% reported wanting to give up at some point during the task (200ct = 49.3% of participants, 400ct = 65.4% of participants, and 600ct = 70.1% of participants). Figure 3 shows the quintile of where in the task participants wanted to discontinue the task. Even though a one-way analysis of variance showed no significance in mean differences for *when* in the task participants wanted to discontinue ($F(2,171) = 2.49$, $p = 0.086$, $\eta p^2 = 0.028$), pairwise comparisons did display that the 600ct condition ($M = 43\%$, SD = 25.2%) wanted to discontinue significantly earlier than the 200ct condition ($M = 53\%$, SD = 24.4%; $p = 0.029$).

A one-way ANOVA showed a significant difference among conditions for the percentage of participants who wanted to discontinue the task ($F(2, 293) = 5.478$, $p = 0.005$), with post hoc tests displaying that significantly fewer participants wanted to discontinue the task in the 200ct condition than the 400ct condition ($p = 0.048$) and the 600ct condition ($p = 0.008$).

Electroencephalogram (EEG). We used the Multi-Scale Entropy method (MSE; Costa et al., 2005) for measuring entropy of Alpha-waves at eight evenly divided stages during the task period. Figure 4 shows entropy and Alpha-wave peaks for each stage during the counting task. Observable peaks of compensation

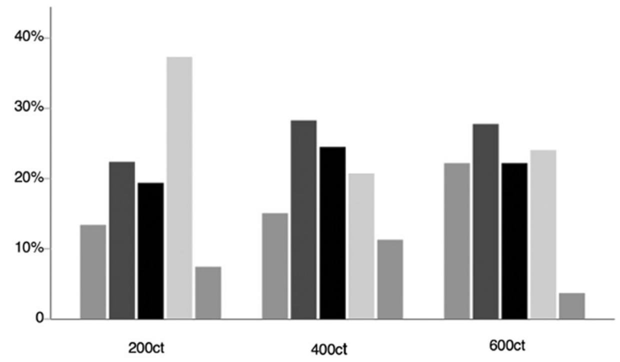

Fig. 3 Discontinuation. The *y*-axis represents the percentage of participants who wanted to discontinue the task for each condition separated into quintiles of task duration.

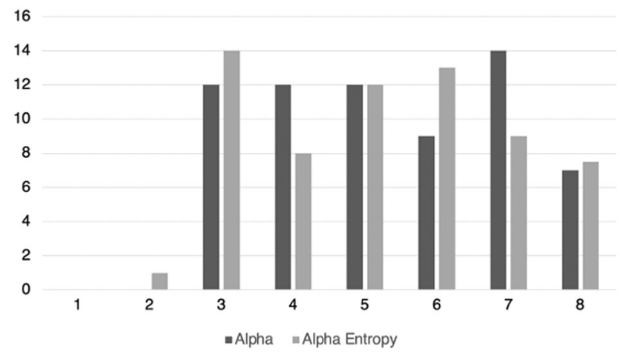

Fig. 4 EEG alpha-wave and entropy peaks. Alpha-wave peaks over eight task stages display periods of fatigue, and were observed during participants' reports of FS and FP. Alpha-waves that are accompanied by low-entropy reflect alpha-wave stability, whereas alpha-waves that are accompanied by high-entropy display alpha-wave instability as participants fought fatigue. Stage 8 displays stable alertness as participants ended their cognitive task, suggesting that energy was not depleted during reports of FP.

signals in Alpha band EEG wave amplitude were observed for the subjects during their reported fatigue periods, stages 3–5, and climaxing in stage 7. Alpha frequencies waned during transitions to alert states, where we surmise that participants assembled new energy resources. Peaks in Alpha entropy reflect Alpha-wave instability, with these fluctuations most likely displaying flexibility in adapting to fatigue, as observed in stages 5–6, alongside reduced Alpha band EEG wave amplitude at stages 6 and 8.

Summary

Self-reports of fatigue revealed a mean FS ~56% of the way through the counting task, and a FP ~71% of the way through, with no significant difference resulting from cognitive load, adding support to the fatigue illusion, namely that fatigue is not indicative of itself, but rather based on an adopted perception resulting in illusory milestones that don't reflect true energy reserves. Between-group differences in level of fatigue around FP provided a manipulation check for the difficulty of the task for each of the three conditions. This difference also shows that demand requirements for a cognitively fatiguing task may interface as cognitive stimulation, either moderating, or postponing, subjective perceptions of when an individual discerns their fatigue to peak for such tasks, or that the relationship between cognitive load and fatigue is better understood as a polynomial, where fatigue only begins to rise when load surpasses stimulation.

Mean reports for where participants felt they made the most mistakes aligned with reported FS, whereas the mode of reports aligned in the 4th quintile with FP, indicating that the area of fatigue sensation, running from about half-way to three-quarters of-the-way through a task, may be particularly susceptible for building the experiences that anticipate energy expenditure during fatiguing tasks, or teleoanticipation (Hampson et al., 2001). The alignment of perceptual reports within this area also supports face validity for our measurement scale for timing of fatigue perceptions.

Observable fallibility and compensation responses for fatigue (e.g., fighting to stay focused), as revealed in the EEG imaging results, displayed objective evidence for participants' consistent subjective responses to the timing of perceived fatigue. Conversely, entropy responses displayed clear endurance during fatiguing periods, specifically as participants fought fatigue and concluded their task. The human brain is a very flexible system, making calculated assumptions about challenging tasks by calling upon energy reserves at consistent stages indicating that full potentials may indeed be hindered by rigid perceptions. Our next investigation considered how individual differences in Affect and personality could influence calling upon these reserves in fatiguing tasks, while also testing the fatigue illusion on an athlete population, recognized for their ability to conceal fatigue.

Study 3: Ballerina Study

Knowing that physical and mental fatigue require similar cognitive resources (Evans et al., 2016), our natural next course of investigation was to design a task to examine the fatigue illusion in a physically fatiguing situation on a population accustomed to fatigue. The Ballerina study tested the fatigue illusion outside the Lab and on a population accustomed to pursuing a task in the face of physical pain and physical and mental exhaustion. Ballet dancers work 5–6 days a week, with full work days consisting of training in the morning and rehearsing through to the evening. Their bodies are trained to withstand physical discomfort, and their stamina aids in the completion of 2- to 3-h ballets in the face of blisters, painful joints and muscles, and in some cases, serious injuries. In contrast to other sports professionals, ballet dancers are required to conceal fatigue and injury, a feature that could challenge the fatigue illusion.

A pilot study was conducted to obtain raw holding times for a physically demanding task (holding *developpé a la seconde*) for both female ($N = 6$) and male ($N = 5$) professional ballet dancers from The Atlanta Ballet. For this study, we recognized, and wanted to account for, biological differences in physically demanding tasks, especially in ballet where male and female dancers are conditioned and trained to perform differently, thus leading to the outcome of biological differences in muscle mass[1]. The pose was consulted on by a professional ballet dancer (see Note 1) who trained for nearly 17 years, and has achieved over a decade of professional experience in ballet companies in both the U.S. and Europe. The criteria of the pose were based on difficulty, requiring that the demand be similar for both men and women, and task feature, that the pose be isometric (e.g., not continuous jumps), so that our objective measure could be easily assessed. We were informed that there exists wide variation in how ballet dancers perceive difficulty in ballet poses, thus developeé a la seconde at 90-degrees was chosen because of its general acceptance as a difficult pose in the ballet field. A developpé a la seconde involves holding the leg fully extended (i.e., without a bent knee) off the ground to the side, typically at a 90-degree angle or higher, and requires a very specific technique (e.g., leg "turned out" so the knee is facing up, pointed foot and toes, hips level, relaxed shoulders, etc.; see Fig. 5).

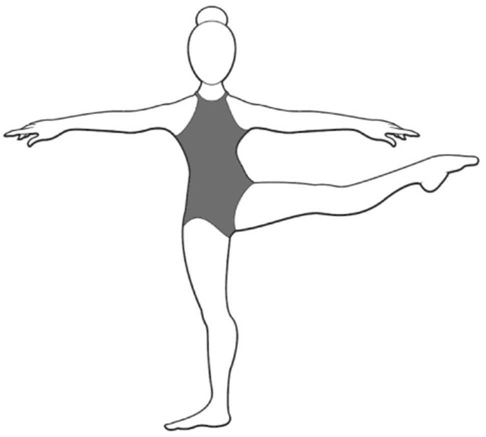

Fig. 5 Developpé a la Seconde. The figure shows the leg extended to the side at 90°. Toes are pointed, leg is turned outward and stretched straight, and shoulders are relaxed.

To explore length of task (similar to Study 1), and to control task-type (similar to Study 2), this study was designed to separate the physical aspect of fatigue as a potential contributor to the fatigue illusion. If physicality of fatigue is absolute, we would expect to see varying standardized set-in points relative to the duration of the task (e.g., 50% of the way through a 2-min task and 25% of the way through a 4-min task). Using the theoretical model of fatigue as a mind/body construct, we hypothesized that FS and FP would appear at consistent milestones for participants regardless of duration of the task, just like in our previous studies.

As in Study 2, an objective measure was used to compare subjective perceptions of timing of fatigue with observable evidence. The fatigue illusion specifies fatigue as a conscious manifestation, however, how it is affected by, and influential to, corporal events is not well understood (St. Clair Gibson et al., 2003). We, therefore, provided this objective measure to investigate this gap.

This study also began to further our investigation into the fatigue illusion by considering affective states and their possible influences on perceptions of fatigue. We hypothesized that negative affective states of dancer participants would correlate negatively with self-reports of FS and FP, and positive affective states of dancer participants would correlate positively with self-reports of FS and FP. This hypothesis stems from research showing that fatigue is positively associated with negative affect and negatively associated with positive affect (Denollet and De Vries, 2006). Considering affective states in our investigation allowed us to examine whether Affect operates as a related mechanism for the emergence of fatigue that can be manipulated by way of mindfulness, or cognitive flexibility. Furthermore, testing the fatigue illusion on a population accustomed to physical discomfort and mental exhaustion expanded the generalizability of our hypothesis.

Methods

Participants. Twelve volunteer dancers (4 male, 8 female) from the Hessen State Ballet in Wiesbaden, Germany participated in the study. They were randomly assigned ahead of the study to either a short-hold group (SH) or a long-hold group (LH) for each gender: (a) three females holding developpé 42 s, (b) five females holding developpé 48 s, (c) one male holding developpé for 70 s, and (d) three males holding developpé for 80 s. All dancers signed an informed consent form stating the possible risks and discomforts due to participation. All dancers were compensated 15 euro for their participation. The data were collected in accordance with the ethical standards for the treatment of human subjects. The study lasted ~30 min.

Measures. A pen-and-paper qualitative questionnaire was administered to examine participants' thoughts about dance, and ballet, specifically. Questions that analyze certain techniques that athletes use to mitigate fatigue, or muster energy, could be useful in our future pursuits to investigate mindful practices in fatigue in accord with Langer's socio-cognitive model (1989). The data from the questionnaire will be reported elsewhere and were not analyzed in the current study that was specifically interested in (a) establishing an illusion of fatigue and (b) exploring if the illusion of fatigue is malleable by way of mindful (Langer, 1989) manipulation.

Furthermore, to examine the relationship between Affect and perceptions of fatigue, participants were asked to complete the Positive and Negative Affect Scale-Short Form (PANAS-SF; Watson et al., 1988) consisting of 20 items (10 positive Affect items, such as "proud" and "determined," and 10 negative Affect items, such as "afraid" and "ashamed"). Participants were asked to gauge the extent to which they felt each Affect at the present moment. Individual Affect was measured by participants' responses on a 5-point Likert scale ranging from 1 (*very slightly or not at all*) to 5 (*extremely*). All forms were pen-and-paper.

Procedure

Subjective measures of fatigue. Upon entering the ballet studio of the Hessen State Ballet where the study took place, each dancer (masked to the study purpose) signed a consent form and then filled out a qualitative questionnaire to gauge perceptions towards ballet as an art form and physical exercise. Next, each dancer was asked to perform a side developpé at 90-degrees with their dominant leg and hold it for the time to which they were randomly assigned (SH or LH). An experimenter placed a stop-watch in front of the participant on a chair so that the participant could record their own time. Each dancer was also digitally video recorded while performing the task for later viewing by three objective observers. After the developpé task was completed, the dancers were given a pen-and-paper self-report form with each second of their holding time listed on a number-line. They were instructed to circle the second for when they started experiencing fatigue (FS) and for when they experienced the most fatigue (FP). For instance, if a dancer was asked to hold developée for 42 s, a scale indicating seconds 1 through 42 was presented to them with the opportunity to circle where on the number-line they felt fatigue for the various questions. Participants were also instructed to circle the number on a 5-point Likert scale for their level of fatigue at the moments of FS and FP (1 = *very mild* to 5 = *severe*). At the end of the study, all dancers were given the pen-and-paper PANAS-SF (Watson et al., 1988) to measure momentary affect at the time of reporting fatigue.

Objective observers. Video recordings of the 12 participants' SH and LH developpé tasks were given to three "blind" objective observers (2 males and 1 female). These objective observers were trained, professional (one current and two retired) ballet dancers. The objective observers were told to watch each video recording, start their own stop-watch at the same time as the experimenter on the recording, and to record in seconds when they believed the videoed dancer (a) started experiencing fatigue, and (b) experienced the most fatigue. Unlike the participant dancers who performed the task, the objective observers had no previous knowledge of the holding time assigned to each dancer. This distinction allowed us to compare perceived subjective fatigue accompanying a known stop-time with observable evidence of fatigue.

The data that support the findings of this study have been deposited in the Harvard Dataverse with the identifier [https://doi.org/10.7910/DVN/CBOYWO].

Results

Self-reports and objective observations were transformed into percentage scores for standardizing purposes. Data for FS and FP were entered for each participant and objective observer as a percent (e.g., a reported 20 s FS for a total hold of 42 s became 47.6% FS), indicating perceived FS for males, females, and objective observers in the SH and LH groups, and perceived FP for males, females, and objective observers in the SH and LH groups.

Preliminary analyses. Descriptive analyses to obtain overall means for all 12 participants showed that dancers reported a *M* FS at 32.6% (SD = 15.3%) of the way through the task and a *M* FP at 70.7% (SD = 19.9%) of the way through the task. Of note, is the more advanced report of FS than our previous studies, which were consistently reported in the 3rd quintile (around half-way) of the respective fatiguing task.

FS means for the three objective observers were 34.2% (SD = 13.33%), 69% (SD = 27.9%), and 16.1% (SD = 8.7%); FP means were 60.8% (SD = 21.35%), 85.1% (SD = 24.04%), and 46.4% (SD = 17.93%). An Intraclass Correlation Coefficient (ICC), based on Hallgren (2012), was calculated to examine inter-rater reliability for the three objective observers. Based on the fully crossed design, a random two-effects model was used to obtain an ICC for observed ratings of FS and FP. Results show poor inter-rater reliability for FS (ICC = 0.29) and good inter-rater reliability for FP (ICC = 0.66), suggesting that objective observations of fatigue in others may be more uniformly coordinated as individuals reach their subjective peak states of exhaustion. Consistent with Study 2, observable evidence for fatigue becomes apparent as the task becomes more subjectively fatiguing, and not before.

Subjective perceptions of FS and FP. To test whether participants perceived a significant difference between FS and FP, we conducted paired sample (within-subject) *t*-tests. Results indicated that participants' perceived FS ($M = 32.6\%$) was significantly earlier in the developpé task than their perceived FP ($M = 70.7\%$; $t(11) = -9.16$, $p < 0.001$; Cohen's $d = 2.15$), suggesting that participants' perceptions of the onset of fatigue is distinctly different than when they perceive fatigue to peak.

As noted above, different hold-times based on gender were established considering that males and females train differently in ballet, and therefore have differences in muscle mass (see Note 1). Holding times for the developpé task were calculated (females having shorter holding times than males) to account for gender differences from our pilot study. An independent-sample *t*-test indicated that there were no significant gender differences in subjective ratings of FS ($t(10) = 1.51$, $p = 0.162$; Cohen's $d = 0.84$; Females' $M = 37.08\%$, SD = 12.02%; Males' $M = 23.66\%$, SD = 19.09%) or FP ($t(10) = 2.19$, $p = 0.053$; Cohen's $d = 1.15$; Females' $M = 78.3\%$, SD = 11.8%; Males' $M = 55.4\%$, SD = 25.5%). Nevertheless, it should be noted that a gender difference for FP was close to significant, and the effect sizes for both FS and FP were large, perhaps due to our small sample size.

If fatigue was simply a physical construct, we would expect fatigue to set in at roughly the same absolute length of time (e.g., 20 s into the task) regardless of the duration of the task. Likewise, FS and FP would be perceived as starting later as a percentage of the way through the task in the SH task relative to the LH task. Independent-sample *t*-tests looking at differences between standardized reports of fatigue for SH and LH conditions revealed no significant difference for FS ($t(10) = 0.068$, $p = 0.947$; Cohen's $d = 0.04$; SH $M = 32.16\%$, SD = 18.91% versus LH $M = 32.83\%$, SD = 14.69%). There was also no significant difference between SH and LH conditions for standardized subjective ratings of FP ($t(3.295) = 0.346$, $p = 0.750$; Cohen's $d = 0.24$; SH $M = 66.65\%$, SD = 33.96% versus LH $M = 72.66\%$, SD = 10.59%). Considering the small group sizes (Males $n = 4$, Females $n = 8$, and SH $n = 4$, and LH $n = 8$), and large variances, these results are not conclusive; however, they suggest that the subjective ratings of FS and FP are not based solely on physical stamina, such that participants would be expected to fatigue after the same number of seconds have elapsed regardless of the task duration. In other words, results of this study indicate that the fatigue illusion functions irrespective of duration of task.

Level of fatigue was not significantly different between the conditions (SH vs. LH) for when participants started experiencing fatigue, $t(10) = 2.1$, $p = 0.062$, Cohen's $d = 1.29$, and when participants experienced the most fatigue, $t(10) = 1.72$, $p = 0.116$, Cohen's $d = 1.05$, although FS approached significance.

Positive and Negative Affect Scale-Short Form (PANAS-SF). To examine whether or not affective states impact perceptions about when fatigue begins and peaks, we first conducted a Principal Components Analysis (Varimax rotation) to determine factor loadings for the 20 individual PANAS-SF items. Five components were extracted from the Principal Component Analysis. The items that correlated on component 1 suggested a representation of "perseverance" (a combination of Determined, Enthusiastic, Proud, Excited and Attentive; for all $r > 0.75$), while the items that correlated on component 2 suggested a representation of "aversion" (a combination of Hostile, Afraid, Scared, Guilty, and Upset; for all $r > 0.75$).

Based on previous research that displays an inverted relationship between Affect and fatigue (Denollet and De Vries, 2006), we hypothesized that a greater degree of Perseverance at the time of reflection would correlate with reports of later FS and FP, and a greater degree of Aversion at the time of reflection would correlate with reports of earlier FS and FP. To test these hypotheses, we conducted one-tailed Pearson Product-Moment correlations between FS and Perseverance, FS and Aversion, FP and Perseverance and FP and Aversion. None of the correlations were significant: FS and Perseverance ($r(11) = 0.19$, $p = 0.27$), FP and Perseverance ($r(11) = -0.08$, $p = 0.41$), FS and Aversion ($r(11) = 0.11$, $p = 0.37$), and FP and Aversion ($r(11) = 0.27$, $p = 0.20$). Although we did expect some relation between timing of fatigue and Affect, this finding indicates that Affect seems not to induce variance in the perceived timing of fatigue, suggesting that the fatigue illusion is unaffected by affective states immediately following a fatiguing task.

Summary. Results from this study provided nuance to our fatigue illusion. Though the results from the Ballerina Study revealed an earlier subjective FS, about 1/3 of the way through the difficult task, than previous studies, we believe this may be due to the unique challenge of the task chosen for this study, suggesting that certain task demands may impact experiential markers of subjective FS ratings. Developeé a la seconde, as performed in this study (90-degrees at the ballet barre without music), is a highly technical step in ballet (see Note 1). The particular demand for executing this ballet position may differ, we propose, drastically from executing a ballet step involving movement and/or accompanied by music. This finding aids in our understanding of the possible limitations of the fatigue illusion, as well as its consistency, namely that fatigue is universally perceived to set-in after sometime, peak significantly later, and then subside, inferring that peaks in fatigue are not sole indicators of energy exhaustion.

Furthermore, we measured the impact of mood on the fatigue illusion. No correlations were found between results of the PANAS-SF and self-reported times of FS and FP, indicating that Affect immediately following difficult tasks does not affect when participants perceive fatigue to manifest or peak. This suggests that the fatigue illusion is a rather fixed phenomenon, unaffected by affective states at the time of reflection, allowing us to move our investigation to other forms of individual characteristics, and their possible impacts on the fatigue illusion.

Study 4: Hand-grip Task

Our natural next line of investigation was to expand our consideration of individual characteristics that could influence perceived fatigue while using a less strenuous physical task with various holding times. Studies 1 through 3 suggested that illusory fatigue milestones may conceivably interfere with individual potentials, as perceived fatigue did not follow task duration or task difficulty. However, variation in the fatigue illusion was identified from findings of earlier subjective FS reports in the Ballerina Study that implemented a highly difficult physical task. This study further examined the exposed constraint of the fatigue illusion by applying another, albeit less strenuous, physical task in the form of a hand-grip. Evidence displays that physically fatiguing tasks utilize both cognitive *and* respiratory/muscular mechanisms simultaneously, leading to perceptions of greater fatigue (Marcora et al., 2009). Our examination proceeded to investigate if the fatigue illusion is fallible to all physical tasks, or if it is better understood as functioning within a difficulty margin. Three conditions were designed with varying physical loads to be compared with a fourth condition that had an open-ended termination time. These gradations allowed us to (a) compare pre-prescribed reference points (end times) with an open-ended task and (b) compare varying conditions of physical load (measured by duration of task). The gradations between conditions were obtained from a pilot study, and were calculated to compare physical load while also conveying physical feasibility to participants. Furthermore, whereas Study 3 only investigated Affect as a possible determinant for perceptions of the timing of fatigue, this study continued investigating other possible individual trait correlates for perceptions of fatigue timing. Specifically, this study began examining our second overarching line of inquiry: whether fatigue milestones are malleable by way of mindfulness. We proposed that trait mindfulness (Langer, 1989), or the ability to reappraise a difficult task, would aid in fatigue management and control, by postponing perceived FS and FP simply by employing a flexible mindset towards a fatiguing task. This notion stems from mindfulness theory, as proposed by Langer (1989), that models individual physio-emotional outcomes as actor-driven, and expands on theoretical frameworks that outline the importance of reappraisals in psychological and physiological responses to stressful states (Jamieson et al., 2012).

For this study, we included various indices to aid in our investigation of the relationship between fatigue and various other psychological traits. We included the PANAS-SF (Watson et al., 1988), the Freewill and Determinism scale-Plus (FAD-Plus; Paulhus and Carey, 2011), and Cohen's Perceived Stress Scale (PSS; Cohen et al., 1983) to investigate these correlations. Based on research suggesting that stress sequesters energy, thus diminishing available energy reserves (Segerstrom, 2007; Hobfoll, 1988), we expected that stress would correlate positively with level of fatigue and negatively (earlier reported times) with FS and FP. Similarly, based on research showing that weaker beliefs in self-determined choice and control predict higher levels of stress (Gooding et al., 2018), and that positive affect acts as a stress-buffer (Pressman and Cohen, 2005), we expected that higher scores of Free Will on the FAD-Plus (the belief that people are responsible for their actions) and positive affect on the PANAS-SF would correlate negatively with level of fatigue, and positively (later reported times) with FS and FP, respectively. We also wanted to explore if scientific determinism on the FAD-Plus (the belief in biological determinants in outcomes) would correlate with level of fatigue, FS, and FP, however we had no directional hypothesis for this relationship, as there are multiple biological determinants for outcomes of perceived fatigue that were not measured in this study (e.g., strength, motivation, etc.). Lastly, we added the Langer Mindfulness Scale (LMS21; Pirson et al., 2012) to test the relationship between mindful outlooks (Langer, 1989) and perceptions of fatigue. To better explain how we expected trait levels of Langerian Mindfulness to influence perceptions of fatigue, mind*less*ness offers a convenient differentiation, defined as "a mindset of rigidity in which one adheres to a single perspective of distinctions/categories drawn in the past and acts automatically, oblivious to context or perspective" (Langer, 1989, cited in Pirson et al., 2012). In the context of fatigue, this portrays the tendency for an individual to perceive fatigue as purely adverse, thus prematurely assessing a difficult task as negative. We propose that Langerian mind*ful*ness, the ability to notice and produce novelty and see things in a new light, provides individuals with the ability to build new assessments of fatigue, so as to optimize fatigue management. Accordingly, we hypothesized that lower scores on the LMS21 would also correlate positively with level of fatigue and negatively (earlier reported times) with FS and FP.

Methods

Participants. Ninety-one male college students ($M_{age} = 19.41$, $SD = 1.37$) of the same private business school as Studies 1 and 2 in the northeastern United States participated in the study for extra credit. In light of the generally accepted gender differences in grip strength, we held gender constant, and used only males for this study. The data were collected in accordance with ethical standards for the treatment of human subjects. The survey lasted ~15 min.

Measures. Qualtrics survey software was used to administer a brief survey including the informed consent form and questions about participants' current physical and psychological conditions, as well as the task itself.

Trait mindfulness was measured using the Langer Mindfulness Scale-21 (LMS21; Pirson et al., 2012), to explore the relationship between participant mindsets and perceptions of fatigue. The LMS21 measures individual levels of mindfulness as defined by Langer (1989), a socio-cognitive construct that consists of four sub-structures: novelty producing, novelty seeking, engagement, and flexibility. The measure contains 21 items (e.g., "I am always open to new ways of doing things" and "I have an open mind about everything, even things that challenge my core beliefs"), and participants' responses are measured using a 7-point Likert scale ranging from 1 (*strongly disagree*) to 7 (*strongly agree*), with some items reverse-coded. Overall scores of the 21-items range from 21–147, with higher scores on the LMS21 indicating higher levels of mindfulness. The overall reliability of the instrument is robust ($\alpha = 0.83$).

The PSS (Cohen et al., 1983) was used to measure perceived stress. This questionnaire consists of 10 items (e.g., "In the last month, how often have you felt that you were unable to control the important things in your life?") and uses a 5-point Likert scale for participants' responses ranging from 0 (*never*) to 4 (*often*). This measure has an internal reliability of 0.72 and a test–retest reliability of 0.55.

The FAD-Plus (Paulhus and Carey, 2011) was used to measure scientific determinism and free-will, two of the four subscales in the index. The FAD-Plus consists of 27 items and participants use a 5-point Likert scale to indicate the degree to which they agree with the statements ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). Scientific determinism and free-will in the FAD-Plus index have a reliability of $\alpha = 0.69$ and $\alpha = 0.70$, respectively.

As in Study 3, the PANAS-SF (Watson et al., 1988) was used to measure whether participants' reports of Affect immediately following the task were correlated with their perceived fatigue.

Procedure. When participants arrived at the laboratory, they were seated in front of a computer that instructed them throughout the study. Participants were first instructed to fill out the digital LMS21 index, and then were randomly assigned to one of four experimental groups for a hand-grip task: (a) No-goal group (b) 120-s group (c) 180-s group, or (d) 240-s group. In the No-goal group, participants were instructed to squeeze a hand-grip exercise tool until the ends touched each other, and to hold the ends together as long as they could. For the other three experimental groups, a specific hold time was established: 120 s for Group 2, 180 s for Group 3, and 240 s for Group 4. After completing the hand-grip task to which they were randomly assigned, participants in the timed groups were asked to report their FS and FP using a self-constructed digital sliding scale created for their specific hold-durations. For instance, if participants were told to hold the hang-grip for 120 s, a sliding scale with seconds 0 through 120 was presented, with the opportunity to mark the second for their FS and FP. For participants who couldn't complete their task, and for participants in the No-goal group, they were asked to report how long they held the hand-grip exerciser in minutes and seconds in a provided slot. For instance, if a participant held the hand-grip for 45 s, they were instructed to put a "0" in the minute's column and "45" in the second's column. All participants were also asked to report their level of fatigue for the task on the same self-constructed 10-point scale (1 = *no fatigue at all* and 10 = *extreme fatigue*) as in Studies 1 and 2 for the moment they started experiencing fatigue and for the moment they experienced the most fatigue. At the end, participants filled out digital versions of the FAD-Plus, PANAS-SF, and PSS indices in that order.

The data that support the findings of this study have been deposited in the Harvard Dataverse with the identifier [https://doi.org/10.7910/DVN/CBOYWO].

Results

Participants' self-reports of FS and FP were transformed into a percentage of their total holding time for standardizing purposes (e.g., a self-report FS of 30 s for an individual holding the hand-grip in the 120 s group would be a FS of 25%).

Participants who couldn't complete the task. Thirty participants (33%) did not complete their full prescribed hand-grip holding task. The average point where participants stopped holding the hand-grip was 56.8% of the way through their respective task, about the time when most participants who didn't complete the task also reported their FP (57.6% of the way through their respective tasks). A one-way analysis of variance showed no significant difference between mean stop times for the participants who did not complete the tasks in the 120- ($M = 58\%$), 180- ($M = 61\%$), and 240- ($M = 54\%$) second groups, $F(2,28) = 0.375$, $p = 0.691$, $\eta^2 = 0.095$.

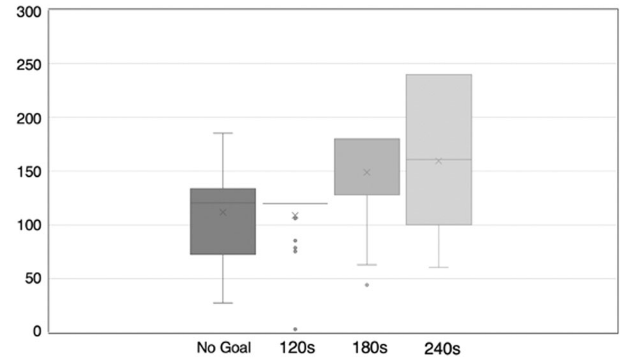

Fig. 6 Group comparisons of actual hold times. Interquartile ranges display an upward trend in achieved holding times for the conditions. The early completion of the No-Goal condition reflects a premature discontinuation of task when individuals are given no end time. The higher upper interquartile in the 240 s condition, that extends towards the higher whisker, also indicates how milestones (a termination point) aid potentials in completing tasks that would otherwise go undiscovered.

Self-reports of Fatigue. Figure 6 shows the group comparisons of actual holding times. In the No-goal group, participants held the hand-grip for a minimum of 27 s and a maximum of 186 s, with a calculated M FS at 32% (SD = 12.43%) of the way through their task and M FP at 44% (SD = 10.65%) of the way through their task. Participants in the 120-s group held the hand-grip for a minimum of 3 s and a maximum of 120 s with a reported M FS at 62% (SD = 29.53%) and M FP at 83% (SD = 19.5%) of the way through their task. Participants in the 180-s group held the hand-grip for a minimum of 44 s and a maximum of 180 s with a reported M FS at 58% (SD = 21.45%) and a M FP at 79% (SD = 23.64%) of the way through the task, and participants in the 240-s group held the hand-grip for a minimum of 61 s and a maximum of 240 s with a reported M FS at 40% (SD = 25.72%) and a M FP at 62% (SD = 23.6%) of the way through their task. Overall, participants reported a FS 48% (SD = 25.98%) and a FP 67% (SD = 25.14%) of the way through the hand-grip task.

A one-way analysis of variance, comparing group means, showed a significant difference in FS for the 4 conditions, $F(3,87) = 8.8$, $p < 0.001$, $\eta^2 = 0.223$, with post hoc tests revealing that the No-goal group ($M = 32\%$) reported significantly earlier FSs than both the 120-s group ($M = 62\%$; $p < 0.001$) and the 180-s group ($M = 58\%$, $p < 0.005$), and that the 240-s group reported a significantly earlier FS ($M = 40\%$) than the 120-s group ($M = 62\%$, $p = 0.010$). There was also a significant difference in means for FP across conditions, $F(3,87) = 18.32$, $p < 0.001$, $\eta^2 = 0.387$, with post hoc tests revealing that the No-goal group reported a significantly earlier FP (44%) than all other conditions: 120-s $M = 83\%$, $p < 0.001$, 180-s $M = 79\%$, $p < 0.001$, and 240-s $M = 62\%$, $p = 0.022$, and that the 240-s group reported a significantly earlier FP ($M = 62\%$) than both the 120-s ($p = 0.003$) and 180-s ($p = 0.022$) groups.

Participants' self-reported level of fatigue when they first started experiencing fatigue was not significantly different across the four experimental conditions, $F(3, 87) = 1.63$, $p = 0.188$, $\eta^2 = 0.053$, nor was there a significant difference for self-reported level of FP across the four experimental conditions, $F(3,87) = 2.02$, $p = 0.117$, $\eta^2 = 0.065$.

Indices. A one-tailed Pearson Product-Moment correlation showed no significant correlations between Free Will and Positive Affect for any of our dependent variables. There was, however, a significant correlation between stress and the level of fatigue at FP ($r = 0.180$, $p = 0.044$) and how long participants held the hand-grip ($r = -0.218$, $p = 0.019$). A two-tailed Pearson Product-Moment correlation showed no significant correlations between scientific determinism and any of our dependent variables.

Results from our one-tailed Pearson Product-Moment correlational analysis displayed a significant negative correlation between participants' level of fatigue at FS and LMS21 scores ($r = –0.293$, $p = 0.002$). Specifically, the subscales novelty seeking, novelty producing, and engagement had a negative correlation with participants' level of fatigue at FS ($r = –0.295$, $p = 0.002$; $r = –0.261$, $p = 0.006$, $r = –0.201$, $p = 0.028$, respectively). Furthermore, novelty producing had a significant negative correlation with participants' level of fatigue at FP ($r = –0.210$, $p = 0.023$), indicating that higher levels of mindfulness for these subscales may work to offset the burden of fatigue. Total mindfulness displayed no significant correlation for self-reports of FS or FP, providing more evidence for the rigor of the fatigue illusion.

Summary. We continued our line of inquiry into the fatigue illusion by examining physical fatigue in a hand-grip holding task. We also included indices that measured individual characteristics to further our investigation into factors that may mediate or moderate perceptions of fatigue. Results from this study indicated that participants without a pre-prescribed holding time (e.g., told to hold the hand-grip for as long as they could) reported a significantly earlier FS than all conditions except the longest holding group (those tasked with holding the hand-grip for 240 s) and FP than all other conditions. Of the 22 participants in the condition tasked with holding the hand-grip the longest (240 s), 6 participants (27.3%) were able to complete the task. This finding demonstrates the influence that goals (even if objectively difficult) have on perceptions of fatigue, specifically that goals, or end times, appear to defer perceptions of when individuals feel their fatigue to set-in and peak during difficult tasks. We arrive at this inference given findings that demonstrate how anticipated durations of fatiguing tasks aid in an individual's ability to regulate exertion, or teleoanticipation (Hampson et al., 2001). Unpredictable durations of fatiguing tasks are believed to invoke earlier perceptions of fatigue because the body lacks the required information to syphon energy appropriately (Hampson et al., 2001). From this finding, we can deduce that by purely providing end times, or goals, one can postpone the fatigue illusion.

Moreover, our results confirmed that level of fatigue, or the extent to which participants felt fatigued during the start of their perceived fatigue, was influenced by specific aspects of trait mindfulness (Langer, 1989). Specifically, individuals who are able to notice and construct novelty, and who are more engaged with their environment, reported lower levels of fatigue at FS. In other words, regardless of where fatigue begins to set-in, individuals who had higher mindfulness scores appeared to feel the effects of fatigue less at the time of reflection. Furthermore, trait stress and the ability to construct novelty had effects on participants' level of fatigue at FP, namely that reports of higher stress were associated with higher levels of fatigue, whereas an individual's competence in novelty producing seemed to mitigate fatigue.

The fatigue illusion also generally retained its rigor in this study; on average, results for reports of FS were reported 48% of the way through the hand-grip, and for FP, 67% of the way through the hand-grip task. Those tasked with a limitless goal reported significantly earlier FSs and FPs, suggesting that simply providing end times, or reference points, aids in perceptions of fatigue. We suggest that goals give individuals benchmarks to gauge energy during teleoanticipation and syphon it where needed. Tasks with an undetermined termination point provide no gauge, and present the potential for indefinite activity, a very ominous notion to conceive, and one that is assumed to be more inhibitory to fatigue management than conducive (Hampson et al., 2001). A logical gauge for energy references during activity may naturally reside around the half and three-quarters mark, even if these references are influenced slightly by task-type such as physical tasks (e.g., participants in the 240-s group reported a significantly earlier FS than the other shortest holding condition, and the Ballerina Study had an overall earlier FS than the other studies). This suggests that whereas the fatigue illusion displays resistance to direct effects of individual character, it may be influenced by these factors indirectly, where perspectives towards reference points in fatiguing tasks mediate the relationship between character and the fatigue illusion. These types of mindsets are grounded in Langerian Mindfulness, such as constructing new ways to approach undertakings. Our next and final study sought to investigate interventions along these lines, that could possibly influence how individuals perceive the timing of fatigue.

Study 5: The Fatigue Illusion and Mindfulness Manipulation

Studies 1 through 4 provided important data for our understanding of fatigue and its role in the mind/body unity theory. We were able to establish that an illusion about the timing of fatigue, where fatigue begins sometime after the start of a task, peaks sometime distinctly later, and abates, exists. Although deviation was found in certain physical tasks, the fatigue illusion seems to follow a general half-way and three-quarters way trajectory, and therefore, provided us with a baseline to begin applying Langerian Mindfulness interventions that could shift assumptions and perspectives of fatigue for the mitigation or elimination of the effects of fatigue.

We employed a mindfulness and discontinuous intervention to investigate whether or not FS and FP could be manipulated. These interventions were designed within the framework of Langerian Mindfulness (Langer, 1989; e.g., the act of challenging adopted forecasts and creating novelty). Trait mindfulness was once again measured using the Langer Mindfulness Scale as a control for investigating interventions of trait mindfulness. While the mindfulness intervention served to examine how individuals may manipulate the undertaking of a task, by creating novelty, the discontinuous intervention served to examine how manipulating the task itself affects individual perceptions (i.e., challenging adopted forecasts through task manipulation). In other words, the mindfulness intervention represented an internal change in perspective, while the discontinuous intervention represented an external change in perspective, both based within Langerian Mindfulness Theory (Langer, 1989).

The mindfulness intervention was developed as a way to continually draw subjects' attention to novelty, as the task inherently required participants to notice a change in difficulty with a change in a difficult finger task, which we expected to also enhance engagement.

The discontinuous intervention was developed as a way to externally manipulate the task, by unexpectedly tagging five additional minutes to a task that was originally instructed to last only five minutes, for a total of ten minutes. Given our previous results, we expected that subjects in this condition would experience fatigue around half-way into the original 5-min task (2.5 min). If fatigue were a purely physical phenomenon, then even after the second part of this task, we would expect participants to report fatigue onset at around 2.5 min (the absolute rather than relative FS), likely exacerbating their overall fatigue.

Methods

Participants. Fifty-seven participants were recruited in two separate-day sessions using the recruiting platform, Prolific. Two participants were excluded from the analysis for not completing the task. Twenty-five participants took part in the first session, and thirty participants took part in the second for a total of fifty-five participants (45.5% female, 54.5% male; $M_{age} = 25$, SD = 7.4). Participants were compensated $3.74 for session 1, and $5 for session 2. The compensation was slightly higher for session 2 due to a large falling-off of participation during our first session. The data were collected in accordance with ethical standards for the treatment of human subjects. The survey lasted ~30 min. The survey design was pre-registered on OSF (https://osf.io/j9xqd). Subjects were informed when recruited that they needed to have a working webcam and Zoom software and that they would be asked to raise their arm and hold it up for no more than ten minutes. Participants, were, however, masked to the study purpose.

Measures. Participants were given the Langer Mindfulness Scale-short form (LMS14; Pirson et al., 2012) to measure trait mindfulness. The LMS14 consists of 14 items that cover three main elements (novelty producing, novelty seeking, and engagement) as constructs of mindfulness proposed by Langer (1989).

State mindfulness was assessed using a reaction-time test where participants were measured on how quickly they could find the "odd shape out" from nine shapes. This test was administered before and after the intervention, including a beginning practice run. This type of test is often used as a metric of Langerian Mindfulness, considering that Langerian Mindfulness's defining characteristic is the act of noticing new things (Langer, 1989). Reductions in reaction time have shown a small, however significant, positive correlation with the LMS14, specifically the subscales: novelty seeking, novelty producing, and engagement (Pirson et al., 2012).

Procedure. The following study, and hypothesis, was pre-registered on Open Science Framework on March 30th, 2021 (https://osf.io/j9xqd).

Upon recruitment to Prolific, participants were instructed to sign a consent form explaining the physical requirements of the task, and informing them that they could stop the task at any time. They filled out a digital version of the LMS14, and then began a practice run of the reaction-time test, followed by the real test. Participants were then randomly assigned one of three Zoom links for our three conditions: (a) discontinuous (b) mindless/continuous (c) mindful/continuous. All conditions had an experimenter conducting instructions in the Zoom sessions. Experimenters for conditions (b) and (c) were masked to all study design components, and the experimenter in condition (a) was masked to everything other than the "discontinuity" of the experiment. Once all the participants joined their respective rooms, they were instructed to change their Zoom name to their Prolific ID, make sure their upper body could be seen in the computer camera, and turn away from the camera. Experimenters then gave them instructions from a script.

Condition (a): Participants were told to hold up their non-dominant hand to the side as if saying "hi," or as if being sworn in. They were told to hold it for five minutes, or as long as they could. The experimenter started a stop-watch and counted down every minute. At the end of the five minutes, the experimenter apologized and explained that all participants needed to do the task again (hence this condition had a discontinuous 10-min duration). The experimenter started the 5-min timer again and counted down the minutes.

Condition (b): Participants were told to hold up their non-dominant hand to the side as if saying "hi," or as if being sworn in. They were told to hold it for ten minutes, or as long as they could. The experimenter started a stop-watch and counted down every minute until ten minutes had elapsed.

Condition (c): Participants were told to hold up their non-dominant hand to the side as if saying 'hi," or as if being sworn in. They were told to hold it for ten minutes, or as long as they could. In addition, the participants in this group were given a mindful task: participants were instructed to try and reach higher with their pinky finger than all other fingers, then their ring finger, etc., until they had gone through all fingers, and to, then, start again with the pinky finger until the ten minutes had ended. The experimenter started the ten-minute timer and counted down every minute until ten minutes had elapsed.

At the end of the Zoom sessions, all participants were given the same link to return to Prolific to finish up the study.

Once back in Prolific, the participants took the same reaction-time test, however with different shapes (without a practice), and were given a digital questionnaire asking about their perceived fatigue. The questionnaire consisted of a sliding scale representing 1 to 10 min, asking participants to answer: "How many minutes into the arm-raising exercise did you first start to experience fatigue?" and "How many minutes into the arm-raising exercise did you feel the most fatigued? to report their FS and FP during the arm-hold task. Note that for the discontinuous task, the full 10-min sliding scale was also presented to participants in that condition. One more question was added to the questionnaire for the second Prolific session that asked participants, "For how much money would you be willing to redo the study right now with your other hand?" Given that all participants were paid for their participation, this question was designed to assess the participants' level of fatigue. We hypothesized that those asking for more money were more fatigued, or less able to overcome their fatigue, than those asking for less money. It is possible that various motivational aspects or extrinsic aspects could play a role in participants' answer to this question, however the extent to which such aspects affect different conditions in different amounts, we assumed to be reduced given our random selection of conditions. The question represents an alternative mechanism by which fatigue is effectively overcome, and by itself does not distinguish between experiencing less fatigue versus an increased ability to deal with fatigue.

Objective observer. To examine objective evidence of fatigue for the participants, all the Zoom recordings were edited into earlier and later cuts of 30 s. The recording cuts were made from the 2- to 2:30-min mark and the 9- to 9:30-min mark. The objective observer was masked to the condition and whether the cut was earlier or later in the task, but not to the study design. The objective observer was instructed to rate each participant on a scale from 1 (*not tired at all*) to 5 (*extremely tired*). The scores were then totaled and averaged for each condition.

The data that support the findings of this study have been deposited in the Harvard Dataverse with the identifier [https://doi.org/10.7910/DVN/CBOYWO].

Results

Self-reports of FS, FP, and fatigue repeat. All three conditions had study-designed hold times of 10 min. Figure 7 shows standardized results for FS and FP for all conditions. Overall reports of FS displayed that participants began feeling fatigued 4.5 min

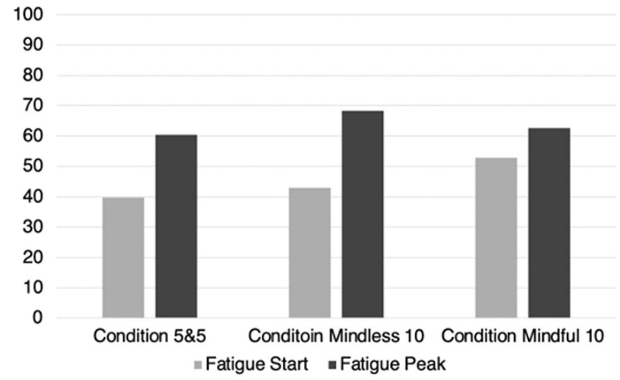

Fig. 7 Standardized FS and FP. No significant differences between conditions for FS and FP as standardized percentages of task were found, suggesting that the fatigue illusion remains robust, even to our interventions. Conversely, the non-significant results between the condition presented as 5 min, that was repeated, and the continuous 10-min conditions, may also indicate that discontinuity of task actually achieves in manipulating the fatigue illusion. However, whether it possibly postpones or advances fatigue was not determined.

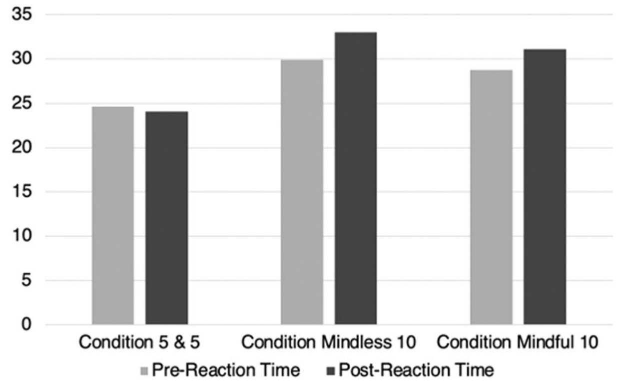

Fig. 8 Pre- and post-intervention reaction times. Whereas reaction times in seconds slowed in both continuous 10-min conditions, individuals in the discontinuous condition displayed faster reaction times on average after the intervention, suggesting that discontinuity of task may function to restore energy reserves.

into the task (45% of the way through the arm-hold) and peaked 6.4 min into the task (64% of the way through the arm hold). The discontinuous (5/5-min hold) condition had a reported FS 4 min (40%, SD = 2.10 min) into the task and a reported FP 6 min (60%, SD = 2.28 min) into the task. The mindless/continuous condition had a reported FS 4.3 min (43%, SD = 2.31 min) into the task and a reported FP 6.8 min (68%, SD = 2.47 min) into the task, and the mindful/continuous condition had a reported FS 5.3 min (53%, SD = 2.1 min) into the task and a reported FP 6.3 min (63%, SD = 2.8 min) into the task. There was no significant difference between reports of FS ($F(2,52) = 1.775$, $p = 0.180$, $\eta^2 = 0.064$) or FP ($F(2,52) = 0.499$, $p = 0.610$, $\eta^2 = 0.019$). A paired-sample within-subjects t-test displayed a significantly earlier FS (4.5 min) than FP (6.4 min; $t(54) = -6.15$, $p < 0.001$, Cohen's $d = 2.29$).

Interestingly, when we compared our interventions, we found that participants in the mindful condition were less fatigued and reported a significantly later FS and FP than those in the discontinuous condition, $t(34) = -1.88$, $p = 0.035$, Cohen's $d = -0.628$. Whereas our previous studies saw that in the cases of physical tasks, the fatigue illusion trended toward earlier reports of FS and FP (earlier than 50% of the way through the task), the mindful condition's FS (53% of the way through the task), was reported later, even though it was not significantly later than the other conditions when all conditions were added into the model. A z-test comparing the mean for the mindful/continuous condition to the overall mean, relative to the standard deviation for the overall scores, divided by the square root of the total sample, indicated that the mindful/continuous condition's FS was significantly later than the overall FS ($z = 2.69$, $p < 0.01$), suggesting that participants in the mindful/continuous condition were able to defer FS relative to the sample average.

A one-way analysis of variance for how much participants were willing to be paid in order to perform the task again showed no significant difference between our conditions $F(2,27) = 2.11$, $p = 0.141$, $\eta^2 = 0.135$, however, our variances did differ significantly. Outliers were observed for both our intervention conditions.

Within-subject results for our interventions. A two-way analysis of variance (pre/post: within-subjects factor and condition: between-subjects factor) displayed a significant main effect for condition ($F(2,52) = 5.88$, $p = 0.005$, $\eta p^2 = 0.185$), but no main effect for pre- and post-intervention ($F(1,52) = 1.2$, $p = 0.278$, $\eta p^2 = 0.023$), and no condition x reaction-time interaction $F(2,52) = 0.603$, $p = 0.551$, $\eta p^2 = 0.023$). Pair-wise comparisons showed a significant difference between the discontinuous condition and the mindless/continuous condition ($p = 0.002$), as well as the mindful/continuous condition ($p = 0.016$). There was no significant difference between the mindless/continuous and the mindful/continuous condition ($p > 0.05$). Figure 8 shows the estimated mean reaction-times pre- and post-intervention for all three conditions.

Further analysis showed a significant difference in means by examining only post-reaction-time mean differences for the discontinuous condition (24 s), the mindless/continuous condition (33 s), and the mindful/continuous condition (31 s; $F(2,52) = 4.11$, $p = 0.022$, $\eta^2 = 0.136$), with post hoc tests displaying that the discontinuous condition had a significantly earlier post reaction-time than the mindless/continuous condition ($p = 0.023$), although not significantly earlier than the mindful/continuous task. In other words, whereas the three conditions performed similarly pre-intervention, the discontinuous task performed significantly better post intervention than the mind*less*/continuous task, although not more than the mind*ful*/continuous task. In fact, the discontinuous condition was the only condition to have a better average reaction-time post-intervention than pre-intervention, perhaps suggesting that discontinuity in fatiguing tasks may aid in a type of de-fatigue.

Objective ratings. Twelve videos, composed of randomly assigned clippings of the participants in their conditional tasks were given to an objective observer to rate observable evidence of fatigue (condition 1 = discontinuous, condition 2 = mindless/continuous, and condition 3 = mindful/continuous). Each video was split into early and later clippings (between the 2- and 3-min mark and between the 9- and 10-min mark) for the 3 conditions, that were rated by an objective observer on a self-constructed scale (1 = *no fatigue* to 5 = *severe fatigue*). Ratings were added up and averaged for all 12 videos: (M cond1 early = 1.95, M cond1 later = 2.35, M cond2 early = 1.68, M cond2 late = 2.65, M cond3 early = 1.33, and M cond3 late = 2.85). A significant difference in ratings for the overall averaged earlier ($M = 1.65$) and later clippings ($M = 2.62$; $F(1,10) = 14.54$, $p < 0.01$, $\eta^2 = 0.59$) suggests, again, that fatigue manifests corporally after the onset of perceptions of fatigue begin. No significant difference between conditions in observable evidence of fatigue ($F(2,9) = 0.02$, $p = 0.98$, $\eta^2 = 0.004$) was observed, indicating that the three conditions exhibited fatigue similarly irrespective of the condition they were in. Furthermore, a mean standard error of ($\sigma^{\bar{x}} = 0.14$), comparing differences of early and late clippings between conditions, indicated that the variation around the mean was low. However, the late—early difference across conditions was indeed significant; the more mindful groups were objectively less fatigued earlier, and more fatigued later, than the less mindful group. Hence, participants displayed a greater amount of fatigue, perhaps in part due to the marginally more difficult mindful subtasks, and yet they did not subjectively experience a greater amount of fatigue. The mindfulness intervention appears to have reduced the feeling of fatigue and also the actual amount of early experienced fatigue. Perhaps changing the mindfulness instructions for the second half of a task would yield even better results; for example, counting the number of out-of-state license plates for the first half of a road trip, followed by a game of pretending to try to follow a random driver without being spotted for the second half, may reduce road fatigue more than doing just one of those activities the whole trip. Even more effective might be if the persons themselves chose how to make the activity more mindful and fun.

Effects of trait and state mindfulness. To examine the contribution of trait and state mindfulness to the variance in self-reports of FS and FP, we ran two linear regressions with trait mindfulness (operationalized as total scores on the LMS14) and state mindfulness (operationalized as the difference in reaction-times for all participants) entered in the first block, and adding the three subscales (novelty seeking, novelty producing, and engagement) in the second block. Results displayed no significant contribution of any of the factors for perceptions of FS ($r^2 = 0.037$, $F(4,50) = 0.487$, $p = 0.745$), suggesting that at least the beginning of the fatigue illusion seems impervious to state and trait mindfulness. Results for FP were significant, however ($r^2 = 0.238$, $F(4,50) = 3.9$, $p = 0.008$). Specifically, those participants with higher scores in novelty producing on the LMS14 had earlier self-reports of FP ($\beta = -0.481$, $p < 0.001$), possibly suggesting that in some fatiguing situations, mindful people who "like to be challenged intellectually," or are "open to new ways of doing things," may perceive certain fatiguing tasks as boring, or lacking the stimulation that "novelty producers" crave, thus peaking earlier than those who are less mindful.

Summary. Results from this study align with our previous findings that support the notion of a fatigue illusion, namely that FS is perceived significantly earlier than FP, that FP is perceived before the termination of a task, and that fatigue is largely felt to begin, peak, and subside at proportional points during fatiguing tasks. Indeed, results reflected reported FSs roughly in the third quintile of the respective task, and FPs roughly in the fourth quintile of the respective tasks, suggesting an approximate half-way/three-quarter-way trajectory of fatigue. These perceived fatigue milestones were unaffected by our interventions, indicating that the fatigue illusion remains robust despite efforts to manipulate it. This finding is particularly interesting in light of our results from objective observations that displayed a difference in conditions for observable evidence of fatigue. Specifically, the mindful/continuous condition was observed to be more fatigued, despite self-reports indicating that they were no more fatigued than the other conditions. This is not to say, however, that evidence for the malleability of the fatigue illusion does not exist as we will attempt to explain. If the fatigue illusion does generally follow a consistent trajectory, beginning approximately half-way and peaking approximately three-quarters-way through a task, then our results from the discontinuous condition offer up two conclusions for evidence that the fatigue illusion may indeed be submissive to manipulation. From one perspective, we can surmise that participants reported that their fatigue, on average, was postponed (true FS = 4 min) more than what we would have expected had the task discontinued for individuals at the prescribed 5 min (expected FS = 2.5 min). The same can be said for FP (true FP = 6 min vs. expected FP = 3.75 min). Note that the sliding scale that was used for reporting FS and FP was presented with the full 10 min. This may have swayed participants to recall the task in its full form (with the added 5 min) and not in its pre-prescribed form. If so, this would be further evidence for the fatigue illusion, as it would mean that perceptions of experienced fatigue may be manipulated even retrospectively. Or, we can also look at the discontinuity of a difficult task from another perspective, where we might also deduce that repeating a task, when individuals feel they have already accomplished their goal, exacerbates fatigue, where the true FS (4 min) is advanced compared to the expected FS (5 min), as with the true FP (6 min) compared to the expected FP (7.5 min). Indeed, this suggests that participants may have had a longer period of delaying fatigue at the end, and perhaps lower fatigue at the end. Conforming to this possibility, this was indeed the only condition to have better reaction times post intervention. Future research will have to test these alternatives. We suggest, that one aspect of Langerian Mindfulness, specifically the enjoyment of producing novelty, helps individuals control how they approach a fatiguing task. In other words, constructing breaks and interruptions in fatiguing tasks that make the task novel and interesting may work to minimize fatigue and even replenish energy reserves.

Be that as it may, individuals who scored higher in novelty producing were not generally less fatigued. Our argument is that boredom and fatigue are essentially the same thing. Our interventions were pre-prescribed, meaning that participants did not individually choose or construct how they approached the task (i.e., they may have not been intrinsically motivated to deal with fatigue or boredom). Recordings displayed that many of the participants picked up their phone during the task, perhaps as a way to make the time go by quickly, or distract themselves from the challenge, a behavior that reflects fatigue management. As this was not controlled for in our study, it is hard to know definitively whether mindful subtasks within fatiguing tasks function better or worse than constructing alternative perspectives.

Conclusion and limitations

Our multiple-studies design, embedded in the theoretical approach of mind/body unity, investigated perceptions of fatigue in a variety of forms, aiming to augment our understanding of the role that cognitions play in fatigue and how those cognitions may become re-framed and molded via mindfulness, lending control to individuals during the sensation of fatigue. Our line of investigation sought to explore (a) whether or not proportional perceptions of fatigue, or fatigue milestones, exists (e.g., regardless of length or complexity of the task), rendering fatigue an illusion and (b) whether perceptions of fatigue are malleable by way of mindfulness, offering individuals control in their own potentialities.

All five studies suggest that fatigue follows a predictable course, beginning sometime after the start of a fatiguing task, peaking sometime distinctly later, and then abating before the end of a task. In fact, most results displayed a half-way and three-quarters way fatigue trajectory, although limitations to these milestones were observed in physically arduous tasks. This fatigue transition was, however, largely universal, and seems to diverge from actual energy expenditures, suggesting that individual potentials may become inhibited by an internalized illusion of exhaustion, what we label the fatigue illusion. Our studies that examined individual

Affect as possible contributors to perceptions of fatigue, where we expected attitudes to have an impact on the reported timing of fatigue, displayed that the fatigue illusion appears to be impervious even to individual trait influences. In light of our results that found some measures of subjective fatigue to be greater in less cognitively demanding tasks, future research should examine the influence of intra-individual characteristics on the fatigue illusion to investigate which individuals would find mental load cognitively stimulating and which would find it cognitively exhausting and inhibitory. Where we saw some fluctuations in the fatigue illusion, namely that fatigue transitioned earlier while keeping distinct start and peak milestones, were in the physical tasks, although as to whether the reason for this is truly due to physical exhaustion is unclear. Whereas the fatigue illusion suggests that fatigue begins to abate towards the end of a fatiguing task, where the end time is known, individuals performing tasks with an undefined end time reported peak fatigue at the time they decided to end the task, indicating that exhaustion is not so much the end of energy reserves, but perhaps a subconscious comprehension of infinite potential; "the task could possibly continue indefinitely, and I must end it now!"

Thus, exhaustion may be more of a reflection of individual mindsets towards certain fatiguing situations, a suggestion that advances our second line of investigation embedded in the application of Langerian Mindfulness (Langer, 1989). Its precepts, pertaining to (a) "the creation of new categories for structuring perceptions," and (b) "enhanced awareness of multiple perspectives in problem solving" (Langer and Moldoveanu, 2000) guided our empirical approach to explore whether the fatigue illusion is malleable by way of individual mindsets. By manipulating the illusory milestones of fatigue, we found that a reconfiguration of task duration (e.g., manipulating reference points for energy gauging), as opposed to employing a mindful task, was influential in shifting the fatigue illusion; however, whether this shift postpones or advances fatigue was not determined. Notwithstanding, shifting the fatigue illusion may be done by 'tricking' the mind so as to construct a new frame for energy expenditure, placing our finding within theoretical models that tie reappraisal processes to beneficial regulatory responses in challenging situations (Gross, 1998; Mauss et al., 2007; Jamieson et al., 2012). A researcher who implemented this method decided to incorporate more steps at the tail end of his cross-country travel (e.g., travel from the airport and to the hotel) so as to better manage, and postpone, the illusion of fatigue. Limitations of this advancement, however, reside within the particular experimental manipulation used. Our interventions were pre-prescribed, meaning that participants did not individually choose or construct how they approached the task (i.e., they may not have been intrinsically motivated to manage fatigue). In this manner, it is hard to know definitively whether mindful interventions within fatiguing tasks function better or worse than constructing alternative perspectives, and future studies would do well to investigate this possibility.

Above and beyond our two-pronged investigation, our studies also advance empirical research on fatigue and mind/body unity. Damasio's theory of the conscious feeling of fatigue (as cited in St. Clair Gibson et al., 2003) states that as physiological changes in the body (e.g., faster heart rate, higher temperature) progressively deviate from the proto-Self, or the Self at homeostasis, negative emotions become tagged to that discrepancy, eliciting an emotional response and behavior. Cumulative perceptions of deviation from the proto-Self (or second-order maps) eventually elicit "the conscious perception of the sensation of fatigue" (St. Clair Gibson et al., 2003: p. 6), however this theory stops short of modeling how the conscious perception of peak fatigue is related to further metabolic and physiological conditions during activity, and what causes someone to terminate a task. Our research contributes a further step, linking objective indications of physiological fatigue with temporality of self-reported fatigue peak, indicating that a metric of perception may be used alongside cumulative maps of the Self during activity. Research that could quantify deviations between the proto-Self and current-Self with physiological changes, and interface that with subjective perceptions of fatigue may advance our understanding about the tandem forces of fatigue in the mind and body.

In light of these results, we acknowledge that the fatigue illusion may function within margins. For example, if someone were asked to stay awake for a week, the common assumption might be that the fatigue illusion would manifest quite differently than a half-way and three-quarters-way trajectory; however, that assumption could be based on an adapted cultural norm about what our society deems is an appropriate sleep cycle. Future research that continues investigating the fatigue illusion within different cultures, that embody varying socio-historical norms, would advance our understanding of the diversity of premature cognitive commitments and their potential restrictions within fatigue. In regards to human potential, Langer states, "Scientists know that while one can fail to find evidence *for* a hypothesis—the hypothesis in this case being that potentials are unlimited—that is not the same thing as finding evidence *against* a hypothesis. One cannot prove that there are no limits. One may just keep surpassing them" (1989: 205).

Data availability

All datasets generated during and/or analyzed during the current studies are available in the Harvard Dataverse repository: https://doi.org/10.7910/DVN/CBOYWO.

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Note

1 Personal interview, 2017

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Competing interests

The authors declare no competing interests.

Ethical approval

The questionnaire and methodology for studies 1, 2, 3, and 4 were approved for by the Human Research and Ethics committee of Bryant University (Ethics approval number: 2016-0928). The procedures used in these studies adhere to the tenets of the Declaration of Helsinki. The questionnaire and methodology for study 5 was approved for by the Human Research and Ethics committee of Fairfield University (Ethics approval number: 3835). The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Informed consent

Informed consent was obtained from all participants for all the studies. For studies 1, 2, 4, and 5, informed consent was obtained digitally and is kept in a password protected file. For study 3, informed consent was obtained by paper and pencil and is kept in a safe by the researcher.

Additional information

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