The Effects of Mindfulness Meditation Training on Multitasking in a High-Stress Information Environment

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Abstract

We describe an experiment to determine the effects of meditation training on the multitasking behavior of knowledge workers. Three groups each of 12-15 human resources personnel were tested: (1) those who underwent an 8-week training course on mindfulness-based meditation, (2) those who endured a wait period, were tested, and then underwent the same 8-week training, and (3) those who had 8-weeks of training in body relaxation. We found that only those trained in meditation stayed on tasks longer and made fewer task switches, as well as reporting less negative emotion after task performance, as compared with the other two groups. In addition, both the meditation and the relaxation groups showed improved memory for the tasks they performed.

Keywords: Attention, information, interruption, mindfulness, meditation, multitasking, stress.

Index Terms: H.1.2. [Models and principles]: User/Machine Systems—*human information processing*.

1 Introduction

Multitasking is a widespread phenomenon in today's information-saturated world, and there is considerable concern about its negative consequences for both personal health and effectiveness. This has resulted in strong requests for guidance and understanding from parents, educators, employers, and workers [39].

Within human-computer interaction (HCI), work has been done to model the multitasking process [30], to investigate its extent and nature through user studies [8], to document its effects on human performance [22], and to ameliorate the negative effects of interruptions on multitasking by deploying new technologies [40].

The present study adopts a complementary approach: to attempt to alleviate some of the problems associated with multitasking by training the human attentional faculty. Human attention is a trainable capacity [20,38], and recent work in cognitive psychology and neuroscience [15] provides strong suggestions that certain forms of meditation are capable of enhancing attentional skills, permitting people both to concentrate more deeply and to switch between objects of attention more fluidly. This raises the possibility that meditation training may improve multitasking behavior.

We describe an experiment in which human resource (HR) managers were given either 8 weeks of training in mindfulness meditation, relaxation training, or nothing (a waitlist control group). Both before and after training, the participants were given a relatively naturalistic and intentionally stressful test of their multitasking abilities. Our results indicate that those in the meditation group experienced less self-reported negative emotion than those in the relaxation or control groups; the meditators and those in the relaxation group also showed improved memory for the details of the work they accomplished during the multitasking test. And subjects who underwent meditation training were less fragmented in their work, switching among competing tasks less frequently and spending greater time on task without increasing overall test time; they also began fewer tasks overall.

In this work, we thus provide initial empirical evidence that attention-training through meditation improves aspects of multitasking behavior. Our findings suggest that further investigation of meditation's effects on multitasking is warranted—to refine the forms of training, to better understand why and how they work, and to better understand what improvements they effect. Moreover, meditation training may be a viable *complement* to technology-based approaches to handling information overload, an approach new technologies could support or enable.

2 Background and Related Work

There is considerable concern today regarding the negative consequences of multitasking, as evidenced by the amount of attention in the popular press: stories abound about the extent of multitasking in the general population, and among students in particular [28,29], feeding worries that widespread multitasking practices are compromising learning and attention [39]. Such concerns are bolstered by a range of studies in cognitive psychology and neuroscience suggesting that human attention is a limited resource, and that multitasking requires rapid task switching, which is costly in speed and accuracy [10,44].

Much of the multitasking work in HCI has been focused on discovering the nature and effects of multitasking on knowledge work. Special attention has been paid to the effects of interruptions as causes of unwanted multitasking. Major findings from these lines of inquiry include that knowledge workers are perpetually fragmented across many simultaneous tasks [8], that stress, speed, and effort increase with increased interruption [22], that the cost of interruption, the nature of the task, and the state of the user are intertwined [1,32], and that heavy multitaskers are actually worse at filtering out irrelevant information [26]. These findings have led to theoretical concepts, including the notions of *working spheres* [12], *communication chains* [37], *reconstruction* [31], and the multitasking *continuum* [30]. In addition to these empirical, descriptive, and theoretical explorations, work has been done to improve multitasking behavior through design, *e.g.*, the *Multitasking Bar* [40] and the *GroupBar* [36]. And studies have investigated whether sensors and machine learning can model human interruptibility to reduce unwanted interruptions and task switching [11].

Another potential line of inquiry into multitasking, which to date has been little investigated, is suggested by recent neuroscientific studies of meditation demonstrating that certain forms of meditation are capable of enhancing attention. While it has been hypothesized for some time that attention is a skill that can be enhanced through training [14], over the past decade a growing body of experimental work in neuroscience has been exploring how certain forms of meditation—broadly referred to as "mindfulness meditation"—may lead to cognitive improvements, including the enhancement of one's attention, such as the ability to remain focused on an object and to ignore distractions [35], as well as to improved emotion regulation [25].

Mindfulness meditation consists of two separate but related practices, which Lutz *et al.* [20] call Focused Attention meditation (FA) and Open Monitoring meditation (OM). In FA training, meditators are instructed to maintain their focus on their breath, the moment-to-moment sensations of "in" and "out." When they are distracted by an interruption, such as a sound, a thought, or an emotion, they are asked to return their focus to the breath once they notice that their mind has wandered. In OM training, by contrast, meditators are instructed to allow into awareness whatever catches their attention, but then to fluidly release attention, thus potentially shifting moment-to-moment from one object of focus to another. FA training appears to strengthen the ability to stay focused, ignoring distracting information [15], while OM training appears to strengthen the ability to attend to a succession of stimuli without being overly drawn in by any one of them [20]. Such skills would seem to be relevant to multitasking insofar as a multitasker must be able to engage with a task, sustaining attention on it in the face of potential distractions, and then disengage from it to engage with another task. The multitasker must also be able to maintain sufficient open monitoring to notice when new potentially task-relevant stimuli arrive.

While this and other recent neuroscientific work on meditation bears directly on the challenges of multitasking, none of it has been applied specifically to the challenges of "media multitasking" [29] in real-world settings. And while recent work in HCI has begun to pursue insights related to meditation for technology design—specifically, the possibility of monitoring and enhancing users' breathing (*e.g.*, [24])—none of it has yet been applied specifically to multitasking. To our knowledge, there has been no experimental work, other than our own initial report [18], exploring whether meditation might improve multitasking as assessed in relatively naturalistic settings.

3 EXPERIMENT

To determine how meditation training might affect multitasking behavior, we tested participants' multitasking abilities to establish a baseline, then offered participants 8 weeks of training, and finally tested participants' abilities a second time. Group A received 8 weeks of mindfulness meditation training, while Group C received 8 weeks of relaxation training. Group B, the waitlist control group, was tested a first time, received no training for 8 weeks, and was tested again; subsequently, this group received 8 weeks of meditation training and was tested a third time, thereby serving as both a control group and a treatment replication group.

3.1 Participants

Participants for the experiment were recruited, by advertisement, from human resource (HR) personnel working in the San Francisco and Seattle areas. All participants were females in good physical and mental health (by self-report), were free of any visual, auditory, motor, or other impairments that would reduce their effectiveness in using a laptop computer, email, or a telephone, and scored within the normal range on standardized self-report measures of anxiety (Beck Anxiety Inventory [4]) and depression (Beck Depression Inventory [3]).

Of the women who volunteered for the study in San Francisco (Group A), 19 were selected based on their availability for the training and testing sessions; 12 of these completed the study by participating in all testing sessions and at least 6 of the 8 training sessions. Of the women who volunteered in Seattle, 38 were selected based on their availability for training and testing and were subsequently assigned to the group (B or C) that best suited their schedule. Group B was initially composed of 22 participants, 15 of whom completed all required testing and training. Group C was initially composed of 16 participants of whom 12 completed all requirements. Participants in the three training groups did not significantly differ in age or education (Group A: N=12; M=44.17 years (SD=11.04); Group B: N=15, M=45.29 years (SD=9.85); Group C: N=12; M=45.83 (SD=10.07)).

3.2 Training

Participants were given 8 weeks of training, either in mindfulness meditation (Group A and, after an 8-week waiting period, Group B) or in body relaxation (Group C). Each group met with the instructor for two hours once per week; participants were also given homework exercises. The inclusion of a waitlist group (Group B) controlled for the possibility of changes in dependent measures that might occur over time without training (*e.g.*, practice effects), and also allowed for treatment replication by providing the 8 weeks of mindfulness training after the 8 weeks of no training. The relaxation group (Group C) provided an active, alternative training, controlling for potential nonspecific effects of expectation, attention from a trainer, *etc*. Both waitlist and active control conditions have been employed in prior studies of mindfulness meditation effects (see, *e.g.*, [27]).

The mindfulness meditation training was based on the teaching of Darlene Cohen [7]. The training, largely organized around Focused Attention (FA) training, emphasized: (*i*) the ability to narrow or widen attentional focus voluntarily, and rest attention in the present moment or task; (*ii*) the flexibility to shift focus voluntarily from one thing to another; and (*iii*) the ability to cultivate awareness of the breath and the body as well as task objects. Cohen offered the training in San Francisco; one of her senior students observed the San Francisco training and offered it to the Seattle participants.

The relaxation training emphasized progressive tensing and relaxing of major muscle groups, aided by relaxation imagery, which previous research has established as effective for enhancing relaxation [6]. This training focuses on systematically and deeply relaxing all major skeletal muscle groups, aided by mental imagery (*e.g.*, "my arms are becoming heavy and warm"). Participants had the use of an audio CD containing relaxation exercises [23] as well as weekly classes with the trainer. The relaxation training involved the same frequency of teacher contact and the same intensity of at-home practice as the mindfulness meditation training.

3.3 Apparatus and Procedure

In designing our multitasking test, our intent was to create a naturalistic knowledge-worker setting. Participants were brought into a typical one-person office outfitted with a telephone and a laptop computer. They were asked to imagine, for the sake of the experiment, that they were a new employee at a company and were being asked to perform a set of knowledge-worker tasks. To complete some of these tasks, they would need to communicate with other employees. The tasks included (*a*) scheduling a meeting (finding a one-hour time slot when all fictional attendees were available); (*b*) finding a free conference room once they had identified the meeting time; (*c*) writing a draft announcement of the meeting; (*d*) eating a small assortment of snacks and drinking a cup of water; and (*e*) writing a memo proposing a creative agenda item for the meeting. Information necessary to perform these tasks came in a barrage of email, instant messages, telephone calls, and knocks on the door. Previously saved text documents were also used. To add time pressure and frame expectations, participants were instructed to complete all tasks in 20 minutes; those who took longer, however, were asked to continue to completion. Task (*a*), finding a meeting time, was the most complex and time-consuming, because meeting attendees sometimes only sent portions of their schedule in a single email message or instant message, and because they sometimes changed their availability (as in real life).

Participants were given instruction in the online tools they would be using. All were familiar with Microsoft Word but not everyone had prior experience with Gmail or Gmail's instant messaging. To help them with task (*a*), they were given a paper calendar grid, a pencil, and an eraser, and were shown how they could fill in the grid as new information about people's schedules arrived. (A participant can be seen working on the paper grid in the upper left-hand corner of Figure 1.) In addition to giving participants a common format to use for completing this task, the paper grid added complexity by requiring them to work on paper as well as on the screen, and to switch between these two media. The need to switch between paper, screen, telephone, and face-to-face encounters meant that participants had to perform cross-device and cross-media multitasking.

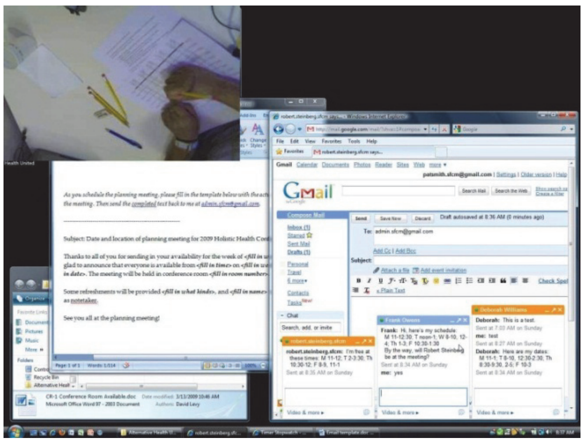

Figure 1: A participant's screen while performing the multitasking test, including an inset video showing use of pencil and paper.

The execution of the test required a researcher to play the role of the various fictional company employees who were communicating with the participant. This researcher, in a Wizard-of-Oz role, was seated at a workstation in a nearby office where she could monitor the progress of the participant and communicate with her in the guise of the appropriate company employee. The researcher worked from a script indicating which action was required at what time. Thus, for example, at minute 8 of the test, the researcher would send an email message from "Jackie Gomez" stating: "Hi, I told you I'd get back to you with my times for Friday. I'm free F: 9-12." (There were three different versions of the script, all having the same structure of communication activities but differing in their details. Participants taking the multitasking test after training, or after the waitlist control period, were given a different version of the test than they had experienced before.)

TechSmith's *Morae* usability testing product allowed the researcher to view the content of participants' screens, as well as to record screen activity, keystrokes, and mouse movements. A webcam and microphone in the participants' office recorded their interactions with the paper schedule and their spoken interactions with an "employee" (the researcher) who occasionally interrupted them with questions or additional tasks; these interactions were also captured by Morae.

Each multitasking test took place no more than 10 days prior to or after the 8-week training. At the beginning of each test session, prior to the actual multitasking test, the participant was given two standardized and commonly used questionnaire measures of present experienced emotion (*i.e.*, how one feels right now): the 20-item Positive and Negative Affect Scale (PANAS) [41], and the 64-item Profile of Mood States-Short Form (POMS-SF) [34]. These reliable and validated self-report inventories yield several subscale scores for both positive emotion and stress-related emotional experience, including negative affect, anxiety/tension, and fatigue.

In addition, the participant was administered the Mindful Attention Awareness Scale (MAAS [5]). The MAAS is a 15-item self-report questionnaire (answers using a 6-point Likert scale, ranging from "almost always" to "almost never") designed to measure the participant's own perception of their daily experience of "the presence or absence of attention to and awareness of what is occurring in the present" [5]. Item examples include "I tend to walk quickly to get where I'm going without paying attention to what I experience along the way"). Baer *et al.* [2] have found good internal consistency for the MAAS, and significant positive correlations with other self-report measures of mindfulness.

Immediately following completion of the multitasking test, participants were asked to complete a 12-item questionnaire (9 open-ended questions and 3 multiple-choice) regarding their memory for various aspects of the task (*e.g.*, names of particular participants in the meeting scheduled, snack foods eaten, the contents of a memorandum, information provided via phone calls, what they were doing when a particular event occurred, *etc.*). Questionnaires were specific to the particular multitasking script administered to each participant. Answers to each question were scored as correct or incorrect, and the total number of questions correctly answered was summed to provide a memory score for each participant at each assessment point.

After the memory questionnaire, the PANAS and POMS-SF questionnaires were again administered to assess changes in mood and affect that occurred over the course of the multitasking test.

Two other questionnaires were administered: At the first test session, prior to the multitasking test, participants were asked to indicate their expectation for benefit from the training on a 3-point scale (no benefit, some benefit, much benefit). At the completion of the final test session, participants were asked a number of questions about the training they underwent and their performance on the multitasking tests, and their answers were audio-recorded.

3.4 Experiment Design and Analysis

The multitasking performance study was a 3 × 2 mixed factorial design with a between-subjects factor of *Group* (A, B, or C) and a within-subjects factor of *Session* (pre- or post-training).

The *Session* factor encodes the pre-/post-training effect. However, as this was a replication study in which Group B, after its wait period, replicated Group A's treatment (meditation training), two separate analyses are warranted, the first in which Group B's pre- and post-training are considered before and after the wait period, making Group B a control condition, and the second in which Group B's pre- and post-training are considered before and after meditation training, making Group B the replication of Group A. Such designs are common in the psychological literature (*e.g.*, [21]).

A general linear mixed-effects model (a.k.a. mixed model) analysis of variance was used to analyze the multitasking performance data. *Group* and *Session* were modeled as fixed effects, while *Subject* was nested within *Group* and modeled as a random effect. Mixed models have numerous advantages over traditional fixed-effects repeated measures ANOVAs, including robustness to missing data and unbalanced designs [17]. For examples using mixed models in the SAS and SPSS statistics tools, see prior work [19,42].

All self-report and memory data were subjected to linear mixed-effects analyses of variance, with *Subject* nested within *Group* and modeled as a random effect. The between subjects factor was *Group*, and within-subjects factors were assessment session (pre- versus post-training), and pre- versus post-multitasking test (nested within assessment session). Additional identical analyses were also computed in which the second and third assessment sessions for the waitlist control group (*i.e.*, after the 8-week wait period and again after the 8-week meditation training) were treated as pre- and post-training assessment sessions, in comparison to the pre- and post-training assessment sessions for the meditation and relaxation training groups. Following testing for main and interaction effects, pairwise comparisons, where appropriate, were computed, contrasting assessment session differences within each group.

The Morae recordings of the multitasking tests were coded in two primary ways: (*a*) they were annotated to indicate when events occurred (*e.g.*, when the phone rang, when a knock on the door took place), and when tasks began, were suspended, resumed, and completed; and (*b*) the participants' communications were coded for accuracy (Did they find the correct time for the meeting? Did they correctly answer whether someone was coming to the meeting?). The coding was carried out by three research assistants who were trained over several months until they had achieved at least 90% agreement.

4 Results

Results were obtained in four primary areas: participants' multitasking performance, their memory for the tasks they were performing, their self-reported emotional state, and their self-reported mindful awareness.

4.1 Multitasking Performance

4.1.1 Overall Test Time

Not surprisingly, subjects improved their overall time taken from pre- to post-test, as task times decreased from 37.6 (*SD*=8.3) minutes to 34.0 (*SD*=7.9) minutes, resulting in a significant effect of *Session* (pre *vs.* post) on test time ($F_{1,88}$=13.97, p<.001). With Group B as replication, the same finding held ($F_{1,82}$=7.60, p<.01).

Perhaps more interestingly, there were no significant differences among groups in total test time, whether for Group B as control ($F_{2,51.8}$=0.36, *n.s.*) or for Group B as replication ($F_{2,47.7}$=1.06, *n.s.*). Neither was there any significant *Group* × *Session* interaction in either case ($F_{2,88}$=0.05, *n.s.*; $F_{2,82}$=1.75, *n.s.*). Thus, although participants seemed to learn generally from pre- to post-test, this learning was symmetric for groups regardless of training intervention (or no intervention).

4.1.2 Number of Activities

An "activity" was defined as participants' test-related behavior that had a definable start and end, such as finding a meeting time, finding a meeting room, or preparing the meeting announcement. Participants switched activities as they wished, postponing their completion until later times. Although there were no overall task time differences among groups, when we look *within* sessions to see how time was spent, differences emerge.

Figure 2 shows the average number of activities per test by *Group* and by *Session*. With Group B as control (waitlist), there was a significant *Group* × *Session* interaction ($F_{2,42.9}$=9.33, p<.001), arising because Group A, the meditation group, showed a significant decrease in the number of activities pre- and post-test ($F_{1,47.1}$=15.38, p<.001), while Groups B (control) and C (relaxation) did not ($F_{1,42.0}$=2.08, *n.s.*; $F_{1,39.1}$=1.60, *n.s.*). For the pre-test, Group A engaged in significantly more activities than Groups B and C ($F_{1,87.0}$=15.40, p<.001). After meditation training, Group A engaged in significantly *fewer* activities than Groups B and C ($F_{1,87.9}$=6.63, p<.05).

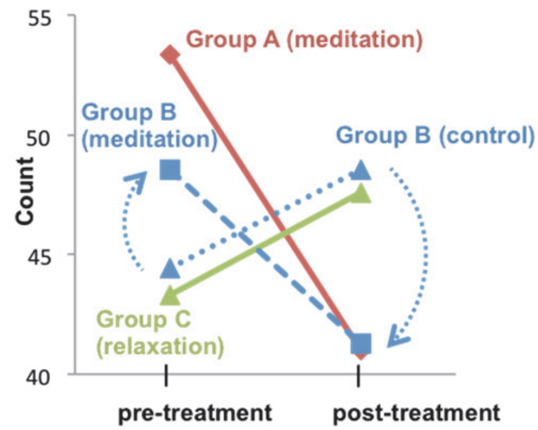

Figure 2: Average number of activities per test by Group and by Session.

With Group B as replication (*i.e.*, after Group B underwent meditation training), there was still a significant *Group* × *Session* interaction ($F_{2,37.4}$=6.73, p<.01), but now because of Group C, the relaxation group, which differed significantly from Groups A and B. After meditation training, the number of activities in Group B was statistically indistinguishable from Group A ($F_{1,81.6}$=0.10, *n.s.*), the original meditation group. Groups A and B showed significant decreases in the number of activities from pre- to post-test ($F_{1,42.5}$=15.63, p<.001; $F_{1,35.7}$=5.06, p<.05), while Group C did not ($F_{1,34.9}$=1.61, *n.s.*). Just prior to meditation (or relaxation) training, there was a trend suggesting Group B may have engaged in more activities than Group C ($F_{1,79.8}$=3.05, p=.08). After meditation (or relaxation) training, however, the trend switches, suggesting Group B may have engaged in significantly *fewer* activities than Group C ($F_{1,80.8}$=3.84, p=.05), just as Group A had done.

Thus, it seems that initially Groups B and C were similar, even after Group B's wait period and Group C's relaxation training. Then, after Group B underwent meditation training, Group B became statistically indistinguishable from Group A, the original meditation group, in terms of the number of activities undertaken in a test. Meditation therefore seems to *reduce* task-switching as measured by the number of activities in a test.

4.1.3 Time per Activity

The initial finding in this section was that there was no significant difference among groups in overall task time taken. Yet we know that Groups A and B, after meditation training, engaged in fewer total activities during the test than Group C or Group B as control. This is possible because groups differed in the amount of time they spent on each activity (Figure 3, next page).

With Group B as control, there was a significant *Group* × *Session* interaction ($F_{2,88}$=5.46, p<.01), owing to Group A, the meditation group, showing a significant increase in time per activity from pre- to post-test ($F_{1,88}$=4.24, p<.05), while Groups B (control) and C (relaxation) showed a significant or marginal *decrease* in time per activity ($F_{1,88}$=4.32, p<.05; $F_{1,88}$=3.43, p=.07). For the pre-test, Group A spent significantly less time per activity than Groups B and C ($F_{1,88}$=9.50, p<.01). After meditation training, there was no longer a detectable difference among the three groups' time per activity.

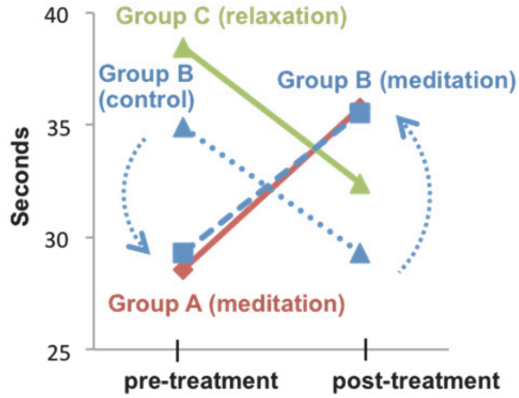

Figure 3: Time per activity per test by Group and by Session.

With Group B as replication (*i.e.*, after Group B underwent meditation training), there was still a significant *Group* × *Session* interaction ($F_{2,82}$=3.98, p<.05), but now because both Groups A (meditation) and B (meditation) differ from C (relaxation). After meditation training, the average time per activity of Group B was statistically indistinguishable from Group A ($F_{1,82}$=0.05, *n.s.*), the original meditation group. Groups A and B exhibited increasing trends in the time spent per activity from pre- to post-test ($F_{1,82}$=3.09, p=.08; $F_{1,82}$=3.48, p=.07), while Group C did not ($F_{1,82}$=2.70, *n.s.*). Just prior to meditation (or relaxation) training, Group B spent significantly less time per task than Group C ($F_{1,82}$=5.32, p<.05). After meditation (or relaxation) training, however, the effect is no longer significant ($F_{1,82}$=0.36, *n.s.*).

Thus, before meditation (or relaxation) training, Groups B and C were similar, but after Group B underwent meditation training, Group B became statistically indistinguishable from Group A, the original meditation group, in terms of average time per activity. In general, meditation seems to *increase* time spent per activity.

4.2 Expectation of Benefit and Memory for Task

The average Expectation of Benefit (on a 3-point scale) was greater for the relaxation training group (M=2.18, SD=.75) and the waitlist group (M=1.93, SD=.88) than for the meditation training group (M=1.42, SD=.52). These differences were significant ($F_{2,195}$=21.65, p<.001). Pairwise comparisons showed that participants in the meditation training group initially expected less benefit than those in the relaxation or waitlist groups (p<.001).

As shown in Figure 4, Task Memory scores improved from pre- to post-training for the meditation and relaxation training groups, although not for the waitlist group. For Task Memory, there was a significant session main effect ($F_{1,121.0}$=24.00, p<.001) and *Group* × *Session* interaction ($F_{2,121.0}$=8.61, p<.001). In *post hoc* pairwise comparisons, both the meditation training group and the relaxation training group showed a significant memory improvement from pre- to post-training (p<.001). However, only the meditation training group showed a significantly greater Task Memory score than the waitlist group after training (p<.05). In analysis comparing the second and third testing sessions for the waitlist control group, they showed a comparable increase from the second session (post-wait) to the third session (post-meditation training), with no significant *Group* × *Session* interaction effect.

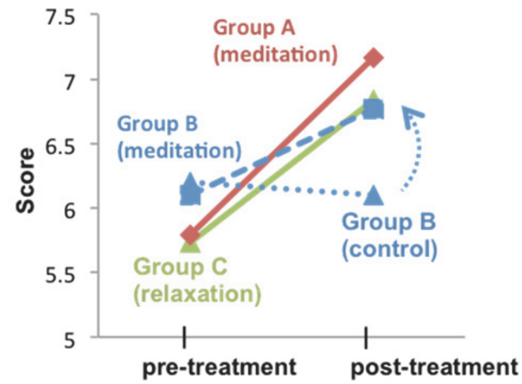

Figure 4: Memory for tasks pre- and post-training.

4.3 Positive and Negative Affect

The self-report measures of positive and negative affect and stress-related emotion (PANAS and POMS-SF), obtained before and after the multitasking test performance at each testing session, confirmed that participants found the test stressful, as intended. A significant pre- to post-multitasking test main effect was found for PANAS Positive Affect ($F_{1,108}$=12.79, p<.001), showing that participants' mood was less positive after the test, and PANAS Negative Affect ($F_{1,91.8}$=14.21, p<.001), demonstrating more Negative mood after task performance. A significant pre- to post-multitasking test main effect was also found for POMS Anger-Hostility ($F_{1,108.7}$=4.23, p<.05; greater Anger-Hostility after task performance), and for POMS Vigor-Activity ($F_{1,107.0}$=7.52, p<.005; less Vigor-Activity after task performance). These results collectively indicate that performing the multitasking test resulted in less positive mood, more negative mood, anger, and decreased sense of energy, supporting the intended stressful nature of the task.

There was evidence for a differential impact of the training conditions upon experienced stress, especially for that reported after multitasking test performance. There was a significant *Group* × *Pre- Post-Task* interaction ($F_{2,91.8}$=4.72, p=.01), and a significant three-way, *Group* × *Session* × *Pre- Post-Task* interaction ($F_{3,103.8}$=2.81, p<.05) for PANAS Negative affect, with *post hoc* pairwise comparisons showing the meditation training group to have significantly (p<.05) less of a pre- to post- task increase in Negative affect, after training, than either the waitlist or relaxation training groups. For the POMS Fatigue-Inertia dependent variable, there was a significant *Group* × *Session* interaction ($F_{2,142.4}$=5.96, p<.005), with *post hoc* pairwise comparisons showing the meditation group and the relaxation group to report less Fatigue-Inertia after, compared to before, their meditation training (p<.05). In analyses comparing the second and third testing sessions for the waitlist control group, participants showed a comparable decrease from the second (post-wait) session to the third (post- meditation training) session on PANAS Negative Affect (*Group* × *Pre- Post-Task* interaction $F_{2,84.6}$=12.623, p<.001), with *post hoc* pairwise tests showing both of the groups that received meditation training to report less (p<.05) Negative Affect after training than the relaxation training group. A similar decrease in POMS Fatigue-Inertia for the waitlist group, from before to after their meditation training (*i.e.*, session 2 to 3) was found (*post hoc* pairwise comparison, p<.05). Thus, the meditation training appeared to have a similar impact for Group B (control) and Group A (meditation).

4.4 Daily Mindfulness

There was a significant *Group* × *Session* interaction ($F_{2,122.0}$=6.807, p<.005) for self-reported daily mindful awareness and attention (MAAS). *Post hoc* pairwise comparisons showed that the meditation group, but not the relaxation group, reported greater mindful awareness and attention after training (p<.05). The waitlist group showed a decrease in self-reported daily mindful awareness and attention following their 8-week waiting period (p<.05). For analysis involving the waitlist group comparison between sessions 2 and 3 (*i.e.*, before to after their meditation training) there was a non-significant trend toward a greater increase in mindful awareness and attention after training for the two meditation groups, compared to the relaxation training group (*Group* × *Session* interaction $F_{2,122.3}$=2.75, p=.068). These results indicate that the meditation training was, as expected, uniquely associated with increased self-reported mindful awareness and attention.

5 DISCUSSION

We discuss the findings just presented and two limitations of the study, followed by a brief reflection on implications.

5.1 Multitasking Performance

We found that those in the meditation group (but not those in the other two groups) showed greater time on task and a reduced number of task-switches post-training as compared with pre-training. This appears to be an implicit effect of the meditation training, since participants were never explicitly instructed during meditation training to shift their attention less often.

To what might this result be attributed? We conjecture that if one's ability to concentrate is weak, then one may be more likely to respond to each new interruption immediately. But focused attention (FA) training appears to strengthen one's ability to notice interruptions without necessarily relinquishing one's current task. Having such skill might therefore give users the *choice* to stay with the current task longer, rather than responding to each interruption immediately.

5.2 Memory for Task

The meditators also showed improved memory for the details of the work they were doing in the post-training multitasking test compared to their performance in the pre-training test, as did those in the relaxation group. Participants in the waitlist control group showed no such improvement; however, once they received the meditation training, they also demonstrated improved memory.

To what might this improved memory be attributed? We conjecture that it was the result of reduced stress. Laboratory studies have demonstrated a strong correlation between increased stress and reduced memory [33].

It is noteworthy that none of the groups showed post-training improvement in *overall* accuracy or speed, other than a practice effect (*i.e.*, participants in all three groups took less time to complete the entire test in the post-training or post-waiting assessment, compared to that before the training). Further work will have to determine whether this is a generalizable result or a result specific to our particular experiment and test design.

5.3 Positive and Negative Affect

All participants found the test stressful, as intended. But in addition, for the meditation-training group after training, there was less negative mood (especially after task performance) and fatigue following the training. (The waitlist and relaxation groups showed no significant decrease.) For the waitlist group, there was a similar post-multitasking test decrease in negative mood, and a trend toward decreased fatigue after this group had received their meditation training. This replication of the negative mood decrease observed for the two groups receiving meditation training supports the premise that this effect is not unique to a particular teacher, since different teachers instructed these two groups.

It is noteworthy that those in the relaxation group, whose primary training centered on body relaxation, did not report the same degree of reduced stress/negative affect as did those in the meditation group. We conjecture that enhancing the meditators' attentional abilities may have reduced their stress by increasing their sense of competence, which mere relaxation did not. Moreover, since mindfulness meditation has been linked to enhanced emotion regulation [25], it is possible that the meditators were better able to modulate their emotional responses to the stressful multitasking test they were performing.

5.4 Daily Mindfulness

Prior studies (*e.g.*, [13]) have demonstrated that 8 weeks of meditation training increases self-reported daily mindfulness. We found that the meditation group, but not the relaxation or the waitlist group, reported significantly greater mindful awareness and attention after meditation training. The waitlist group actually reported a *decrease* in mindfulness during the wait period, but following meditation training showed a non-significant trend toward greater mindfulness.

5.5 Limitations of the Study

The study was largely designed around the teaching and availability of the Zen teacher Darlene Cohen. This meant that some of the recruitment, training and testing needed to take place in the San Francisco Bay Area, where she was based, and that the timing of the training needed to conform to her busy and changing schedule. This affected the design and execution of the study in two ways.

First, because some participants were recruited in San Francisco and others in Seattle, we were not able perform a fully randomized assignment to groups. However, the groups did not differ on assessed demographic characteristics, and there was nothing to suggest any pre-training differences that would have affected the observed training results.

Second, our test apparatus required human intervention, both in the administration of the test (where the experimenter played a Wizard of Oz role) and in the data analysis (where human coders were needed to identify and provide timing information for some of the participants' activities). This introduced unwanted variability and potential error that could be avoided in the future by designing a fully automated test, recording, and analysis apparatus.

5.6 Some Implications of the Study

Meditation is already being introduced into the modern office in the hope that it can effect positive changes in worker performance and well-being [9]. The present study offers some support for such interventions, suggesting that they may lead to improved memory and reduced stress. As for the observed reduction in task switching, whether this ultimately constitutes a positive change is beyond the scope of the present paper. While our study thus provides evidence that meditation training may be useful in the workplace, it also points to the benefits of relaxation. Moreover, it raises important—and as yet unanswerable—questions about the similarities and differences between these two forms of training, and whether and how they might be combined.

6 DESIGN IMPLICATIONS

Human attention is an essential component of all cognitive tasks; in this respect, all design work in HCI must take properties of the human attentional system into account. Indeed, since its early roots in human factors research during World War II (*e.g.*, airplane cockpit design), HCI has been engaged in two interrelated activities: *studying* the attentional system and *designing* for attention. In the work reported here we propose a third complementary activity: *training* the human attentional faculty.

This third activity brings into focus an important dimension of human attention, namely its variability. This variability is manifested in at least three ways: First, individuals differ from one another in their attentional strength and skill. Second, the strength of each individual's attention varies throughout the day depending on a variety of factors; attention, like muscle strength, is a resource that can be depleted. And third, an individual's attentional capacity can be enhanced through explicit or implicit training. Clearly, the success or quality of one's activities depends crucially on a proper fit between the task one is performing, the way one is performing it, and one's attentional state.

In light of the complex and variable relationship between task and attention, we suggest that future systems might help users develop and maintain awareness of the state of their attention and modify their working strategies accordingly. Further, systems might direct users in ways that would ultimately enhance their attentional capacity. We suggest four design directions that follow from this:

1. Giving feedback on attentional state. While it is unlikely in the short term that systems will be able to monitor and assess users' attentional state directly, it is not hard to imagine methods of performing such tasks indirectly, in light of the strong correlation between physical and attention fatigue. It may be possible, for example, to detect physical fatigue based on measurable user behaviors with the mouse, keyboard, and windowing systems. And certainly, greater possibilities exist if sensing is extended beyond just the mouse and keyboard and the user's windowing environment. One can imagine any number of biophysical awareness displays arising from sensors capable of detecting users' respiration (*e.g.*, [24]), heart rate, skin conductance, and so on, as well as the use of cameras and chair sensors to detect changes in user state.

2. Recommending User Action. Beyond sensing and giving users' feedback on their attentional state, a next step could involve offering the user suggestions about remedial action they might take. The most obvious example would be to take a break, and to turn to some other activity, such as meditation [16], that might help the user restore their attentional strength.

3. Adjusting Design to Attentional Capacity. As already noted, people differ in their overall attentional capacity. This suggests that a one-size-fits-all approach to systems design will not work, and an *ability-based design* [43] approach may be warranted. Ability-based design, which comes from accessible computing, attempts to leverage all that users *can* do by having highly adaptive or adaptable systems that are aware of, and responsive to, a user's *individual* capabilities and needs. By testing users to discover, for example, whether their ability to disregard irrelevant information is strong or weak, a system could better choose when to interrupt users with notifications, given their relative priority and the user's capacity for dealing with them.

4. Augmenting Attentional Capacity. One can also imagine developing online tools that could train people's attention. Developing games, for example, that would be fun to play while also training specific attentional skills seems like a promising area for further exploration.

7 FUTURE WORK

Results of this experiment leave several questions unanswered. First, although the mindfulness training, relaxation training, and waitlist groups were similar in demographic characteristics and responses to the administered self-report questionnaires, constraints on instructor availability resulted in an experimental design in which participant assignment to group was not fully randomized. Future attempts at replication will therefore need to employ a fully randomized controlled design. Second, although the mindfulness-based training appeared superior to both the waitlist and the relaxation training conditions, in regard to time on task, task-switching frequency, and self-reported negative affect, the causal mechanisms by which the mindfulness training impacts task performance and stress remain unclear. Possible contributors to the reduction in task-related emotional distress include: greater body awareness, and consequent intentional relaxation when tension is noticed; and more advantageous task-performance strategies (*e.g.*, greater focus on one task at a time, and resultant reduced working-memory demands), with consequent greater confidence and reduced experience of stress. The increase in memory for task details may also be the result of a reduction in stress, which occurred for at least some of those in the relaxation group. The observed longer time spent on tasks before switching after mindfulness training could be the result of reduced physiological arousal (and hence reduced reflexive responding to new events), and/or a change in how attention is deployed (*e.g.*, a more open and stable, rather than a narrowly focused, attentional field that is susceptible to distraction). The future testing of these various causal explanations will require experiments in which both biological measures of physiological arousal and cognitive measures of the theoretic components of attention are included. Such experiments would require larger sample sizes, allowing adequate power for the testing of moderating and mediating effects of the processes measured. In the future, we also hope to supplement self-reports of affect with objective, biometric measures of stress-related physiology, such as skin conductance.

8 CONCLUSION

The present study builds on a growing body of scientific literature suggesting that human attention is a trainable resource and that certain forms of meditation constitute a viable form of such training. The evidence presented here suggests that meditation training may effect positive changes in the multitasking practices of computer-based knowledge workers, and thus offers encouragement to those who would design workplace or technology interventions to take advantage of this possibility.

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