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ORIGINAL RESEARCH ARTICLE

Office Openess Affects Stress Regulation and Teamwork: A Neurophysiological Field Study

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Abstract

Stimulating and sustaining teamwork can be a strategic asset for an organization. Yet, little has been done to objectively assess how office design affects team performance. We conducted a neuroscience field experiment of employees ($N=96$) to examine how different open-office configurations impact three measures of neurophysiologic stress, affect, and creative problem-solving in three existing office configurations that varied in their degree of openness. Physiologic stress was lowest in the most open work setting resulting in higher performance and more rapid post-work physiologic recovery compared to less open configurations. We identified three core factors driving these results: high perceived privacy, a more pleasant ambience, and increased autonomy. This multimodal approach identifies neurophysiologic mechanisms linking office design to team performance.

Keywords Creative problem-solving · Connection · Job Satisfaction · Productivity · Workspace design · Teamwork · Behavioral economics · Experiment · Design

Introduction

In a recent survey, 87% of employees reported that they prefer to work in attractive and comfortable offices (Kohll, 2019). However, proving that office layout matters to organizational performance, and why it matters, has been difficult because of the plethora of measures used and the over-reliance on impressions rather than objectively measurable actions (Dewey, 2007). Impressions of office space impact employee mood and motivation (Bjerke et al., 2007), but because affective states are difficult to report consistently (Augustine et al., 2010; Yannakakis & Hallam, 2011), research that combines subjective and objective measures improves the ability to assess the impact of office layouts. Measures of neurologic activity add another

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dimension when seeking to understand how office design affects people at work. The present study investigates how differences in office openness affect team performance and seeks to identify why such differences occur.

Understanding how workplace design affects team performance is particularly important as office usage has changed due to the COVID-19 pandemic. Many employees have acclimated to working from home and are loath to return to the office. As a result, companies have instituted greater flexibility for colleagues who now have the option to work in offices some days and at home during others (Wakabayashi, 2021). Companies like Apple, Google, and Salesforce believe it is important for employees to work from their offices at least one-half time and have instituted rules to ensure this occurs (Yankowski, 2021). Employees might be persuaded to return to the office voluntarily when its design is aesthetically attractive and effectively facilitates teamwork. Even pre-pandemic, businesses have sought to appeal to employees and stimulate team performance using new types of office plans, especially open and flexible designs. For example, Google designed "team pods" with whiteboards, desks, chairs, and storage units that can easily be modified to promote teamwork by in-person and virtual team members (Wakabayashi, 2021).

The trend toward open and shared office spaces began in the 1970s and its momentum has continued in twenty-first century (International Facility Management Association, 2010). Open office plans are popular for two main reasons: presumed increased communication among employees and cost savings. Work in teams has increased by over 50% in the last two decades (Cross et al., 2016; Green, 2012), and open offices are thought to improve interactions among colleagues making it easier to get to know and work with others. Closeness among work colleagues has been shown to increase motivation, knowledge sharing, creativity, group effectiveness, and company financial performance (Brand, 2009; Collins & Clark, 2003; Evans & Davis, 2005; Hua, 2007; Hwang & Kim, 2013; Kotlarsky & Oshri, 2005; Oh et al., 2004; Rashid et al., 2009).

The rise of telecommuting has turned the office into a culture space, a social milieu that facilitates connections, learning, and teamwork (Fayard et al., 2021). When properly designed, open office configurations endow conversations with content-rich face-to-face interactions that include nonverbal cues, touch, and empathy (Fayard et al., 2021). Indeed, a Google study found a high correlation (0.81) between teamwork and innovation (Google Enterprise EMEA, 2010). Work occurs at desks rather than in conference rooms, something open office spaces facilitate (Green, 2012). Open office spaces also cost less to set-up, change, and renovate than closed offices, providing another reason to choose them (Kim & De Dear, 2013; Maher & von Hippel, 2005; Samani & Rasid, 2015).

Despite their advantages, open offices have shortcomings. Open layouts can distract employees with noise and movement while increased proximity to colleagues may result in perceived crowding (Laurence et al., 2013) that can diminish self-regulatory resources that are necessary to be productive (De Croon et al., 2005; May et al., 2005; Roelofsen, 2008; Samani & Rasid, 2015; Veitch et al., 2007). In addition, an open office design may diminish the sense of privacy and control, both of which can negatively affect performance and may result in counterproductive workplace behaviors (De Croon et al., 2005; Kim & De Dear, 2013; MacMillan, 2012;

Samani & Rasid, 2015). Physical office space can both build and strain relationships between employees (Khazanchi et al., 2018). Whether open office plans improve or diminish workplace performance is an open question, as is the human response to open designs.

Office Layouts and Emotions

Most work is a combination of cognitive, physical and emotional labor (Lee et al., 2017). Although emotional responses capture the value of an experience (Zak, 2022; Seth, 2013), they are often overlooked when evaluating office layouts. Indeed, employees typically personlize their office spaces with emotionally meaningful decorations which may be a way to influence their emotional states (Scheiberg, 1990). When emotional responses are conisdered, they are usually measured via self-report (Ayoko et al., 2014; Cronin, 2014; Fineman, 2000). The use of self-report measures to assess emotional states at work is questionable for several reasons (Carmeli & Colakoglu, 2005; Davis et al., 2011; Spector, 1994). For example, changes in office layout may prime employees to report greater productivity or energy at work to align with leadership's expectations. A change of any type may cause a temporary uptick on self-report measures such as affective states or productivity simply due to a Hawthorne-type effect (Brennan et al., 2002; Román, 2009; Singh et al., 2010). Some studies have relied on peer assessments of performance (Amabile et al., 2005; Rego et al., 2014), but these reports may be biased in which one's own affective state is projected onto others. Yet, positive affect has been shown to improve both teamwork and creativity, so it is important to measure it (Amabile, 1988). Indeed, physical settings have been shown to influence affect (Brief & Weiss, 2002; Küller et al., 2006) leading one to expect that office layouts would, via this route as well as perhaps directly, influence teamwork.

Stress and Teamwork

Brain responses are the proximate cause of changes in affect (Berridge & Kringelbach, 2013; Merritt et al., 2022; Soon et al., 2008). Therefore, the present study supplements self-reports of emotional states with neurophysiologic responses while employees performed objectively-measurable work-like tasks. That is, we report results from a behavioral neuroscience field experiment that tests if office spaces of varying openness improve employee teamwork and if so, the mechanisms behind this. While most of the research on office configurations has focused on individual responses (Sailer, 2014), work increasingly depends on collaboration with colleagues (Boskamp, 2023). Thus, in order to produce the most useful findings, we focus on how office design affects teamwork.

A variety of neural responses could be measured to assess how office plans influence teamwork, but our focus here is on stress. High levels of stress inhibit individual and team performance (Colligan & Higgins, 2006) and negatively impact employee wellness (Ganster & Rosen, 2013). The Yerkes-Dodson law suggests that moderate stress (eustress) may be performance enhancing (Le Fevre et al., 2003), although recent investigations indicate that even moderate stress/arousal inhibits performance (Corbett, 2015; Hancock & Ganey, 2003; Hanoch & Vitouch, 2004).

We obtained three measures of stress from the peripheral nervous system to quantify how office layout affects team performance. By using multiple measures, we sought to reduce the inherent noise when measuring physiologic systems (Zak et al., 2022). In addition, study participants were employees who were placed in existing spaces at a large manufacturing company capturing an ecologically valid setting that aids generalization. Finally, rather than compare conventional private offices, which are generally used for individual work, to open office designs, we compared three existing office layouts that varied in their degrees of openness while groups of employees completed a work-type task through which creative problem-solving could be objectively measured. The responses could be influenced by differences in background noise of the more open spaces so this was included as a control (Park and Lee, (2017).

Figure 1 summarizes the hypothesized flow from office design to teamwork that the experiment was designed to test. The figure posits that office design will affect participants' neurophysiologic activity and psychological states that in turn affects teamwork.

Based on the research discussed above, we hypothesized that.

H1: Physiologic stress will be lower in more open office layouts
H2: Open office space will increase positive affect.
H3: Team performance will be higher in more open office layouts.

Methodology

Location Employees at a large company in the U.S. Midwest were invited via company email to participate. The email was from the experimenters and emphasized that participation was voluntary. The study was done during work hours and employees could earn $25 for their participation that took approximately 1.5 h. The data were collected over 4.5 days. The five-member research team was not acquainted with any of the participants. At the conclusion of each study session, participants were paid in cash.

Participants A total of 96 participants (46 women; average age = 43.5) volunteered for this study and were randomly assigned to one of the three locations in groups of four. The study was approved by Solutions IRB Institutional Review Board (# 1,303,221) and all participants provided written informed consent prior to inclusion. Data were anonymized by assigning an alphanumeric code to each individual.

Fig. 1 Hypothesized flow from space configuration to teamwork productivity

Statistical Analysis The sample size was chosen using G*power (Faul et al., 2007) using the average size effect and standard errors for the change in the R-R interval in Barraza et al. (2015). The statistical power for 95 observations was estimated at 0.95. The statistical analysis compares team performance while participants worked in teams in one of the three office spaces that varied in their degree of openness. The initial analysis examined overall effects using F-tests, t-tests, and Pearson's correlations. Multiple analyses were used to generate a portfolio of findings in order to provide convergent evidence for the tested hypotheses (Mayo, 2018). Factor analysis was also used to identify the aspects of office types that were most desirable. This approach is used because of the multiple attributes that are expected to be associated with office space desirability in order to create categories of attributes that co-vary and are therefore more easily interpreted (Kline, 2014).

Office Spaces All locations were open in that they did not have floor-to-ceiling walls; none were closed meeting rooms or cubicles. The experiment was run while non-experiment employees walk by, talked on the phone, and worked at desks nearby. The first location, L1, was designed for group meetings (Fig. 2). It had relatively high amount of privacy with two curved three-foot high partitions, a low table, chairs for four, and light foot traffic nearby. Other employees were sitting approximately eight feet from this space. The average maximal sound level in this space during the experiment was 78 dB.

The second location, L2, was a partially open group workspace (Fig. 3). Employees in this space sat at a high table with stools, with only one partition around it. There was little foot traffic, and others worked at desks as close at six feet away. It was quieter than L1, with average maximum sound level of 73 dB.

The third location, L3, was a busy space used by employees and visitors with continuous foot traffic (Fig. 4). It had a low table and chairs for four without any partitions. L3 was the most open space of those tested. It was moderately noisy, having an average maximum sound level of 92.4 dB.

Openness of each tested location, which was judged by how much of the space was surrounded by partitions, from low to high, was L1 < L2 < L3.

Fig. 2 The least open space, L1

Fig. 3 The moderately open space, L2

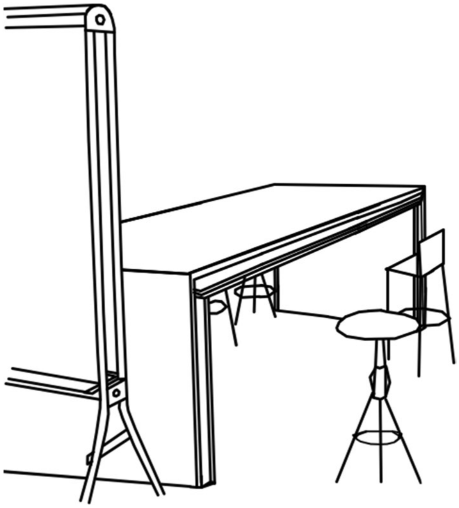

Fig. 4 The most open space, L3

Physiologic Data In order to obtain data on stress responses, three neurophysiologic measures were obtained: adrenocorticotropin hormone (ACTH; Melmed et al., 2015), the change in heart rate (HR; Vrijkotte et al., 2000) from baseline to a work-type group task (described below) to post-task, and electrodermal activity for the same period (EDA; Anusha et al., 2018). Three measures were included because of the inherent noisiness of physiologic responses (Marmarelis, 2012).

ACTH is produced by the anterior pituitary and increases neurologic and cardiovascular arousal to meet physical, cognitive or emotional demands. ACTH is released within seconds to a few minutes after demand onset making it an effective short-term stress marker whereas cortisol release often requires 5–10 min making cortisol inappropriate for the short task participants were asked to complete (Brunson et al, 2001). The cascade of effects of ACTH include an increase in HR (Gotthardt et al, 1995). This was included as a second measure of arousal. Finally, a third measure of physiological arousal, EDA, captures the increases electrical conductance due to palmar sweat and has been used extensively to capture stress responses (Giannakakis et al, 2019).

After consent, participants were led to a private room where a qualified phlebotomist obtained a blood sample drawn from an antecubital vein. Two 8-ml EDTA whole-blood tubes were drawn in a sterile field using Vacutainer® blood- collection kits. Blood tubes were stored on ice before centrifuged at 1500 rpm at 4 °C for 12 min following previous protocols (Zak et al., 2005). Plasma was aliquoted into 2-ml polypropylene Fisher brand microtubes and placed on dry ice. Microtubes were then transferred to an -80 °C freezer until analysis. The initial draw measured basal levels of the fast-acting arousal marker ACTH. A second blood sample was taken after the behavioral task to measure the change in ACTH. The Yerkes National Primate Research Center at Emory University (Atlanta, GA) assayed ACTH using a radioimmunoassay (RIA) produced by DiaSorin, Inc. (Stillwater, MN, USA). The inter-assay CVs < 11%.

After the first blood draw, participants were fitted with disposable EDA Ag–AgCl sensors on the middle and index fingers of participants' non-dominant hand and a three-lead electrocardiogram (ECG) using disposable Ag–AgCl sensors above the right clavicle, below the left ribs and above the left clavicle. Participants were instructed to wash their hands with supplied non-detergent bar soap prior to EDA sensor placement. ECG (sampling rate 1 kHz) and EDA (sampling rate 250 Hz) were collected using a Biopac MP150 data acquisition system with BioNomadix® transmitters and recorded with AcqKnowledge® software version 4.2 (Biopac Systems Inc., Goleta, CA). Baseline EDA and ECG data were obtained by having participants sit quietly for five minutes in their assigned location with others from their group.

After data collection was completed, EDA data were visually inspected for signal loss. Data drop-offs shorter than 1 s were replaced with averages from adjacent parts of the waveform and random noise due to experimenter-observed movement was smoothed using mean-value replacement from adjacent parts of the waveform (Johannsen & Zak, 2020). As is standard, a 10-Hz low-pass filter was applied to remove high-frequency noise (Norris et al., 2007), and a square root transformation was used to account for skew (Dawson et al., 1989). The average skin conductance level (SCL) was then measured from this cleaned data for the final two minutes of the baseline period and the change in SCL from baseline was calculated during the behavioral task and for two minutes after the task ended. SCL is a tonic measure of neurologic arousal (Figner & Murphy, 2011).

Data cleaning for ECG data included removing artifacts manually and using a band-pass finite impulse response (FIR) filter that remove both high- and low-frequency noise, and then smoothing the waveform (Subbiah et al., 2014). A precise way to measure changes in cardiac activity is to capture the R-R interval in the P-Q-R-S-T wave. The R-R interval was then transformed into heart rate (HR) for easier interpretation of the findings. The change in HR from baseline was analyzed for the period of the behavioral task and for two minutes after the task was over.

Behavioral Tasks Participants completed a work-type problem-solving task under a time constraint to measure team performance. Each team of four was given a disassembled mechanical apple peeler and pictures of the assembled device. They were then asked to correctly assemble as many pieces as they could in five minutes. Productivity was measured by the number of pieces each group correctly assembled. This task was designed to be similar to tasks study participants, who were employed at a manufacturing company, would typicaly do.

Surveys Surveys measured demographics, attributes of each location, psychological states, and perceptions of the work task. The measures included closeness to work colleagues (Inclusion of Other in Self (IOS); Aron et al., 1992) and changes in affect from baseline (Positive and Negative Affect Schedule (PANAS); Watson et al., 1988). The Workspace Satisfaction Questionnaire, designed to evaluate open offices, was used to assess location desirability (WSQ; Veitch et al., 2002) while organizational trust and job enjoyment were measured using the Ofactor survey (Johannsen & Zak, 2020; Zak, 2017). All these surveys are used in interpersonal research and are statistically validated.

The IOS survey asks participants to identify the degree of connection to others by indicating how much two ellipses overlap, which are linearly scored (1–6), with higher values indicating greater closeness. The PANAS has participants rate (1–5) 20 adjectives describing their current emotional state (e.g. distressed, excited, etc.). Averages are used to create positive and negative affect scales with highly reliable measures (Cronbach's alphas >0.80). In the WSQ survey, participants rated 18 physical aspects of a space (e.g. lighting, temperature, etc.) using a Likert scale (1–7). Each item was assessed individually. The Ofactor survey has 16 questions about workplace behaviors that are rated (1–10) and averaged in pairs to identify the eight foundational factors that produce organizational trust (e.g. "I feel comfortable approaching my manager with work concerns ") with overall trust the average of all 16 questions. Additional questions asked participants to rate themselves immediately following the team task on how much energy and effort they put into it, how pressured they felt, and if they believed they were productive using a Likert scale (1–7). Figure 5 shows the order that participants completed each phase of the experiment.

Data Availability The data are available at Open ICPSR openicpsr-162681.

Conflict on Interest The authors declare they do not have a conflict of interest.

Results

The Table 2 in the Appendix shows the correlations among key variables.

Desirability Location had a significant effect on desirability ratings, ($F(2, 92)=7.83$, $p<0.01$; Fig. 6). The most open space, L3, was rated most desirable ($M=4.8$, $SD=0.85$), followed by L2 ($M=4.4$, $SD=0.83$) and then least open space, L1 ($M=4.0$, $SD=0.78$). Bivariate differences were statistically significant (L2 > L1, $t(62)=-1.97$, $p=0.05$; L3 > L1, $t(61)=-3.98$, $p<0.01$; L3 > L2, $t(61)=-1.99$, $p=0.05$). Spending time in more desirable locations was associated with feeling closer to colleagues ($r=0.32$, $p<0.01$). Demographic variables such as age, gender, or whether participants had children did not vary across locations (ps >0.05).

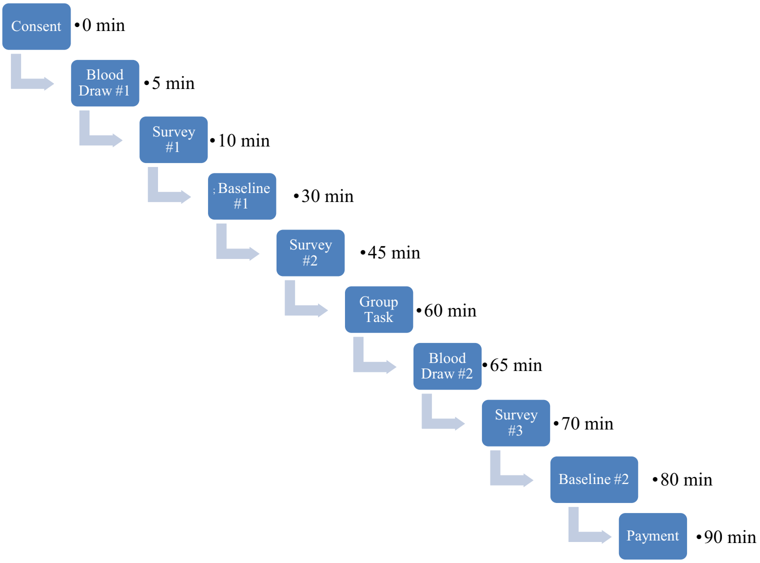

Fig. 5 The timeline of the experiment

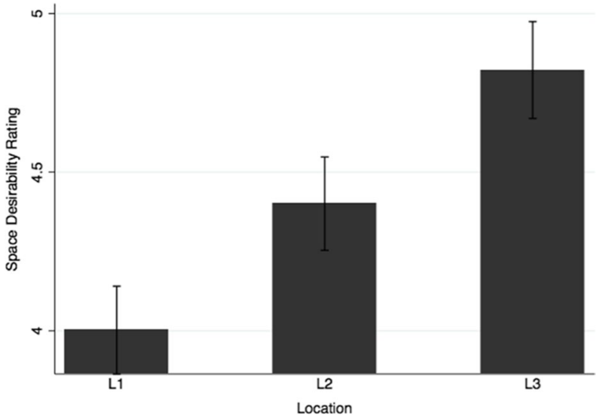

Fig. 6 Workspace satisfaction rating for each location. L1 = the least open space; L2 = the moderately open space; L3 = the most open space. Bars are SEs

Team Performance Location affected performance in the creative problem-solving task ($F(2, 93) = 5.57$, $p < 0.01$). The percentage of parts correctly assembled was lowest in the least open location L1 ($M = 39.7$) compared to L2 and L3 (L2: $M = 52.9$, $t(62) = -2.69$, $p = 0.01$; L3: $M = 53.5$, $t(62) = -3.21$, $p = 0.01$; Fig. 7).

Neurophysiology Basal stress as measured by ACTH did not vary by location (ACTH: $F(2, 83) = 2.04$, $p > 0.1$; HR: $F(2, 75) = 1.54$, $p > 0.10$). Yet, location affected how rapidly participants shed task-induced stress. The percentage change

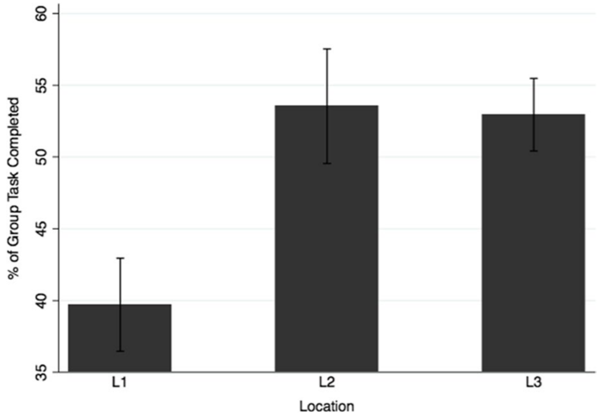

Fig. 7 Team performance on the creative problem-solving task at each location. L1 = the least open space; L2 = the moderately open space; L3 = the most open space. Bars are SEs

in ACTH from baseline to post-task was significantly negative in the most open L3 location (M = -9.1%, $t(26)$ = -2.07, p = 0.05), but not different from zero in either L1 ($t(30)$ = -0.65, $p > 0.1$) or L2 ($t(27)$ = 0.70, $p > 0.10$; Fig. 8).

As additional evidence, the percentage change in HR from the task to the post-task rest period fell for all three locations ($F(2, 76)$ = 4.92, p = 0.01), and was largest for the most open space L3 (M = -13.6%), compared to L2 (M = -8.9%, $t(51)$ = 2.67, p = 0.01) and L1 (M = -8.6%, $t(50)$ = 3.07, $p < 0.01$; Fig. 9).

A similar pattern was found for the change in SCL ($F(2, 64)$ = 5.40, p = 0.01; Fig. 10). The percentage change in average SCL from baseline to post-task remained elevated in the more closed locations but returned to baseline in the most open location (L1: M = 47.1%, $t(22)$ = 2.85, p = 0.01; L2: M = 12.0%, $t(24)$ = 2.76, p = 0.01; L3: (M = 3.2%, $t(18)$ = 0.01, $p > 0.1$).

Psychological Responses Neither the average change in affect (PANAS, $F(2, 92)$ = 0.15, $p > 0.1$) nor post-experiment average affect ($F(2, 92)$ = 2.42, p = 0.09) was significantly different across locations. Those who enjoyed the task felt closer

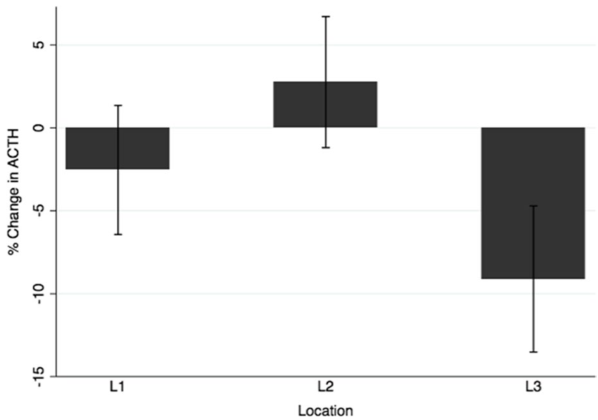

Fig. 8 Percentage change in adrenocorticotrophic hormone (ACTH) after finishing the creative problem-solving task at each location. L1 = the least open space; L2 = the moderately open space; L3 = the most open space. Bars are SEs

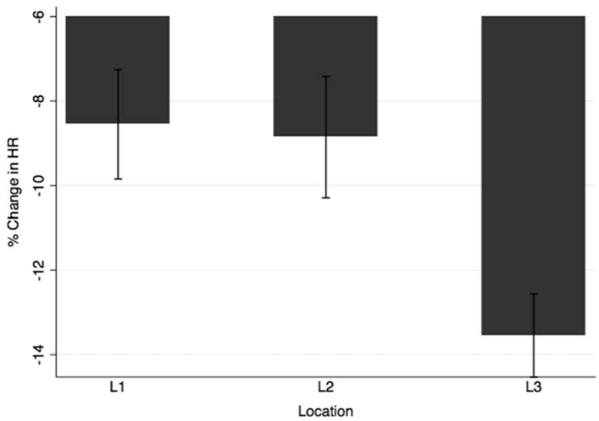

Fig. 9 Percentage change in heart rate (HR) after finishing the creative problem-solving task at each location. L1 = the least open space; L2 = the moderately open space; L3 = the most open space. Bars are SEs

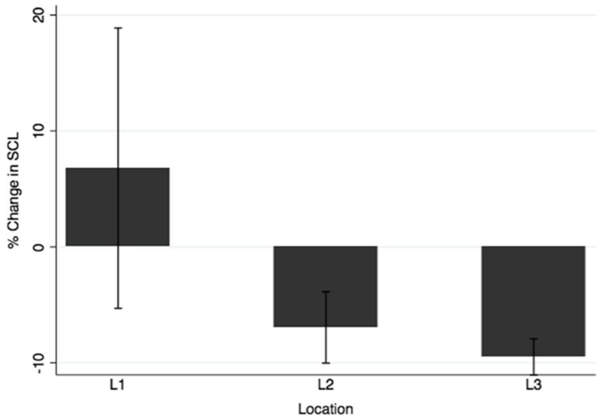

Fig. 10 Percentage change in skin conductance levels (SCL) after finishing the creative problem-solving task at each location. L1 = the least open space; L2 = the moderately open space; L3 = the most open space. Bars are SEs

to team members ($r = 0.24$, $p = 0.02$) and put in more effort ($r = 0.63$, $p < 0.01$). In addition, the change in feelings of closeness to colleagues during the work task was positively associated with positive affect ($r = 0.26$, $p = 0.01$), enjoyment in the task ($r = 0.23$, $p = 0.03$), feeling pressured during the task ($r = 0.23$, $p = 0.02$), and effort expended during the task ($r = 0.20$, $p = 0.05$).

The percentage change in ACTH was negatively correlated with the percent change in feelings of closeness to one's colleagues ($r = -0.26$, $p = 0.02$). This is meaningful because a reduction in ACTH after the work task was only found for the most open L3 space ($t(26) = -2.07$, $p = 0.05$). Organizational trust did not vary by location ($F(2, 92) = 0.44$, $ps > 0.1$) but was associated with feelings of closeness to colleagues ($r = 0.20$, $p < 0.05$). Those who reported higher organizational trust reported feeling more energized ($r = 0.40$, $p < 0.01$) and productive ($r = 0.36$, $p < 0.01$) during the task.

Components of Workspace Satisfaction We conducted a principal component analysis on the 12 items of the WSQ to better understand workspace satisfaction. We retained the three factors that had eigenvalues greater than the Kaiser criterion of 1 (Kaiser, 1960). Next, we conducted an oblique rotation on the normalized factor loadings matrix: Table 1 shows the factor loadings after rotation.

The three factors that affect workspace satisfaction were:

1. Privacy for conversations, visual privacy, satisfaction with speech noise, satisfaction with background noise, and satisfaction with distractions;
2. Lighting, air quality, air movement, temperature, and beauty;
3. Ability to alter conditions, and satisfaction with the distance from other people.

We combined the variables for each factor, using the coefficients predicted by the factor analysis, calling the first factor "Privacy" (Cronbach's $\alpha = 0.84$), the second factor "Ambience" (Cronbach's $\alpha = 0.82$), and the third factor "Autonomy" (Cronbach's $\alpha = 0.62$). Satisfaction with workspace design was strongly associated with each of the three factors: autonomy explained 82% of variation in satisfaction, privacy explained 79%, and ambience explained 63%.

Comparing each factor by location, we found that Privacy was significantly higher in the most open work space L3 compared to L1 ($t(59) = -2.28$, $p = 0.03$). No differences were found for Privacy comparing the other workspaces ($p > 0.10$). Ambience was the highest in L3 (compared to L1: $t(59) = -4.48$, $p < 0.01$; compared to L2: $t(59) = -2.30$, $p = 0.03$). Finally, we found that Autonomy, similar to Privacy,

Table 1 Summary of principal-component factor analysis results. Bolded loadings are those that form each of the three distinct groups of factors

	Rotated Factor Loadings		
Item	Privacy	Ambience	Autonomy
Privacy for conversations	**.7547**	−.0639	.2338
Visual privacy	**.7956**	−.3331	.2683
Satisfaction with speech noise	**.9688**	−.1310	−.0375
Satisfaction with background noise	**.9413**	.0084	−.4376
Satisfaction with distractions	**.5034**	.0621	.3567
Lighting	−.1121	**.7577**	.2070
Air quality	−.2066	**.9614**	.0308
Temperature	−.2020	**.8440**	−.1087
Beauty	−.0302	**.5931**	.3354
Air movement	.1118	**.7719**	−.2437
Ability to alter conditions	.2214	.1691	**.5419**
Satisfaction with the distance from other people	.0106	.0549	**.8280**
Eigenvalues	4.82	1.98	1.08
% of variance	40.17	16.48	9.03
Cronbach's α	.84	.82	.62

Note: Factor loadings over .50 are in bold was significantly higher in L3 compared to L1 ($t(59) = -2.28$, $p = 0.03$) and marginally higher in L3 compared to L2 ($t(59) = -1.94$, $p = 0.06$), but not statistically different in L2 compared to L1 ($t(62) = -0.38$, $p > 0.10$). All three components of workspace design satisfaction linearly improved the change in closeness to colleagues from before to after work (Privacy: $r = 0.29$, $p = 0.01$; Ambience: $r = 0.23$, $p = 0.03$; Autonomy: $r = 0.23$, $p = 0.03$).

Discussion

Teamwork has been shown to enhance problem-solving and learning (Sears & Reagin, 2013), and may stimulate creativity (George & King, 2007; Hargadon & Bechky, 2006). These aspects, among many others, are essential ingredients of organizational success. Yet, little has been done to objectively assess how variations in office layouts affect team performance.

We found that office openness influenced creative problem-solving by teams. Collaborative work in the most open space not only increased the enjoyment of and the effort put in to the work task, it also enabled participants to shed the physiologic stress of work more rapidly. These effects occurred even though the most open office space was noisier than the other areas and had the most foot traffic. Despite previous studies reporting that noise hinders the performance of complex tasks more than simple tasks (Mehta et al., 2012), our finding was more nuanced: Performance for a complex team task was higher when the background noise was judged to be satisfactory ($r = 0.20$, $p = 0.05$). This indicates that open spaces can be busy and somewhat noisy yet still promote team performance. Indeed, the desirability of the work environment has been associated with job satisfaction and employee wellbeing (Wells, 2000). Our findings suggest there may be a feedback loop from space desirability to teamwork to enjoyment and positive affect. While it is possible that participants in the open office layout had greater positive affect because of people socializing around them, this is unlikely because the work task was timed so that there was little time to observe others. If replicated, this finding provides both an economic rationale and a well-being rationale for open office designs.

An additional and increasingly important implication of our findings is the substantial increase in loneliness in developed countries (Ernst et al., 2022). The increase in positive affect and interpersonal interactions in open office plans may provide succor to employees who struggle with loneliness in their private lives by providing additional motivation to build relationships (Aanes et al., 2009; Beller, 2023). Desirable office layouts may also motivate employees to spend more time in the office, among their colleagues, rather than work from home which can improve mental health (Cheng et al., 2023). Declining birth rates in most regions of the planet make employee physical and mental health critical issues for leaders of organizations and office design may be one approach to keep people from exiting the workforce (D'Oliveira & Persico, 2023; Saltzman et al., 2020).

The mechanism producing better teamwork appears to be physiologic stress modulation that was more pronounced in the most open office space. This is a more nuanced finding than we posited in Hypothesis 3. Our analysis showed that all three measures of physiologic stress showed the largest drops from work to the post-work period in the most open space compared to less open areas. The neurochemical correlates of stress inhibit the release of oxytocin (Cox et al., 2011), a brain signal that motivates positive social interactions and teamwork (Zak, 2012). High-trust organizations outperform low-trust ones on multiple dimensions, including job satisfaction, employee retention and even employee sick days (Johannsen & Zak, 2020; Zak, 2017). Conversely, chronic stress reduces cognitive performance, emotional regulation, leadership abilities, and teamwork (Golkar et al., 2014; Harms et al., 2017; Rasmussen & Jeppesen, 2006; Teixeira et al., 2015). Our data indicate it is not office design itself that affects the brain's ability to shed stress after work, but the way people interact with each other that is facilitated in open office layouts. When teamwork caused colleagues to feel closer to each other, they put in more effort while doing the work task and reported enjoying it, resulting in a positive mood boost supporting Hypotheses 1 and 2.

Work is increasingly done in teams (Colbert et al., 2016) and our findings indicate that organizations can modify office layouts to improve team performance. Our analysis showed that office layouts with greater perceived privacy, ambience, and autonomy can improve colleague interactions and team performance. Much prior research, though not all, has shown that open office configurations reduce perceived privacy by putting colleagues in proximity with each other (Davis et al., 2011; Laurence et al., 2013; Lee & Brand, 2005). Perceived privacy appears to be mediated by attentional responses (Birnholtz et al., 2007) and the demanding task assigned to participants required significant attention as the neurologic data revealed that may account for the privacy finding. Privacy perceptions may also be influenced by personality traits such as introversion that were not measured in this study. Proximity to others may create concerns as people return to work post-pandemic, militating against open office designs. Our data were collected prior to the COVID-19 pandemic and should be therefore applied with some caution post-pandemic.

By combining objective physiologic and behavioral data with self-reports we have sought to create new insights into how office design affects teamwork. While the data collected per participant was high, the number of participants was only moderate and therefore the reported findings should be replicated and extended to different locations, variations in office layouts, and the types of work tasks teams are asked to do. Indeed, different office layouts may provide new insights into the components of desireability as the factor loadings for our analysis were moderately low, likely due to the moderate sample size, indicating there are additional attributes that contribute to people's subjective evaluations of work environments. Further, the first constructed factor, that we named "privacy," could have equivalently been called "noise" or "distractions." Our findings for desireability components are not tied to our efforts to name a group of related factors.

There are a few avenues through which our findings should be extended. For example, increasing the types of office plans tested, measuring a larger number of individual and team work tasks, and varying the location of study that affects the demographics of the study pool. Further, because we could only utilize employee time for a short period, many questions were left unanswed because of lack of time to collect additional data. For example, we were unable to examine the relationship between creativity and tenure –whether senior employees were better or worse at creative problem-solving compared to junior employees. The stereotype of older employees being less creative does not appear to be supported (Ng & Feldman, 2013) and future research should test the relationship between job tenure, creative problem-solving and office openness.

We see this contribution as primarily methodological, providing a set of techniques to capture responses from employees at work in order to understand how the built environment affects brain and behavior. We note that this study is not longitudinal and thus captures productivity differentials as a result of openness at a particular point in time. To see if the increase in productivity is durable, the study should be extended to follow employees over time. Indeed, new wearable technologies that capture neurophysiologic states noninvasively and in real-time are ideal for such an approach (Merritt et al., 2022; Lin et al., 2022).

Conclusion

Many employees work in open offices. This neuroscience field study was designed to explore the mechanisms through which office openness affects teamwork, enjoyment, and health. Much of the extant literature indicated that open office spaces are stressful and inhibit performance. Our findings call this conclusion into question. By using neurophysiologic measures, a creative problem-solving task to measure team performance, and by conducting the study at a workplace with employees rather than college students in a laboratory, the results provide new insights into how real workspaces affect teamwork. The methods used in this study can be applied to understand a variety of organizationally- relevant questions including the preconditions for team performance, employee affect and stress recovery, lighting, task duration, team sizes, and how to design for increased closeness to work colleagues, among many other possible applications. The present contribution reveals why open office plans will continue to be popular – given the right conditions, they can make employees happier, healthier, and more productive. Office design matters.

Appendix

Table 2 Pairwise correlations

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(1) Age	1.000														
(2) Children	0.521*	1.000													
	(0.000)														
(3) Location	0.153	0.055	1.000												
	(0.135)	(0.597)													
(4) Space desireability	0.026	0.013	0.325*	1.000											
	(0.801)	(0.904)	(0.001)												
(5) Background noise	0.059	−0.011	0.189	0.174	1.000										
	(0.570)	(0.912)	(0.066)	(0.091)											
(6) Change Pos Affect	−0.077	0.055	−0.054	0.101	−0.069	1.000									
	(0.458)	(0.594)	(0.601)	(0.329)	(0.508)										
(7) Change Neg Affect	−0.062	−0.034	−0.036	−0.020	−0.018	0.113	1.000								
	(0.552)	(0.742)	(0.726)	(0.849)	(0.862)	(0.274)									
(8) Change Closeness	−0.069	−0.039	0.056	0.321*	0.215*	0.261*	0.116	1.000							
	(0.506)	(0.706)	(0.595)	(0.003)	(0.037)	(0.086)	(0.265)								

Table 2 (continued)

Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
(9) Team Performance	0.042	−0.011	0.277*	0.047	0.198	0.009	0.123	0.016	1.000						
	(0.687)	(0.915)	(0.006)	(0.650)	(0.054)	(0.928)	(0.234)	(0.880)							
(10) Change ACTH	0.137	0.111	−0.116	−0.136	0.014	−0.071	−0.103	−0.260*	0.077	1.000					
	(0.209)	(0.307)	(0.289)	(0.215)	(0.902)	(0.518)	(0.348)	(0.017)	(0.479)						
(11) Change SLC	0.004	0.071	−0.204	−0.046	−0.094	−0.252*	−0.035	−0.262*	−0.013	−0.014	1.000				
	(0.974)	(0.560)	(0.093)	(0.708)	(0.444)	(0.037)	(0.778)	(0.027)	(0.913)	(0.912)					
(12) Change HR	0.110	0.034	0.107	−0.129	0.029	−0.043	0.065	0.088	0.048	−0.163	−0.136	1.000			
	(0.329)	(0.762)	(0.343)	(0.252)	(0.796)	(0.705)	(0.569)	(0.438)	(0.672)	(0.171)	(0.283)				
(13) energized	0.200	0.085	0.153	0.237*	0.154	−0.071	−0.016	0.190	0.054	0.096	−0.177	−0.050	1.000		
	(0.052)	(0.411)	(0.138)	(0.021)	(0.139)	(0.498)	(0.880)	(0.066)	(0.601)	(0.382)	(0.150)	(0.659)			
(14) productive	0.242*	0.077	0.081	−0.042	0.097	−0.082	0.180	0.042	0.032	0.132	−0.098	0.118	0.567*	1.000	
	(0.019)	(0.458)	(0.440)	(0.686)	(0.355)	(0.433)	(0.083)	(0.691)	(0.762)	(0.231)	(0.432)	(0.301)	(0.000)		
(15) male	−0.070	−0.038	−0.026	−0.018	−0.075	0.147	0.022	−0.086	0.003	−0.129	−0.307*	0.063	0.152	0.008	1.000
	(0.497)	(0.713)	(0.805)	(0.865)	(0.467)	(0.156)	(0.831)	(0.410)	(0.976)	(0.237)	(0.010)	(0.575)	(0.143)	(0.941)	

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Data Availability As stated in Methods.

Declarations

Ethical Approval The study was approved by Solutions IRB Institutional Review Board (# 1303221) in accordance with the Declaration of Helsinki.

Informed Consent All participants provided written informed consent prior to inclusion.

Conflict of Interest None.

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