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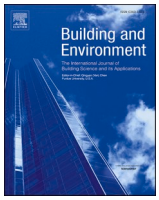
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# Effects of spatial autonomy on sense of control and work-related outcomes in VR-simulated home-based work environments

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ABSTRACT

Spatial autonomy—the opportunity to enact one's spatial preferences in the physical environment—is an underexplored dimension of indoor environmental quality in home-based work (HBW) environments. This study examined how two forms of spatial autonomy, location control and configuration control, influence workers' sense of control and work-related outcomes in virtual reality (VR)-simulated HBW environments. Using high-fidelity VR, two repeated-measures experiments compared autonomy-supported conditions with autonomy-restricted conditions. Study 1 focused on location control by comparing a self-selected preferred work location with an imposed least-preferred location. Study 2 focused on configuration control by comparing a self-configured furniture layout with an imposed layout that was incongruent with participants' stated spatial priorities. Across both studies, autonomy-supported conditions increased participants' sense of control and improved workspace satisfaction, inclination to use the same workspace, and self-rated performance. Configuration control generally produced stronger and more consistent effects than location control across subjective outcomes. By contrast, effects on objective cognitive performance were more modest and less consistent. The findings suggest that, in HBW environments, the benefits of spatial autonomy operate primarily through an enhanced sense of control and are especially pronounced when workers can meaningfully configure their immediate workspace. These results highlight the need for adaptable home workspace design and hybrid-work policies that recognize unequal opportunities for spatial autonomy in home-based work.

## 1. Introduction

The COVID-19 pandemic in 2020 triggered a rapid, large-scale shift toward home-based work (HBW) [1]. This forced transition, while disruptive at the time, created an unprecedented opportunity to observe the effects of HBW at scale, which had previously been difficult due to its limited prevalence [2]. Notably, this shift has proven more than temporary. Since 2020, HBW and hybrid arrangements have persisted in many advanced economies. For example, in the United States, workers have spent about 28% of working days at home on average since the start of 2023 [3], compared with pre-pandemic levels of 14.4% [4], suggesting that HBW has become a "new normal" in work organization.

This widespread adoption raises important questions about how home environments shape work experiences. Prior research has emphasized the advantages of HBW, including spatial and temporal flexibility—the freedom to choose work location and schedule—as well as greater job autonomy in organizing, pacing, and managing tasks (e.g., [5,6]). Such flexibility has been shown to lower stress [7,8] and improve work performance [2,9,10].

Underlying these benefits, workplace research has identified a broader principle: employees' *spatial autonomy*—the *objective* capacity for control over one's physical surroundings—strongly influences productivity, job satisfaction, and health-related outcomes [11–14]. This suggests that HBW's advantages may stem not only from temporal and

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task flexibility, but also from the spatial control that residential settings theoretically provide.

However, experiences during the COVID-19 pandemic revealed a more complex reality. While the literature emphasized flexibility and autonomy, many teleworkers faced significant spatial constraints. Wütschert et al. [15] documented issues such as poor ergonomic conditions, multi-use spaces, noise, and lack of privacy. An industry survey by CommercialCafe [16] reported that only 36% of remote workers had a dedicated workspace: 34% worked in living rooms, kitchens, or bedrooms, and 69% indicated that a dedicated workspace was essential for HBW. Such inadequate work environments blur the boundaries between work and personal life [17,18] and have been associated with increased family conflicts, which may in turn reduce well-being, work engagement, and productivity [19].

These experiences highlight a critical yet underexplored dimension of HBW: the role of spatial autonomy in residential work environments—specifically, workers' ability to control where they work and how their immediate workspace is configured. The importance of such autonomy has been well established in office research. In traditional offices, attempts to support spatial autonomy have included workspace personalization, which allows employees to adjust their physical environment to individual preferences [20], and activity-based working (ABW), which provides a variety of work settings for different tasks, from focused work to collaboration [21]. More recent hybrid-work research further shows that the characteristics of both office and home workspaces influence workers' workspace choices [22] and are associated with perceived work performance, comfort and well-being [23]. Across these lines of research, a recurring mechanism is *sense of control*—the *subjective* perception of having control over one's environment—which has been shown to mediate the relationship between spatial autonomy and work-related outcomes [20,24].

Home environments, however, carry fundamentally different psychological associations. As private domains, residential spaces are often experienced as places where individuals expect greater ownership and control over their physical surroundings than in offices, reflecting psychological territoriality and a desire to personalize space [25]. This expectation translates into concrete forms of spatial freedom, such as choosing where to work within the home, arranging furniture according to personal preferences, and controlling environmental factors such as lighting, temperature, and privacy [26–29].

This heightened expectation creates a critical psychological dynamic. According to expectation-disconfirmation theory, the gap between expectations and actual experiences shapes satisfaction and frustration levels [30]. Therefore, when an HBW environment does not allow workers to enact the spatial control they expect, the resulting loss of perceived control may be particularly salient. In this study we use the term *spatial autonomy restriction* as an operational concept developed for the present research. Building on prior work on autonomy, workplace control and personalization, and expectation-disconfirmation [20,24,30,31], it refers to a condition in which workers cannot enact their preferred work location or workspace configuration. This issue extends beyond the exceptional circumstances of the pandemic because residential environments vary widely in available space, privacy, household composition, and the degree to which occupants can modify their surroundings across individuals and households. A worker in a spacious home with a dedicated room may be able to enact their spatial preferences relatively easily, whereas another in a small apartment shared with family members may face chronic spatial constraints. HBW does not necessarily create these inequalities; rather, it may expose or amplify pre-existing differences in housing conditions by shifting the locus of spatial constraint to the dwelling itself. Although opportunities for spatial autonomy also vary across office settings, in HBW they are more directly tied to workers' own housing resources.

Despite the well-documented effects of spatial autonomy in office environments, systematic research examining this construct in HBW contexts remains limited [32]. To address this gap, the present study examines how spatial autonomy in HBW environments affects workers' sense of control and work-related outcomes. In this study, spatial autonomy is not treated as preference itself, but as the opportunity to enact one's stated spatial preferences in a work setting. Drawing on two streams of office research—location choice in ABW [21] and workspace personalization [20,33]—we focus on two focal dimensions of spatial autonomy in this study: *location control*, defined as the opportunity to choose where to work within the home, and *configuration control*, defined as the opportunity to arrange and personalize furniture and equipment within a given space. These two dimensions do not exhaust the broader concept of spatial autonomy, but were selected because they correspond to established streams of workplace research, can be operationalized in a controlled VR experiment, and map onto actionable design and policy levers in HBW. Distinguishing between these two forms of control also matters because they operate at different levels of spatial control and imply different intervention strategies: location control depends on access to multiple suitable work areas within the home, whereas configuration control can often be supported through furniture arrangement and layout adjustments even within a single fixed space.

This study addresses three research questions:

(1) How does the opportunity to enact one's preferred work location within a home environment affect sense of control and work-related outcomes?
(2) How does the opportunity to enact one's preferred workspace configuration affect sense of control and work-related outcomes?
(3) Do location and configuration control differ in the strength and consistency of their effects?

To address these questions, we conducted two repeated-measures experiments in virtual reality (VR)-simulated HBW environments. Study 1 examined location control by comparing a self-selected preferred work location with an imposed least-preferred location, whereas Study 2 examined configuration control by comparing a self-designed workspace layout with an imposed layout incongruent with participants' stated spatial priorities. This design allowed the two forms of spatial autonomy to be examined separately while assessing their effects on the same set of psychological and work-related outcomes.

## 2. Theoretical background

### 2.1. Spatial autonomy and sense of control

Spatial autonomy refers to 'the capacity to take control' over space [34]. The term 'autonomy' originates from the Greek roots *auto* (self) and *nomos* (governance), denoting an individual's capacity for self-determination and self-regulation [35]. Autonomy comprises both objective and subjective dimensions. The objective dimension concerns whether opportunities for control are actually provided. The subjective dimension refers to perceived levels of control, or a 'sense of control,' termed by Shapiro [36]: it can be defined as "individuals' beliefs about how much control they possess and their ability to gain control if necessary" ([37], summarizing [36]) including expectations about managing environmental demands and uncertainty [38,39].

These two dimensions do not always align. Individual differences, cognitive factors, and social contexts can moderate the relationship between objective autonomy and subjective control. For example, people with a strong internal locus of control perceive more opportunities and are more likely to believe that their actions will affect outcomes, even in identical situations, whereas those with an external locus of control perceive fewer choices and less impact of their actions [40]. Huang et al. [41] found that when employees were taught how to adjust their desks and chairs, their sense of control increased significantly even though the physical environment remained unchanged. In open-plan offices, individuals may feel psychologically unable to exercise control

due to concerns about the social consequences, despite having objective opportunities to do so [24]. The level of privacy also influences the conversion of objective control into subjective control [42].

Despite this conceptual distinction, existing studies have often conflated objective spatial autonomy with subjective sense of control, measuring one while implying that effects stem from the other. Nevertheless, both dimensions have been shown to produce significant psychological and behavioral effects. Classic research by Langer and Rodin [43] demonstrated that nursing home residents given environmental choices (room decoration, plant care) experienced improved health, vitality, and life satisfaction. Glass and Singer [44] found that participants provided with a button to stop unpredictable noise exhibited lower stress responses, even though they never actually used the button—suggesting that perceived control alone was sufficient. More recently, Park et al. [45] found that the mere presence of a balcony enhanced remote work satisfaction, although balcony utilization rates were significantly low. These findings collectively demonstrate that both the provision of spatial choice and the perception of control can independently influence worker outcomes.

The relationship between these two dimensions has been clarified by Lee and Brand [24]. They demonstrated that objective control over the physical work environment (e.g., furniture rearrangement, personalization, and environmental adjustability) operates through sense of control as a mediating variable to influence outcomes such as job satisfaction, group cohesion, and workplace satisfaction. Their findings revealed that providing spatial autonomy enhances outcomes not merely through the physical changes themselves, but through the psychological experience of feeling in control. This mediation model has important implications: it suggests that even when workers do not extensively utilize spatial autonomy (as in the Glass & Singer and Park et al. studies), the knowledge that control is available enhances their sense of control, which in turn improves outcomes. Building on this mediation framework established in office contexts, the present study examines whether this mechanism operates similarly in HBW environments, where spatial autonomy takes on different meanings and constraints than in traditional offices.

To operationalize spatial autonomy in the HBW context, this study distinguishes between *autonomy-supported* and *autonomy-restricted* conditions. In autonomy-supported conditions, workers are able to enact their stated spatial preferences; in autonomy-restricted conditions, this enactment is prevented through an imposed location or configuration. This operationalization is particularly relevant to HBW since the opportunity to enact spatial preferences may depend on different aspects of the domestic environment. For location control, this involves choosing among rooms that differ in room identity, privacy, household meaning, and perceived work suitability. For configuration control, it involves arranging the immediate workspace through furniture placement, desk orientation, visual field, and separation between work and domestic functions. Thus, the central comparison is not preference alone, but whether the opportunity to enact preference is translated into a stronger sense of control and more favorable work-related outcomes.

### 2.2. Spatial autonomy in the work environment

The work environment's impact on employees' psychological and physical responses and productivity has been extensively studied (e.g., [46–49]). Sufficient natural light enhances comfort and work efficiency [50], while excessive noise can severely impair concentration and raise stress [51]. Spatial layout also influences workers' movement patterns and collaboration [52].

However, the optimal levels of these environmental factors vary considerably across individuals. What constitutes comfortable lighting for one worker may be insufficient or excessive for another; preferred noise levels differ depending on task type and personal concentration patterns; some workers thrive in bustling, collaborative spaces, while others require quiet, isolated environments for focused work. Given this heterogeneity in environmental preferences, the ability to adjust one's work environment to personal needs—spatial autonomy—becomes a particularly important factor for worker well-being and productivity [31]. In other words, even if an environment meets average standards or organizational norms, it may not support individual workers effectively when they lack appropriate opportunities to adapt it to their specific needs and preferences. At the same time, this does not imply that greater spatial autonomy is always preferable; the optimal degree and form of spatial autonomy may vary across individuals, tasks, and contexts.

In traditional office settings, however, workers often lack this control. Organizations typically make standardized decisions about workspace locations (where employees sit or work), furniture arrangements (how spaces are configured), and environmental conditions (temperature, lighting, and noise levels) to accommodate collective needs and operational efficiency. Individual workers have limited opportunity to adjust these factors to suit their specific job characteristics or personal preferences. This lack of spatial autonomy can have adverse psychological effects beyond the direct discomfort of suboptimal environmental conditions: it undermines workers' sense of identity, belonging, and agency [31,53].

The transition to HBW theoretically shifts this dynamic. As private domains, residential spaces might be expected to provide greater spatial autonomy than offices, free from organizational standardization. However, as noted in the introduction, HBW presents its own constraints in terms of location and configuration control—constraints that differ qualitatively from those in offices and affect workers unevenly depending on housing conditions and household composition. This study focuses on these two specific dimensions of spatial autonomy in HBW contexts.

These two dimensions reflect different levels of spatial control. Location control refers to the opportunity to choose where to work within the home, representing macro-level spatial control (analogous to location choice in ABW; [21]). Configuration control refers to the opportunity to arrange and personalize furniture and equipment within a given workspace, representing micro-level spatial control (akin to workspace personalization; [20,33]).

Although conceptually distinct, location and configuration control may operate both complementarily and independently. For instance, workers may have multiple workspace options but be unable to modify each space's configuration (high location control, low configuration control), or they may freely arrange personal furniture within a fixed location (low location control, high configuration control). This independence suggests that each dimension may contribute uniquely to workers' sense of control and subsequent outcomes.

Given the heterogeneity in individual preferences for environmental factors established above, and the varying constraints workers face in achieving spatial autonomy within their homes, understanding how autonomy restriction in each dimension affects work-related outcomes becomes critical. While research on office environments has focused on providing autonomy within standardized settings, HBW research must examine the consequences of restricted spatial autonomy in situations where workers expect control over domestic space but cannot enact their preferred work location or configuration.

### 2.3. Work-Related outcomes and research hypotheses

This study focuses on work-related outcomes that are theoretically linked to spatial autonomy. In workplace research, work performance is commonly conceptualized as a multidimensional construct that may include task performance, contextual or citizenship performance, adaptive performance, and counterproductive work behavior [54–57]. Because the present study used a short-term VR-based experiment rather than a longitudinal field study of organizational performance, we focused on proximal work-related outcomes that could be meaningfully assessed within a controlled experimental session.

Sense of control is treated as the key psychological mediator through

which objective opportunities for spatial control are translated into subjective experience. Workspace satisfaction captures workers' affective evaluation of the work environment, whereas inclination to work in the same workspace captures a behavioral intention to use or choose the workspace again. Subjective performance is represented by self-rated performance and distraction, reflecting workers' perceived ability to work effectively in the environment. Objective cognitive performance is represented by two short working-memory tasks. Since these tasks captured short-term cognitive processing under controlled experimental conditions, objective performance was treated as an exploratory outcome rather than a primary hypothesized endpoint. Based on the conceptual framework established above, we propose the following hypotheses (see Fig. 1).

#### 2.3.1. Study 1: location control

**H1a**. Restricting workers' opportunity to enact their preferred work location within the home (location-control restriction) will reduce their sense of control.

**H1b**. Location-control restriction will reduce workspace satisfaction and inclination to work in the same workspace, and these effects will be mediated by reduced sense of control.

**H1c**. Location-control restriction will reduce self-rated performance and increase distraction, and these effects will be mediated by reduced sense of control.

#### 2.3.2. Study 2: configuration control

**H2a**. Restricting workers' opportunity to enact their preferred workspace configuration (configuration-control restriction) will reduce their sense of control.

**H2b**. Configuration-control restriction will reduce workspace satisfaction and inclination to work in the same workspace, and these effects will be mediated by reduced sense of control.

**H2c**. Configuration-control restriction will reduce self-rated performance and increase distraction, and these effects will be mediated by reduced sense of control.

## 3. Methodology

### 3.1. Research design and participants

This study employed a fully repeated-measures experimental design with two autonomy conditions (autonomy-supported and autonomy-restricted) using VR technology to empirically examine how spatial autonomy in a home-based work environment influences workers' sense of control and work-related outcomes. VR technology enables precise manipulation of environmental variables while maintaining ecological validity [58,59], thereby allowing participants to engage with realistic scenarios without being subjected to real-world stress or disruption. Recent work has also emphasized the value of immersive virtual environments for occupant comfort, adaptive behavior, and human-built environment interaction research because they enable controlled exposure to environmental stimuli that are difficult to isolate in real buildings [60,61]. Experiments were conducted separately for the two dimensions of spatial autonomy: location control (Study 1) and configuration control (Study 2). In each experiment, all participants experienced both the autonomy-supported and the autonomy-restricted conditions, with the order of condition presentation randomized and counterbalanced to control for sequence effects. The operationalization of spatial autonomy support and restriction in each experiment is summarized in Table 1.

The experiments took place at the VR Zone on the TU Delft campus between February 6 and March 10, 2023, a period when home-based work had become relatively well established following the COVID-19 pandemic. A total of 43 adults met the following inclusion criteria: ability to communicate in English, current employment or PhD enrollment/candidacy, and prior experience with HBW. The participants had a mean age of 33.80 years ($SD = 8.29$). Of the 43 participants, 23 were female, 19 were married or in a domestic partnership, and the sample included 15 Europeans and 28 Asians. Recruitment was conducted via campus posters, email, and LinkedIn. Monetary compensation was provided upon completion of both experiments. The study was approved by the TU Delft Human Research Ethics Committee (approval date: January 27, 2023).

### 3.2. Setup and infrastructure

The VR setup included an Oculus Quest 1 head-mounted display, second-generation Oculus Touch controllers, and a high-performance gaming PC. The Oculus Quest 1 provides binocular immersive display output with a resolution of 1440 × 1600 pixels per eye, a 72 Hz refresh rate, and six-degree-of-freedom inside-out tracking, which was sufficient for the seated and room-scale exploratory tasks used in this study. Before each session, the VR system was checked to ensure consistent visual quality and tracking accuracy. The experiment was conducted in a designated section of the VR Zone at the TU Delft Library (see Fig. 2), a dedicated indoor VR laboratory with building-level HVAC operation. Although the room was maintained as a stable indoor environment throughout the sessions, temperature and humidity were not continuously logged; this is acknowledged as a limitation.

Two separate virtual environments were developed using the Unity3D engine. For Study 1 (location control), an apartment model with five rooms was created: living room, kitchen, master bedroom, child's bedroom, and guest bedroom. Each bedroom was assigned a different notional occupant to create distinct spatial meanings: a couple, a child, and a guest. A home office was intentionally excluded to avoid bias from

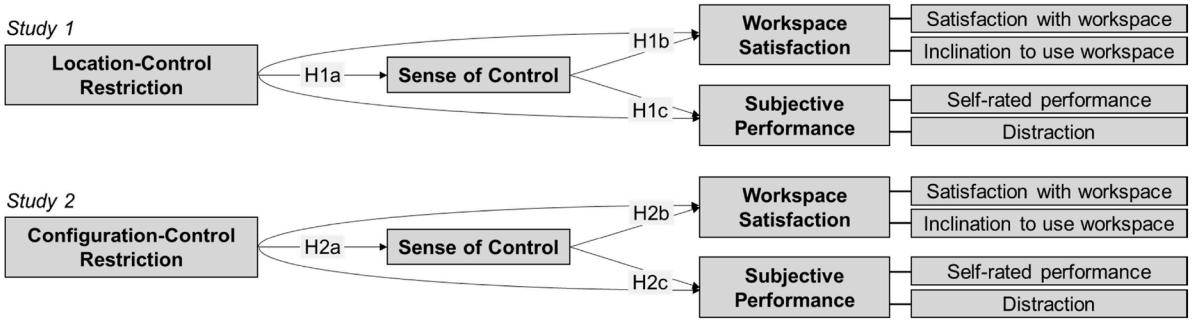



**Fig. 1.** Hypothesized relationships among autonomy restriction, sense of control, and work-related outcomes. H1a-H1c refer to Study 1 (location control), and H2a-H2c refer to Study 2 (configuration control). Objective cognitive performance was examined as an exploratory outcome.

**Table 1**
Operationalization of spatial autonomy support and restriction in the two VR experiments.

| Study | Dimension | Autonomy-supported condition | Autonomy-restricted condition | Controlled elements | Interpretation |
|---|---|---|---|---|---|
| Study 1 | Location control | Participant worked in the self-selected preferred room | Participant worked in the least-preferred assigned room | Room size, ceiling height, window size, external view | Opportunity vs. restriction in enacting preferred work location |
| Study 2 | Configuration control | Participant worked in their self-designed furniture layout | Participant worked in a layout deliberately incongruent with stated priorities | Same room, same furniture set | Opportunity vs. restriction in enacting preferred workspace configuration |



**Fig. 2.** Experimental setting in the VR Zone.

an already work-optimized space. Furniture appropriate to each room's function was included, and every room contained a table or desk and chair suitable for work. To reduce major spatial-quality confounds, all rooms had identical floor area (3.7 m × 4.8 m) and ceiling height (2.85 m), in addition to having the same window size and external view (see Fig. 3). This design reduced differences in basic physical size and view while preserving differences in domestic room identity, which are inherent to location choice in real HBW settings.

For Study 2 (configuration control), a square empty room measuring 4.2 m × 4.2 m was created (with ceiling height 2.85 m), with one window and one door. Participants could arrange a set of provided furnishings: a desk and chair set, wardrobe, bookshelf, chest of drawers with a potted plant, bed, bedside table, and wall-mounted world map. To efficiently collect participants' configuration plans, a physical scale model (1:20 scale) of the room and furnishings was produced (see Fig. 4).

In both environments, visual realism, lighting, and spatial acoustics were carefully adjusted to produce an immersive experience resembling an actual residential space.

### 3.3. Experimental procedure

Each experimental session lasted approximately 90 min and followed a standardized protocol, including briefing and consent, VR acclimation, task practice, Study 1, Study 2, questionnaires, and debriefing. Upon arrival, participants were greeted by the experimenter, received a detailed explanation of the study, and provided written informed consent. They were then fitted with the VR equipment and began an acclimation session designed to familiarize them with both the VR environment and the experimental tasks.

During this acclimation session, participants practiced navigating the virtual space using teleportation or direct walking and rehearsed sitting at a virtual desk while physically seated in the laboratory. They also completed practice trials of both cognitive tasks to ensure they fully understood the procedures and response requirements before the experimental trials began.

Once the acclimation session was completed, participants remained in the VR headset and were presented with the introductory scenario for the upcoming virtual situation. The scenario was designed to create a home-like situation without requiring participants' actual homes to be recreated in VR. It also reduced the influence of pre-existing memories of, or ownership over, participants' own home, thereby allowing all participants to begin from a comparable domestic context. This information was delivered visually and auditorily as follows:

*"In this virtual situation, you recently moved to Yokohama in Japan to stay there for several months because of work. Fortunately, your friend, A,*




**Fig. 3.** Representative VR scenes from Study 1. (a) Living room, (b) kitchen, (c) child's bedroom, (d) master bedroom, (e) guest bedroom, and (f) corridor. (The participant's starting point is indicated by a white circle.).




**Fig. 4.** Study 2 environment and procedure. (a) Participant arranging furniture with a physical scale model, (b-c) floor plan perspective of the VR environment used in Study 2, and (d) list of furniture and accessories available for arrangement.

*who lives in Yokohama, went on a long-term business trip with the whole family and lent you the house. Thus, you are currently living in A's apartment with your two other colleagues. In the next VR scene, please thoroughly explore the house to familiarize yourself with the space. Press the button below to start."*

After reading and hearing the scenario, participants pressed a button to begin exploring the virtual house for the first study, which focused on location control. Participants freely explored the virtual house without a time limit, then removed the headset to identify their most and least preferred workspaces from the five available rooms. They explained their choices in a brief semi-structured interview before returning to the VR environment. Participants then completed cognitive tasks and subjective evaluations in two conditions: one in which they worked in their preferred location (autonomy-supported condition) and another in which they were assigned to their least-preferred location (autonomy-restricted condition). This contrast was used to examine location-control restriction as the difference between being able to enact a self-selected work location and being assigned to an imposed location within the same domestic setting.

The second study focused on configuration control. Participants first used a physical scale model to arrange furniture according to their ideal workspace design and described the key factors influencing their decisions. During the interview, the experimenter asked each participant to identify the three most important criteria behind their preferred arrangement. Based on these inputs, two VR layouts were prepared: one matching their preferred arrangement (autonomy-supported condition) and one designed by the experimenter to be incongruent with the three stated priority criteria (autonomy-restricted condition). The specific priority criteria varied across participants—for example, desk orientation, proximity to the window, bed visibility, separation between work and sleeping areas, or openness around the desk—but the same individualized principle was applied across participants (see Supplementary Figure S1.1). While the VR environments were being prepared, participants completed demographic and background questionnaires. They then experienced both conditions in VR, performing the cognitive tasks and completing the evaluations for each.

At the end of both experiments, participants completed the post-experiment questionnaires assessing the nature of the tasks and their sense of presence in VR. They were then debriefed and compensated for their participation. Breaks were available upon request at any point during the session, and participation could be discontinued at any time. One participant withdrew from the autonomy-restricted condition in Study 2 due to cybersickness, and their data for that experiment were excluded from the analysis.

### 3.4. Experimental tasks

Two standardized working-memory tasks, vowel-counting and alpha-span, were selected to create a cognitive load similar to real work situations. Both were delivered in an auditory format to minimize interference with the VR visuals and to realistically simulate multitasking during home-based work.

The first task followed Mascio's [62] vowel-counting to assess temporary storage and concurrent information processing. In each session (i.e., per experimental scenario), participants were given four problems, and each problem consisted of four words presented auditorily. They were asked to report the total number of vowels contained in the words for each problem. Scores were calculated as the absolute difference between the participant's response and the correct total; lower scores indicated better performance.

The second task was the alpha-span task [63] to reflect the organization and restructuring of information required in real work contexts. Participants listened to words and then recalled them in alphabetical order based on their initial letters. Each set included two problems with four words and two problems with five words. Scoring followed Craik et al. [63]'s standardized method, with higher scores indicating better performance.

Each question was presented auditorily twice before participants responded. The vowel-counting task lasted approximately 3–4 min per condition, whereas the alpha-span task lasted approximately 4–6 min per condition.

### 3.5. Measures and data analysis

#### 3.5.1. Primary dependent variables

Measures were adapted from Lee and Brand [24] for use in the home-based work context. All items were rated on a 7-point Likert scale (1="No, not at all" to 7="Yes, very much so") (see Supplementary 2).

Sense of control was measured with four items assessing perceived control over the workspace, for example: "I feel my workspace was under my personal control" (Cronbach's $\alpha$=0.970).

Workspace satisfaction was assessed in two sub-dimensions: satisfaction with workspace (five items; e.g., "Overall, I was satisfied with this workspace"; Cronbach's $\alpha$=0.886) and inclination to work in this workspace (two items; e.g., "I prefer this workspace to my current workspace in real life"; Cronbach's $\alpha$=0.906).

Work-related performance was assessed using both objective cognitive task performance and subjective performance indicators. Objective cognitive performance was measured through performance on the two working-memory tasks. Subjective performance was measured via two indicators: distraction (three items; e.g., "I found it difficult to concentrate on the task in this workspace"; Cronbach's α=0.637) and self-rated performance (two items comparing performance in the experiment to typical performance; Cronbach's α=0.789). For multi-item measures, mean scores were calculated to reduce measurement error and enhance reliability.

#### 3.5.2. Control variables

Participants reported their experience and extent of home-based work in response to questions.

Perceived visual complexity was assessed using two items (Cronbach's α=0.846), for example, "I think this workspace was visually too complex." This variable was included as a covariate because visual complexity may influence distraction, satisfaction, and perceived performance independently of the intended autonomy manipulation. We therefore statistically controlled for perceived visual complexity in the mediation analyses, while treating broader interpretations concerning cognitive load, aesthetic impressions, and comfort cautiously since these constructs were not directly measured.

#### 3.5.3. Post-experiment checks

Two post-experiment questionnaires assessed ecological validity and VR realism. The nature of the experimental task was rated following Fischer et al. [64] on four dimensions (complexity, difficulty, pleasantness, interest) using a 5-point scale. Ratings indicated that the vowel-counting task was perceived as relatively simple and less demanding (complexity: $M$ = 2.30, $SD$=1.21; difficulty: $M$ = 2.63, $SD$=1.18) compared with the alpha-span task, which was viewed as more complex and challenging (complexity: $M$ = 3.30, $SD$=1.21; difficulty: $M$ = 3.88, $SD$=1.16). These differences suggest that the two tasks successfully represented varied work situations while avoiding extremes of difficulty.

Sense of presence in VR was measured using [65] 20-item scale, covering spatial immersion, interaction, and perceived realism. The mean score of 3.54 ($SD$=1.01) indicated a high level of presence, suggesting that participants experienced the VR environment as a realistic representation of home-based work.

#### 3.5.4. Data analysis

All statistical analyses were conducted using SPSS version 29.0, with the significance level set at α=0.05 for all tests. Prior to hypothesis testing, descriptive statistics were computed for all primary dependent variables. Frequency analyses were performed to summarize participants' self-selected preferred and least-preferred workspaces in Study 1. These preliminary analyses provided context for interpreting the manipulation checks and mediation analyses. A priori power analysis was not conducted because this study was designed as an exploratory VR-based repeated-measures experiment. Nevertheless, the within-subject design increased statistical sensitivity by reducing inter-individual variability, and effect sizes are reported alongside significance tests to support interpretation.

For the autonomy-supported versus autonomy-restricted comparisons, paired-sample $t$-tests were conducted within each experiment to compare sense of control and work-related outcomes. Effect sizes were calculated using Cohen's $d$ to assess the magnitude of these differences. In addition, to determine whether the type of autonomy (location vs. configuration) influenced sense of control when the same autonomy level was applied, cross-experiment comparisons were performed. Specifically, sense of control in the autonomy-supported condition of Study 1 was compared with that of Study 2, and the same comparison was made for the autonomy-restricted condition.

To test the main hypotheses, mediation analyses were conducted using Hayes' PROCESS macro (Model 4) [66]. For each experiment, indirect effects of spatial autonomy on outcome variables through sense of control were examined. The analyses used 5000 bootstrap samples to generate percentile bootstrap 95% confidence intervals. An indirect effect was considered statistically significant if the confidence interval did not include zero. Perceived visual complexity was included as a covariate in all mediation models to control for its potential confounding influence on both sense of control and the outcome variables. For each model, the explained variance ($R^2$) was reported for the mediator and outcomes, along with unstandardized coefficients ($b$) for paths involving the covariate (i.e., visual complexity).

Paired-sample $t$-tests were based on the available paired cases for each specific comparison. Mediation analyses were conducted separately as covariate-adjusted regression-based models; therefore, path coefficients are interpreted as adjusted associations and are not expected to correspond directly to unadjusted paired mean differences.

## 4. Results

### 4.1. Descriptive statistics and preliminary analyses

As shown in Fig. 5, across both studies, the autonomy-supported condition consistently produced higher levels of sense of control, satisfaction, inclination, and self-rated performance, while distraction was lower compared to the autonomy-restricted condition. Task 1 error scores were lower, and Task 2 scores were slightly higher in the autonomy-supported condition, although objective cognitive performance patterns were less consistent than subjective outcomes. Visual complexity ratings were also lower in the autonomy-supported conditions than in the autonomy-restricted conditions.

In Study 1, the most frequently selected preferred workspaces were living room (34.9%) and the guest bedroom (32.6%), closely followed by kitchen (27.9%). The most frequently selected least preferred workspace was the child's bedroom (48.8%), followed by the kitchen (30.2%) and master bedroom (11.6%). The kitchen became a controversial place for working, while other spaces received coherent opinions (see Supplementary Figure S1.2).

### 4.2. Pairwise comparisons of experimental conditions

#### 4.2.1. Autonomy-supported versus autonomy-restricted conditions (within-experiment)

In Study 1 (location control), paired-sample $t$-tests revealed significant differences between the autonomy-supported and autonomy-restricted conditions for most outcome variables (see Table 2; detailed trajectory plots are provided in Supplementary Figure S1.3). When participants were able to enact their preferred work location, they showed lower Task 1 error rates ($M$ = 0.326 vs. 0.477, $p$ = 0.035), and higher Task 2 scores ($M$ = 3.616 vs. 3.227, $p < 0.001$). Visual complexity ratings were also markedly lower in the autonomy-supported condition ($M$ = 2.721 vs. 4.430, $p < 0.001$).

For the primary subjective variables, the autonomy-supported condition yielded significantly higher workspace satisfaction ($M$ = 4.814 vs. 2.847, $p < 0.001$); lower distraction ($M$ = 3.605 vs. 4.442, $p < 0.001$); greater sense of control ($M$ = 4.081 vs. 2.663, $p < 0.001$); higher inclination to work in the same workspace ($M$ = 3.849 vs. 1.605, $p < 0.001$); and better self-rated performance ($M$ = 4.035 vs. 3.163, $p < 0.001$). These results indicate that being able to work in a self-selected rather than imposed location was associated with higher sense of control and more favorable subjective work-related evaluations.

In Study 2 (configuration control), the autonomy-supported condition again produced clear advantages in sense of control and subjective work-related outcomes (see Table 3; detailed trajectory plots are provided in Supplementary Figure S1.4). Workspace satisfaction was higher in the autonomy-supported condition ($M$ = 5.867 vs. 3.462, $p < 0.001$); distraction was lower ($M$ = 3.024 vs. 4.159, $p < 0.001$); sense of control

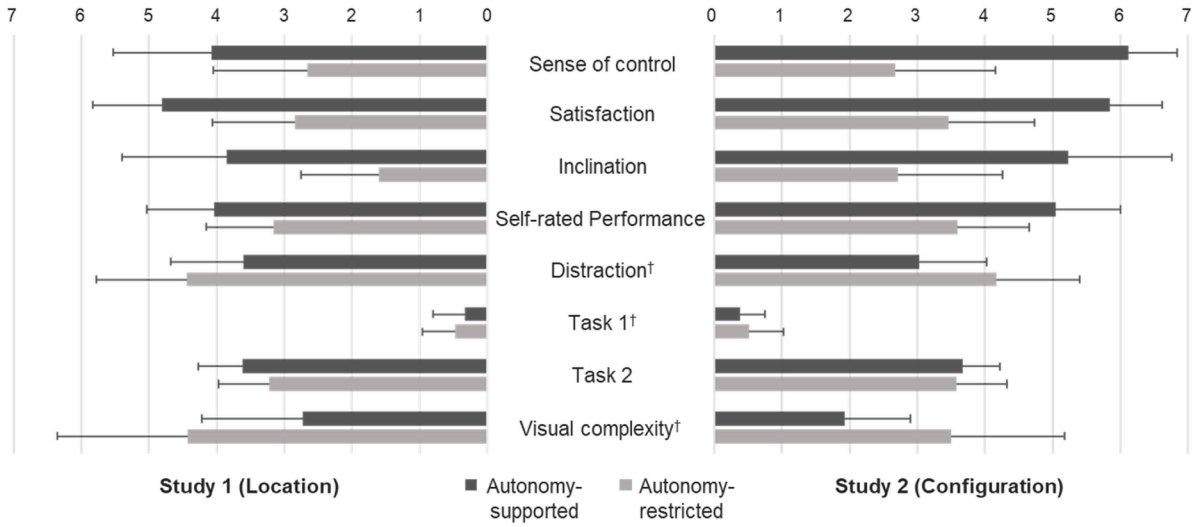



**Fig. 5.** Mean scores (bars) and standard deviations (error bars) of outcome variables under autonomy-supported and autonomy-restricted conditions across Study 1 and Study 2.
† Higher values indicate poorer outcomes.

**Table 2**
Paired-sample *t*-test results for Study 1 comparing autonomy-supported and autonomy-restricted location-control conditions across subjective work-related outcomes, objective cognitive performance, and perceived visual complexity.

| Outcome | Autonomy-supported *M* (*SD*) | Autonomy-restricted *M* (*SD*) | Mean difference | *t*(*df*) | *p* | Cohen's *d* |
|---|---|---|---|---|---|---|
| Sense of control | 4.081 (1.451) | 2.663 (1.392) | 1.419 | 5.448 (42) | < .001 | 0.831 |
| Workspace satisfaction | 4.814 (1.022) | 2.847 (1.216) | 1.967 | 7.935 (42) | < .001 | 1.21 |
| Inclination to use workspace | 3.849 (1.553) | 1.605 (1.152) | 2.244 | 8.628 (42) | < .001 | 1.316 |
| Self-rated performance | 4.035 (1.002) | 3.163 (0.986) | 0.872 | 4.278 (42) | < .001 | 0.652 |
| Distraction | 3.605 (1.077) | 4.442 (1.337) | −0.837 | −4.250 (42) | < .001 | −0.648 |
| Task 1 error | 0.326 (0.471) | 0.477 (0.484) | −0.151 | −2.185 (42) | 0.035 | −0.333 |
| Task 2 score | 3.616 (0.653) | 3.227 (0.748) | 0.39 | 3.733 (42) | < .001 | 0.569 |
| Perceived visual complexity | 2.721 (1.493) | 4.430 (1.920) | −1.709 | −5.368 (42) | < .001 | −0.819 |

*Note.* Cohen's *d* refers to the standardized mean difference for paired comparisons. Task 1 scores indicate error scores; higher values represent poorer performance. Higher distraction and higher perceived visual complexity also indicate less favorable outcomes. Objective cognitive performance measures were analyzed as exploratory outcomes.

**Table 3**
Paired-sample *t*-test results for Study 2 comparing autonomy-supported and autonomy-restricted configuration-control conditions across subjective work-related outcomes, objective cognitive performance, and perceived visual complexity.

| Outcome | Autonomy-supported *M* (*SD*) | Autonomy-restricted *M* (*SD*) | Mean difference | *t*(*df*) | *p* | Cohen's *d* |
|---|---|---|---|---|---|---|
| Sense of control | 6.143 (0.707) | 2.667 (1.488) | 3.476 | 14.355 (41) | < .001 | 2.215 |
| Workspace satisfaction | 5.867 (0.762) | 3.462 (1.271) | 2.405 | 11.262 (41) | < .001 | 1.738 |
| Inclination to use workspace | 5.262 (1.531) | 2.714 (1.543) | 2.548 | 7.785 (41) | < .001 | 1.201 |
| Self-rated performance | 5.071 (0.954) | 3.583 (1.070) | 1.488 | 7.827 (41) | < .001 | 1.208 |
| Distraction | 3.024 (1.002) | 4.159 (1.239) | −1.135 | −5.078 (41) | < .001 | −0.784 |
| Task 1 error | 0.375 (0.376) | 0.512 (0.506) | −0.137 | −1.904 (41) | 0.064 | −0.294 |
| Task 2 score | 3.655 (0.560) | 3.571 (0.754) | 0.083 | 0.701 (41) | 0.487 | 0.108 |
| Perceived visual complexity | 1.917 (0.981) | 3.500 (1.678) | −1.583 | −6.062 (41) | < .001 | −0.935 |

*Note.* See Table 2 for explanations of Cohen's *d* and score interpretation.

was substantially greater ($M = 6.143$ vs. 2.667, $p < 0.001$); inclination to work in the same workspace was higher ($M = 5.262$ vs. 2.714, $p < 0.001$); and self-rated performance was higher ($M = 5.071$ vs. 3.583, $p < 0.001$). Visual complexity ratings were also significantly lower in the autonomy-supported condition ($M = 1.917$ vs. 3.500, $p < 0.001$).

By contrast, objective cognitive task performance showed limited evidence of condition differences. Task 1 error rates were lower in the autonomy-supported condition (M = 0.375 vs. 0.512, p = 0.064), although this difference did not reach conventional significance at the two-tailed level. Task 2 scores did not differ significantly (M = 3.655 vs. 3.571, p = 0.487). These findings indicate that being able to enact one's preferred workspace configuration produced robust improvements across subjective measures, while effects on objective cognitive task performance were weaker and less consistent.

Overall, spatial autonomy support, whether through location or configuration, consistently fostered a positive psychological connection to the workspace, as evidenced by increased satisfaction and a heightened sense of control. However, objective cognitive performance showed a more limited and task-dependent pattern. This suggests that, in short-term VR-based HBW tasks, the effects of spatial autonomy may be more immediately reflected in perceived control, satisfaction, and self-rated performance than in objective cognitive task scores.

#### 4.2.2. Location versus configuration control (within-condition)

Since the same participants completed both studies, we conducted within-subject comparisons across the two studies (location vs. configuration). When comparing the two studies under the autonomy-supported condition, several significant differences emerged (see Table 4; detailed trajectory plots are provided in Supplementary Figure S1.5). Visual complexity ratings were higher in the location-control study (M = 2.721) than in the configuration-control study (M = 1.919, p = 0.006). Workspace satisfaction was lower in the location-control study (M = 4.814) than in the configuration-control study (M = 5.837, p < 0.001), and distraction levels were higher (M = 3.605 vs. 3.031, p = 0.001).

Participants in the configuration-control study reported greater sense of control (M = 6.111 vs. 4.081, p < 0.001); higher inclination to work in the same workspace (M = 5.221 vs. 3.849, p < 0.001); and higher self-rated performance (M = 5.047 vs. 4.035, p < 0.001) than in the location-control study. No significant differences were observed between studies for Task 1 error rates (p = 0.442) or Task 2 scores (p = 0.668).

In the autonomy-restricted condition (see Table 5; detailed trajectory plots are provided in Supplementary Figure S1.6), visual complexity ratings were higher in the location-control study (M = 4.429) than in the configuration-control study (M = 3.500, p = 0.009). Workspace satisfaction was lower in the location-control study (M = 2.848) than in the configuration-control study (M = 3.462, p = 0.012), and Task 2 scores were lower (M = 3.214 vs. 3.571, p = 0.005).

Inclination to work in the same workspace was also lower in the location-control study (M = 1.619) than in the configuration-control study (M = 2.714, p < 0.001), and self-rated performance was lower (M = 3.143 vs. 3.583, p = 0.018). No significant differences were found between studies for Task 1 error rates (p = 0.724), distraction (p = 0.184), or sense of control (p = 0.958).

Between-study comparisons showed that, under the autonomy-supported condition, configuration control (Study 2) produced stronger and more consistent effects than location control (Study 1) on sense of control, workspace satisfaction, inclination to use the workspace, and self-rated performance. Under the autonomy-restricted condition, differences were less pronounced but still favored Study 2 on satisfaction, inclination, self-rated performance, and visual complexity.

These manipulation check and comparison results indicate that the autonomy-supported and autonomy-restricted conditions produced substantial differences in participants' perceptions and subjective work-related outcomes across both studies. The consistent advantages observed for autonomy-supported conditions, and the relative strengths of configuration control in between-study comparisons, provide a basis for examining the mediating role of sense of control in linking spatial autonomy to work-related outcomes.

### 4.3. Sense of control as mediator

To empirically test the psychological mechanisms underlying the observed differences between autonomy-supported and autonomy-restricted conditions, we conducted a series of mediation analyses. These analyses aimed to determine whether the objective opportunity to enact spatial preferences influences work-related outcomes indirectly through the internal state of sense of control, rather than solely through direct environmental effects.

#### 4.3.1. Location control

Fig. 6 presents the mediation model for Study 1, showing how restriction of location control influenced outcome variables through sense of control, with perceived visual complexity included as a covariate (see Supplementary Table S1.7). In line with H1a, location-control restriction significantly reduced participants' sense of control ($b$=–0.945, $p = 0.005$).

For H1b, sense of control was positively associated with workspace satisfaction ($b = 0.345$, $R^2$=0.678, $p < 0.001$), while perceived visual complexity was negatively associated with satisfaction ($b$=–0.235, p < 0.001). The direct effect of location-control restriction on satisfaction was –1.077, and the indirect effect through sense of control was significant ($ab$=–0.326, 95% bootstrap CI [–0.630, –0.065]); the total effect was –1.403. A similar pattern was observed for inclination to work in the same workspace ($R^2$=0.650): sense of control was positively associated with inclination ($b = 0.483$, $p < 0.001$), whereas perceived visual complexity was negatively associated with inclination ($b$=–0.209, $p = 0.005$). The direct effect of location-control restriction on inclination was –1.203, and the indirect effect through sense of control was significant ($ab$= –0.456, 95% bootstrap CI [–0.864, –0.104]); the total effect was –1.659. These findings support H1b, indicating that reduced sense of control partly explained the unfavorable effects of location-control restriction on satisfaction-related outcomes.

For H1c, the results differed across subjective performance indicators. When predicting distraction ($R^2$=0.188; higher values indicate poorer outcomes), sense of control was not a significant predictor ($b = 0.080$, $p = 0.403$), whereas perceived visual complexity was positively associated with distraction ($b = 0.223$, $p = 0.006$). Location-control restriction had a marginal direct effect on distraction ($b = 0.570$, $p = 0.059$), but the indirect effect through sense of control was not significant ($ab$=–0.076, 95% bootstrap CI [–0.354, 0.089]); the total effect was 0.494. By contrast, self-rated performance ($R^2$=0.363) was positively associated with sense of control ($b = 0.236$, $p = 0.001$), while perceived visual complexity was a negative predictor ($b$=–0.148, $p = 0.014$). The direct effect of location-control restriction on self-rated performance was not significant ($b$=–0.284, $p = 0.206$), whereas the indirect effect through sense of control was significant ($ab$=–0.223; 95% bootstrap CI [–0.450, –0.041]); the total effect was –0.507. Thus, H1c was supported for self-rated performance, but not for distraction.

For the exploratory objective cognitive task measures, mediation through sense of control was limited and less consistent. Task 1 error rates ($R^2$=0.091; higher values indicate poorer outcomes) were positively associated with sense of control ($b = 0.088$, $p = 0.023$), while perceived visual complexity was not significant. Location-control restriction had a positive direct effect on Task 1 error ($b = 0.275$, $p = 0.022$), whereas the indirect effect through sense of control was

**Table 4**
Paired-sample $t$-test results comparing location control and configuration control under the autonomy-supported condition across subjective work-related outcomes, objective cognitive performance, and perceived visual complexity.

| Outcome | Location-control $M$ ($SD$) | Configuration-control $M$ ($SD$) | Mean difference | $t(df)$ | $p$ | Cohen's $d$ |
|---|---|---|---|---|---|---|
| Sense of control | 4.081 (1.451) | 6.111 (0.731) | −2.029 | −9.572 (42) | < .001 | −1.460 |
| Workspace satisfaction | 4.814 (1.022) | 5.837 (0.777) | −1.023 | −6.741 (42) | < .001 | −1.028 |
| Inclination to use workspace | 3.849 (1.553) | 5.221 (1.537) | −1.372 | −6.967 (42) | < .001 | −1.062 |
| Self-rated performance | 4.035 (1.002) | 5.047 (0.956) | −1.012 | −6.158 (42) | < .001 | −0.939 |
| Distraction | 3.605 (1.077) | 3.031 (0.992) | 0.574 | 3.516 (42) | 0.001 | 0.536 |
| Task 1 error | 0.326 (0.471) | 0.378 (0.372) | −0.052 | −0.777 (42) | 0.442 | −0.118 |
| Task 2 score | 3.616 (0.653) | 3.663 (0.556) | −0.047 | −0.432 (42) | 0.668 | −0.066 |
| Perceived visual complexity | 2.721 (1.493) | 1.919 (0.969) | 0.802 | 2.918 (42) | 0.006 | 0.445 |

*Note.* See Table 2 for explanations of Cohen's $d$ and score interpretation.

**Table 5**
Paired-sample *t*-test results comparing location control and configuration control under the autonomy-restricted condition across subjective work-related outcomes, objective cognitive performance, and perceived visual complexity.

| Outcome | Location-control *M* (*SD*) | Configuration-control *M* (*SD*) | Mean difference | *t*(*df*) | *p* | Cohen's *d* |
|---|---|---|---|---|---|---|
| Sense of control | 2.679 (1.405) | 2.667 (1.488) | 0.012 | 0.053 (41) | 0.958 | 0.008 |
| Workspace satisfaction | 2.848 (1.230) | 3.462 (1.271) | −0.614 | −2.621 (41) | 0.012 | −0.404 |
| Inclination to use workspace | 1.619 (1.163) | 2.714 (1.543) | −1.095 | −3.716 (41) | < .001 | −0.573 |
| Self-rated performance | 3.143 (0.990) | 3.583 (1.070) | −0.441 | −2.474 (41) | 0.018 | −0.382 |
| Distraction | 4.460 (1.347) | 4.159 (1.239) | 0.302 | 1.352 (41) | 0.184 | 0.209 |
| Task 1 error | 0.488 (0.484) | 0.512 (0.506) | −0.024 | −0.355 (41) | 0.724 | −0.055 |
| Task 2 score | 3.214 (0.752) | 3.571 (0.754) | −0.357 | −2.948 (41) | 0.005 | −0.455 |
| Perceived visual complexity | 4.429 (1.943) | 3.500 (1.678) | 0.929 | 2.750 (41) | 0.009 | 0.424 |

*Note.* See Table 2 for explanations of Cohen's *d* and score interpretation.

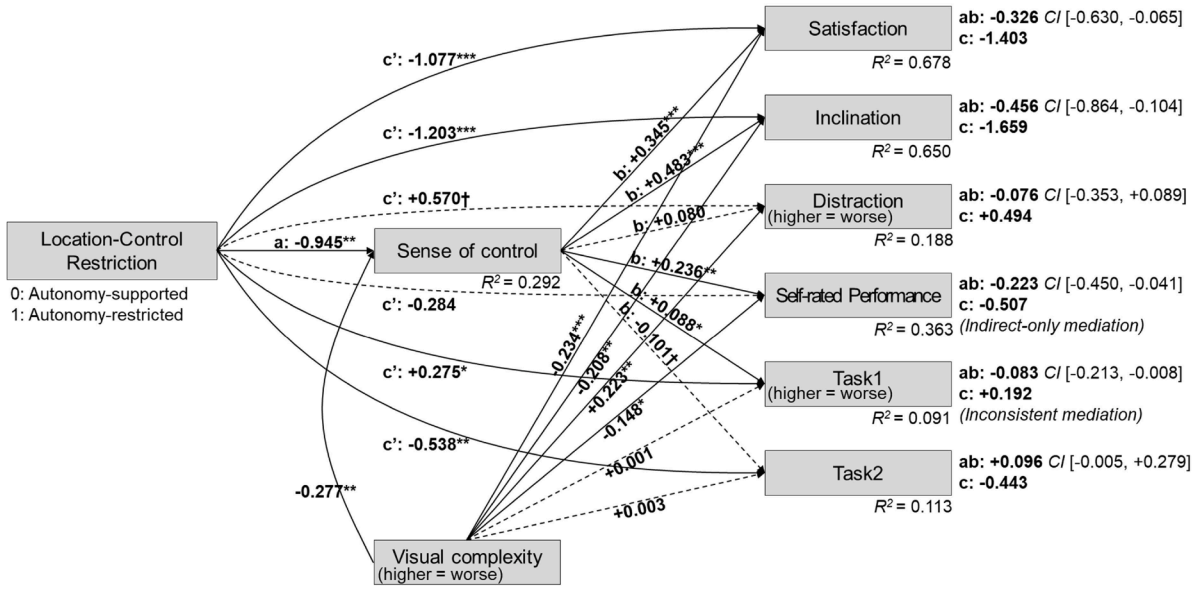



**Fig. 6.** Study 1 (location control): Mediation models with sense of control. Restriction of location control was coded as X_res (0 = autonomy-supported, 1 = autonomy-restricted). Unstandardized path coefficients are shown (a: X_res → sense of control; b: sense of control → outcome; c′: direct effect of X_res on the outcome; ab: indirect effect). (†$p < 0.10$, *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$).

negative and significant (*ab*=−0.083; 95% bootstrap CI [−0.213, −0.008]), indicating an inconsistent mediation pattern; the total effect

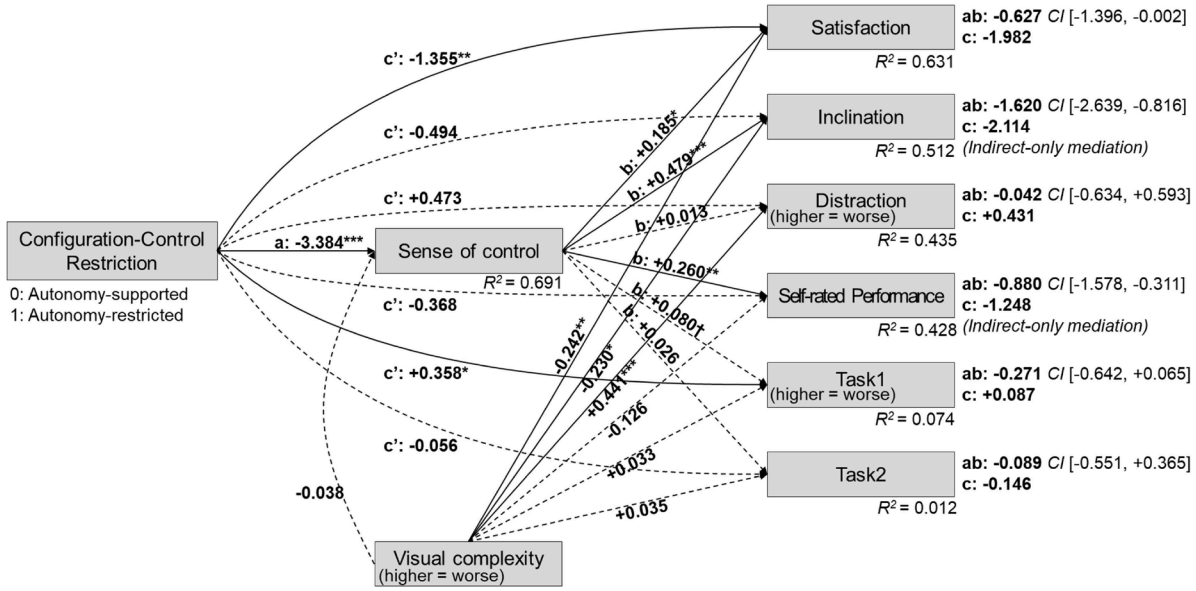



**Fig. 7.** Study 2 (configuration control): Mediation models with sense of control. Restriction of configuration control was coded as X_res (0 = autonomy-supported, 1 = autonomy-restricted). See Fig. 6 for notation and conventions.

was 0.192. Task 2 scores ($R^2$=0.113) were not significantly predicted by sense of control ($b$=−0.101, $p$ = 0.078) or perceived visual complexity ($p$ = 0.949). Location-control restriction had a significant direct effect on Task 2 scores ($b$=−0.538, $p$ = 0.003), whereas the indirect effect through sense of control was not significant ($ab$=0.096; 95% bootstrap CI [−0.005, 0.279]); the total effect was −0.443.

Overall, the Study 1 mediation results supported H1b and partially supported H1c. Significant indirect effects through sense of control were found for workspace satisfaction, inclination to work in the same workspace, and self-rated performance, indicating that the unfavorable effects of location-control restriction on these outcomes were partly explained by reduced perceived control. In contrast, no significant mediation through sense of control was observed for distraction or Task 2 scores, and Task 1 error showed an inconsistent mediation pattern. These results suggest that, in Study 1, sense of control primarily mediated subjective evaluations and self-rated performance, whereas its role was weaker or less consistent for distraction and objective cognitive performance.

#### 4.3.2. Configuration control

Fig. 7 presents the mediation model for Study 2, showing how conFfiguration-control restriction influenced outcome variables through sense of control, with perceived visual complexity included as a covariate (see Supplementary Table S1.8). Consistent with H2a, configuration-control restriction strongly predicted lower sense of control ($b$=−3.384, $R^2$ = 0.690, $p$ < 0.001), whereas perceived visual complexity showed no significant effect on the mediator ($b$=−0.038, $p$ = 0.689).

For H2b, sense of control was positively associated with workspace satisfaction ($b$ = 0.185, $R^2$=0.631, $p$ = 0.048), while perceived visual complexity was negatively associated with satisfaction ($b$=−0.242, $p$ = 0.003). Configuration-control restriction had a significant direct effect on satisfaction ($b$=−1.355, $p$ = 0.001), and the indirect effect through sense of control was also significant ($ab$=−0.627; 95% bootstrap CI [−1.396, −0.002]); the total effect was −1.982.

A stronger mediation pattern was observed for inclination to work in the same workspace ($R^2$=0.512): sense of control was positively associated with inclination ($b$ = 0.479, $p$ < 0.001), whereas perceived visual complexity was negatively associated with inclination ($b$=−0.230, $p$ = 0.046). The direct effect of configuration-control restriction on inclination was not significant ($b$=−0.494, $p$ = 0.391), but the indirect effect through sense of control was significant ($ab$=−1.620; 95% bootstrap CI [−2.639, −0.816]); the total effect was −2.114. These findings support H2b, indicating that reduced sense of control partly explained the unfavorable effects of configuration-control restriction on satisfaction-related outcomes.

For H2c, the results again differed across subjective performance indicators. When predicting distraction ($R^2$=0.435; higher values indicate poorer outcomes), sense of control was not a significant predictor ($b$ = 0.013, $p$ = 0.890), whereas perceived visual complexity was strongly associated with distraction ($b$ = 0.441, $p$ < 0.001). Configuration-control restriction had no significant direct effect on distraction ($b$ = 0.473, $p$ = 0.226), and the indirect effect through sense of control was also not significant ($ab$=−0.042; 95% bootstrap CI [−0.635, 0.593]); the total effect was 0.431.

By contrast, self-rated performance ($R^2$=0.428) was positively associated with sense of control ($b$ = 0.260, $p$ = 0.005), while perceived visual complexity was not significant ($b$=−0.126, $p$ = 0.106). The direct effect of configuration-control restriction on self-rated performance was not significant ($b$=−0.368, $p$ = 0.348), whereas the indirect effect through sense of control was significant ($ab$=−0.880; 95% bootstrap CI [−1.578, −0.311]); the total effect was −1.248. Thus, H2c was supported for self-rated performance, but not for distraction.

For the exploratory objective cognitive task measures, mediation through sense of control was not supported. Task 1 error rates ($R^2$=0.074; higher values indicate poorer outcomes) were marginally associated with sense of control ($b$ = 0.080, $p$ = 0.055), while perceived visual complexity was not significant. Configuration-control restriction had a significant direct effect on Task 1 error ($b$ = 0.358, $p$ = 0.046), but the indirect effect through sense of control was not significant ($ab$=−0.271; 95% bootstrap CI [−0.642, 0.065]); the total effect was 0.087. Task 2 scores ($R^2$=0.012) were not significantly predicted by sense of control ($b$ = 0.027, $p$ = 0.674) or perceived visual complexity. Configuration-control restriction had no significant direct effect on Task 2 scores ($b$=−0.056, $p$ = 0.836) and no significant indirect effect through sense of control ($ab$=−0.090; 95% bootstrap CI [−0.551, 0.365]); the total effect was −0.146.

Overall, Study 2 mediation results supported H2b and partially supported H2c. Significant indirect effects through sense of control were found for workspace satisfaction, inclination to work in the same workspace, and self-rated performance, indicating that the unfavorable effects of configuration-control restriction on these outcomes were partly explained by reduced perceived control. In contrast, no significant mediation through sense of control was observed for distraction or the objective cognitive task measures. Distraction was instead strongly associated with perceived visual complexity. These results suggest that, in Study 2, sense of control primarily mediated satisfaction-related outcomes and self-rated performance, whereas its role was limited for distraction and objective cognitive performance.

## 5. Discussion

### 5.1. Spatial autonomy and sense of control in HBW

This study examined the psychological and behavioral effects of spatial autonomy restriction in VR-simulated HBW environments. Focusing on location control and configuration control, we tested whether restrictions on enacting participants' preferred work location or workspace configuration reduced sense of control and, in turn, affected work-related outcomes. Overall, the findings indicate that spatial autonomy restriction primarily influenced subjective evaluations and self-rated performance through reduced sense of control, while effects on distraction and objective cognitive task performance were weaker or less consistent.

The mediation analyses further clarified the psychological pathway through which spatial autonomy affected work-related outcomes. Sense of control robustly influenced affective and motivational outcomes—workspace satisfaction and inclination—as well as self-rated performance, implying that spatial autonomy exerts much of its benefit by making workers feel more satisfied, engaged, and capable in their work environment. By contrast, effects on objective cognitive performance were weaker and less consistent. This distinction suggests that the immediate benefit of spatial autonomy in short VR-based HBW tasks is more clearly psychological and evaluative than cognitive-performance-based.

Beyond differences across outcome types, the results also varied between location control and configuration control. Configuration control produced stronger and more consistent effects than location control across most subjective outcomes. This suggests that control over the immediate workspace may be especially salient in HBW because it allows workers to directly shape task-relevant features such as desk orientation, furniture arrangement, visual background, and the separation between work and domestic functions. Location control also mattered, but its effects were necessarily embedded in the meanings of domestic rooms. Choosing among rooms at home involves not only spatial choice but also room identity, privacy, household meaning, interior atmosphere, and perceived work suitability. Accordingly, the Study 1 contrast should be interpreted as a comparison between self-selected and imposed workspace locations in a domestic setting, rather than as a fully isolated test of abstract spatial autonomy.

One way to interpret the strength and consistency of these autonomy effects in HBW is through the lens of expectation-disconfirmation.

Residential spaces are typically treated as domains where people expect greater control than in organizational settings [25]. When these expectations are not met—as in the autonomy-restricted conditions—the psychological impact may be amplified relative to comparable constraints in offices, where limited control is more normatively accepted.

The configuration-control findings are consistent with this interpretation. Configuration-control restriction produced especially large drops in sense of control, suggesting that the inability to arrange one's immediate workspace may be experienced as a salient loss of spatial agency in HBW. This may partly reflect the stronger expectations of personal control attached to domestic space. Whereas office workers often accept limited spatial choices as part of organizational life, the freedom to arrange and personalize one's home environment is closely linked to territorial identity and everyday self-organization. In this sense, a preference-incongruent layout may be experienced not only as practically inconvenient, but also as a restriction on the worker's ability to claim and organize domestic space for work. However, since the present study did not directly measure prior expectations or perceived violation of residential control, this interpretation should be examined more directly in future research.

The effects on inclination to work in the same workspace were especially pronounced, which links the present findings to prior office research. Earlier studies have shown that workspace control, personalization, and ABW settings can support satisfaction, perceived performance, and work engagement, although their effects vary by context and outcome [20,21,24,33]. The present findings extend this literature to HBW by showing that restrictions on spatial autonomy were associated with markedly less favorable workspace evaluations, most clearly in workers' reduced inclination to keep using the same workspace.

Taken together, these findings also extend recent post-pandemic research showing that hybrid workers' choices between home and office are shaped by workspace attributes and individual preferences [22,23]. Whereas prior studies have often compared home and office environments as broad categories, the present study shows that the degree of spatial control within the home also matters. This is especially relevant because HBW does not automatically provide autonomy; rather, workers may have unequal ability to select, modify, or protect a suitable workspace within domestic settings.

This observation also has broader implications for a housing-based dimension of work inequality. By this term, we refer to the possibility that unequal housing resources—such as available space, privacy, room choice, and the ability to rearrange furniture—may translate into unequal opportunities for spatial autonomy under HBW. Although housing inequality was not the direct focus of this study, the findings suggest that workers' capacity to enact spatial preferences may be one pathway through which domestic conditions shape workers' experiences of HBW. Future studies should examine this pathway more directly across diverse housing types, household compositions, and socioeconomic contexts.

Finally, this study also contributes to the growing use of immersive virtual environments in architectural and environmental engineering research. Recent reviews and experiments indicate that VR can support controlled investigation of occupant comfort, adaptive behavior, and human–built environment interaction by allowing systematic manipulation of environmental conditions while preserving a sense of spatial presence [60,61]. The present study applies this logic to HBW by experimentally isolating participants' opportunity to enact spatial preferences under controlled residential scenarios.

### 5.2. Role of perceived visual complexity

Perceived visual complexity was included as a covariate because visual characteristics of a workspace may influence environmental evaluation independently of spatial autonomy. Environmental perception research has long identified visual complexity as an important dimension of environmental preference and appraisal, although its effects depend on related qualities such as coherence, order, and legibility [48,67]. Research on visual cognition has also shown that visual clutter can make visual search and information processing more difficult [68]. Although the present study did not measure objective image-based or spatial metrics of visual complexity, these prior studies provide a useful basis for interpreting why perceived visual complexity was particularly associated with distraction and satisfaction-related outcomes, but showed limited association with objective cognitive task performance. This suggests that perceived visual complexity was more closely related to participants' workspace experience and evaluation than to immediate task scores.

More broadly, workplace research shows that workspace satisfaction is shaped by multiple environmental qualities, including privacy, concentration, comfort, and perceived usability [69,70], as well as opportunities for spatial choice or personalization [20,24,33]. The present findings suggest that perceived visual complexity may be one perceptual cue through which workers evaluate whether a home workspace feels focused, usable, and sufficiently separated from domestic activities. In HBW settings, such visual-perceptual qualities of the workspace may be especially relevant because domestic cues, clutter, and weak visual separation between work and non-work functions can make it harder for workers to experience the space as a dedicated workspace.

These findings suggest that spatial autonomy alone may be insufficient for favorable workspace experience if the chosen or imposed workspace is perceived as visually complex. Even when workers can choose or configure a workspace, excessive visual clutter or poorly separated domestic cues may still undermine concentration and satisfaction. However, this interpretation should be understood as an association between participants' subjective impressions of visual complexity and workspace experience, not as evidence of a causal effect of objectively measured visual complexity. From a design perspective, these findings point to the value of combining user control with strategies for managing visual clutter, background complexity, and the visual separation of work and domestic functions in autonomy-supportive home workspaces.

### 5.3. Limitations and future research directions

This study has several limitations. First, spatial autonomy was manipulated in a short-term VR experiment of approximately 90 min. Although VR allows precise and ethical control of environmental variables and produces a reasonable sense of presence, real HBW involves far more complex and dynamic conditions, including actual household interruptions, long-term adaptation, physical ergonomics, social negotiation with household members, and organizational expectations. The experimental scenario should therefore be interpreted as a controlled simulation rather than as a substitute for longitudinal field research.

Second, objective performance was assessed using standardized working-memory tasks. Unlike subjective satisfaction, sense of control, and self-rated performance, these cognitive indicators showed less consistent changes in response to autonomy, particularly in the configuration-control condition. The tasks capture short-term cognitive processing but do not fully represent the broader range of knowledge work outcomes relevant to HBW. Future studies should combine short cognitive tasks with longer work simulations, behavioral logs, physiological indicators, and more realistic work-related outputs.

Third, the sample consisted of 43 adults recruited at a single university, primarily knowledge workers and PhD candidates with prior HBW experience. Sense of control is known to be influenced by individual differences (e.g., locus of control) and social and organizational contexts (e.g., privacy norms, managerial culture). Furthermore, residential conditions vary widely across individuals and socioeconomic groups. The generalizability of our findings is therefore limited. Future studies should examine larger and more diverse samples, and explore how individual traits and social contexts moderate the impact of spatial autonomy in HBW environments.

Fourth, since each participant contributed data to both conditions,

observations were not independent. Mediation analyses were conducted using PROCESS as an initial, pragmatic approach with bootstrapping; thus, indirect-effect estimates should be interpreted with caution. Future research could further examine these mediation pathways using analytic approaches specifically designed for repeated-measures or multilevel data.

Fifth, we interpreted the results partly through expectation-disconfirmation and broader housing-based work inequality perspectives, but we did not directly measure participants' a priori expectations, distress, or actual housing constraints. In addition, Study 1 cannot fully separate autonomy from room preference, room identity, and perceived suitability because real location choice in the home inherently involves these factors. Future research should test more tightly controlled designs that manipulate choice independently of room identity, while also examining how housing resources shape actual opportunities for spatial autonomy.

Finally, this study examined only two dimensions of spatial autonomy: location control and configuration control. These dimensions were selected because they could be operationalized in a controlled VR experiment, but they do not exhaust the broader concept of spatial autonomy. Future research should examine additional forms of spatial control in HBW, such as privacy regulation, control over ambient conditions, and boundary management within the home.

## 6. Conclusion

This study shows that spatial autonomy is an important determinant of sense of control and work-related outcomes in HBW environments. Across two VR-based experiments, autonomy-supported conditions—defined as the opportunity to enact one's preferred work location or workspace configuration—enhanced sense of control, workspace satisfaction, inclination to use the workspace, and self-rated performance. Configuration control generally produced stronger and more consistent effects than location control on subjective outcomes, while effects on objective cognitive task performance were weaker and less consistent.

These findings offer practical contributions to home workspace design and hybrid work policy. For home workspace design, the results suggest that workers benefit from being able to adjust desk orientation, visual background, storage, and separation between work and domestic zones, even when a dedicated home office is unavailable. Movable furniture, lightweight partitions, modular storage, and cable-management systems may support configuration control. For hybrid work policy, organizations should avoid assuming that all employees have equivalent spatial autonomy at home. Support may include access to office workspaces, coworking alternatives, equipment or furniture allowances, and guidance for reducing visual complexity and improving workspace adjustability. In this sense, hybrid work policy should consider not only the number of remote-work days, but also whether employees can secure sufficient control, privacy, and concentration in their home workspace.

## Declaration of generative AI in the manuscript preparation process

During the preparation of this work, the authors used ChatGPT and Claude to improve language and readability. After using these tools, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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## CRediT authorship contribution statement

**So Yeon Park:** Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Visualization, Writing – original draft, Writing – review & editing. **Diwen Tan:** Investigation, Methodology, Writing – review & editing. **Mengchen Dong:** Conceptualization, Methodology, Writing – review & editing. **Sung-Bin Yoon:** Data curation, Formal analysis, Writing – review & editing. **Rachel Lee:** Conceptualization, Methodology, Project administration. **Caroline Newton:** Conceptualization, Investigation, Methodology, Project administration, Writing – review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.buildenv.2026.114996.

## Data availability

Data will be made available on request.

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