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From stress to success: Guidance-contingent effects of stress in Augmented Reality and their implications

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HIGHLIGHTS

- A 2 × 2 study with 123 participants analyzed stress and guidance effects on users.
- Stress effects on performance and acceptance are contingent on the level of guidance.
- Findings highlight a Situated Action perspective on AR applications.
- A trade-off between performance and acceptance of an application is shown.
- The study informs theory and hypothesis building for future pervasive AR research.

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ABSTRACT

Not all information helps equally: context determines what supports effective action. This Situated Action principle might matter for Augmented Reality (AR), as different designs might be used in response to different user states. Accordingly, we investigate how stress and guidance level jointly influence performance and acceptance through a 2 × 2 experiment ($N = 123$) in AR-assisted assembly. Participants underwent stress induction or relaxation before using AR applications with high (step-by-step) or low (level-based) guidance. Our findings challenge simple stress-regulation models: guidance level reconfigured the pathways to outcomes. Under high guidance, stress predicted faster completion but reduced hedonic motivation and acceptance. Under low guidance, performance decoupled from stress, with utilitarian and hedonic motivations driving both efficiency and reuse intention. Structural equation modeling supports these guidance-contingent mechanisms. By introducing a Situated Action perspective, we demonstrate that different AR applications can reshape how tasks are solved, potentially impacting AR application design as well as future context-adaptive and pervasive AR systems. These implications are discussed. Our study offers a theoretical basis for hypothesis development and advances theory on how AR shapes user behavior.

1. Introduction

In today's technological environment, where tools increasingly function as personalized and ubiquitous assistants, understanding and responding to user context has become critically important (Rauschnabel et al., 2024; Grubert et al., 2016). Augmented Reality (AR) enables the integration of virtual information with the physical world, thereby shaping users' perceptions of reality (Rauschnabel et al., 2022; Billinghurst et al., 2015). In many contexts, AR can support more efficient task execution and reduce user stress (Alessa et al., 2023). These characteristics make AR a promising platform for developing context-aware and adaptive applications (Lindlbauer, 2022).

As Schmidt et al. (1999) noted, context is a crucial factor in human–computer interaction because it provides surrounding information that supports interpretation and action. While context has traditionally been understood primarily as the immediate physical environment (von der Au et al., 2023), it can be extended to include users' dynamic cognitive

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and emotional states (Grubert et al., 2016). Stress, in particular, is a fundamental yet complex response that can influence performance, technology acceptance, and interaction (Zsidó, 2023; Elliott et al., 2021; Cheng and Huang, 2022).

Consider an instructor guiding a trainee in assembling a complex machine. The instructor may adapt their approach based on the trainee's stress level: if the trainee appears overwhelmed, explanations may be simplified and reassurance provided; if the trainee appears confident and engaged, the instructor may increase pace and reduce support. Such empathetic adjustments help align task demands with users' current capacities. Analogously, digital systems may adapt to users' stress states to provide more personalized and effective support. This idea is often discussed under empathic computing (Cai, 2006) or empathic mixed reality (Piumsomboon et al., 2017; Chang et al., 2025). Although these concepts may also include elements such as information sharing, their core premise is that systems should infer and respond to users' affective and cognitive states.

Although prior research has demonstrated the feasibility and potential value of stress-adaptive AR applications (Lindlbauer et al., 2019; Lindlbauer, 2022; Stefanidi et al., 2022; Kennard et al., 2020; Qin and Bulbul, 2023), users' responses and behaviors following such adaptations remain underexplored. Much of this work implicitly assumes that adaptations function as compensatory mechanisms that regulate undesirable physiological states toward an optimal level (e.g., moderate stress). In contrast, Situated Action Theory conceptualizes action as emergent and contextually accomplished rather than as the execution of pre-specified plans (Nardi, 1996; Suchman, 1987). From this perspective, perception and behavior are shaped by available cues, constraints, and situational affordances, which users interpret and enact in the moment. Consequently, the effects of an adaptation may be contingent on how the system configures these affordances in a given context, rather than following a general, linear compensation logic. Therefore, research is needed to understand how users respond to different guidance designs under varying stress levels, particularly as AR applications are increasingly deployed across domains such as education, training, healthcare, and entertainment (Rauschnabel et al., 2022; Billinghurst et al., 2015).

Importantly, understanding users' responses under stress requires going beyond performance outcomes alone. The acceptance of AR applications often depends, among other factors, on users' utilitarian and hedonic perceptions, which are known to shape reuse intentions and long-term adoption (Vieira et al., 2022; Quandt and Freitag, 2021; Venkatesh et al., 2012). Different guidance designs may therefore not only influence efficiency, but also alter how enjoyable or useful an application is perceived, potentially creating trade-offs between performance and acceptance. Given the complex role of stress and its potential interaction with motivational processes, user-centered research is needed to examine how guidance level and user state jointly shape motivational pathways and outcome variables such as performance and acceptance.

To address these gaps, we conducted a 2×2 experiment examining how guidance level and pre-task stress jointly influence users' perceptions, motivations, and performance in an AR assembly task. Rather than evaluating a stress-adaptive system, we focus on interaction effects between stress and guidance to derive empirical insights that can inform hypothesis generation and future research on context-adaptive AR.

Our results indicate that the effects of stress on perception and behavior are contingent on the guidance level, suggesting that guidance can play a crucial yet non-trivial role in shaping user responses. In addition, the findings highlight the importance of utilitarian and hedonic motivations, which may create trade-offs between task performance and technology acceptance. Building on these results, we outline implications for design and call for future work to validate and extend our findings in more complex, real-world scenarios, including research on fully implemented context-adaptive AR apps.

Contribution Statement. Our contributions are empirical and theoretical in nature (Wobbrock and Kientz, 2016). We contribute:

1. **A Situated Action perspective for AR research.** We demonstrate that the effects of user states (stress) on performance and acceptance are not universal but contingent on task-support design (guidance level). This suggests that adaptive AR should be conceptualized less as stress regulation and more as the reconfiguration of problem-solving affordances, which offers a theoretical basis for hypothesis development in future stress-adaptive and pervasive AR research.
2. **Empirical evidence of guidance-contingent mechanisms.** High guidance creates stress-driven performance (faster completion under stress), while low guidance creates motivation-driven performance (stress-independent, hedonic, and utilitarian motivations predict both efficiency and reuse intention). Consequently, guidance can be conceptualized as a contextual design factor rather than reflecting a linear compensation for undesirable psychological states.
3. **Empirical evidence of performance-acceptance trade-offs.** Hedonic motivation was positively associated with reuse intention. However, in the high-guidance condition, stress reduced hedonic motivation, thereby lowering acceptance, while simultaneously improving performance. Thus, design choices might create competing pathways between efficiency and acceptance that cannot be simultaneously optimized.

2. Background and related work

This section clarifies how stress is understood in the context of stress-adaptive applications, reviews prior work on the relationships between stress, performance, motivation, and usage intentions, and discusses existing approaches to stress adaptation in AR and virtual reality (VR). Based on this review, we summarize key insights and identify open questions that motivate the present empirical investigation.

2.1. Terminology and scope

Stress is a fundamental yet complex human factor that has attracted growing attention across disciplines in recent decades (Shields, 2020; Crum et al., 2013; Bienertova-Vasku et al., 2020). Because the term is used in many fields, a unified definition remains difficult.[1] A foundational description by Selye (1956) defines stress as *"the non-specific response of the body to any demand for change."* However, the concept remains ambiguous, as it is defined and operationalized differently across research domains. In essence, stress occurs when task demands exceed an individual's perceived coping capacity. Accordingly, higher demands or reduced coping capacity are associated with higher levels of experienced stress.

For example, a worker assembling a complex product using an AR construction manual may experience stress due to increased task demands or limited coping resources. Task demands may arise from time pressure, social evaluation, task complexity, or information overload (Lundberg et al., 1989; Lundberg and Johansson, 2000). At the same time, pre-existing stress unrelated to the task may reduce attentional resources and further constrain coping capacity (Butler, 1993). From this perspective, stress reflects the dynamic interplay between situational demands and individual capacity.

Due to its subjective nature and interdisciplinary use, stress overlaps with related constructs such as mental workload, arousal, and anxiety, which capture aspects of immediate demands, individual capacity, and physiological responses (Kosch et al., 2023; Roos et al., 2021; Alsuraykh et al., 2019; Daviu et al., 2019; Duckro et al., 1989). In contrast,

[1] https://www.stress.org/what-is-stress, last accessed June 2, 2026.

concepts such as chronic stress or stress-related medical conditions (e.g., post-traumatic stress disorder) focus on long-term effects rather than short-term fluctuations (Crosswell and Lockwood, 2020). Accordingly, this work focuses on situational stress and immediate user responses.

2.2. The impact of stress on performance and motivation

According to Selye (1956), the body's physiological response to stress is similar regardless of whether the triggering stimulus is positive or negative, leading to the distinction between distress (negative) and eustress (positive). However, this dichotomy has been criticized as misleading, as stress responses depend on individual and situational factors rather than being inherently good or bad (Bienertova-Vasku et al., 2020).

Several theoretical models describe the relationship between stress and performance. Motivation Intensity Theory suggests that increasing task demands can elevate effort when successful task completion is perceived as attainable (Ewing et al., 2016). Similarly, Valence–Arousal Models propose that higher arousal can enhance capacity to meet task demands under certain conditions (Gaertner et al., 2021; Zsidó, 2023). Another example is the Yerkes–Dodson Law, which describes stress and performance as an inverted U-shaped relationship (Yerkes and Dodson, 1908; Welford, 1973; Ganem et al., 2022). Although the law has been criticized for oversimplification, the general insight that moderate stress levels can be associated with higher performance persists (Hancock and Ganey, 2003), leading to the assumption that aligning task demands with users' stress levels may enhance performance (Crum et al., 2013).

Beyond performance outcomes, stress can shape users' attitudes toward an experience by shifting hedonic and utilitarian motivations and shaping intentions for continued use (Elliott et al., 2021; Cheng and Huang, 2022; Yang et al., 2020). In technology adoption research, these motivational appraisals and continued use intentions are key determinants of application success (Tamilmani et al., 2021; Venkatesh et al., 2012). Accordingly, differences between systems in how they support users under stress may translate into meaningful differences in adoption-relevant outcomes.

2.3. Stress-adaptive applications in augmented & virtual reality

Inspired by Physiological Computing, digital systems can be adjusted in real time based on physiological signals such as stress, with the aim of aligning system behavior with users' current states to enhance efficiency and user experience (Fairclough, 2009; Loewe and Nadj, 2020). In other words, adapting applications according to emotional or cognitive states may therefore influence how users perceive and interact with task support. For instance, users experiencing higher stress may benefit from simplified instructions, whereas users in calmer states may prefer more detailed information.

Physiological Computing intersects with Pervasive AR, which integrates individual context such as human, environmental, and system factors to enable continuous, context-aware AR experiences (Grubert et al., 2016). However, the use of psychophysiological data remains technically and methodologically challenging (Fairclough, 2009), limiting much prior research to controlled laboratory settings (Loewe and Nadj, 2020), particularly in AR contexts addressing stress (Grubert et al., 2016). Nonetheless, recent advances in non-intrusive sensors and artificial intelligence increasingly enable physiological monitoring in real-world environments (Schmidt et al., 2018; Koceska et al., 2021; Qin and Bulbul, 2023).

Research on stress-adaptive and pervasive AR applications has primarily focused on the technological feasibility of balancing users' stress states by implementing simple adaptations such as modifying task-support strategies, specifically the guidance level, based on physiological indicators. These adaptations commonly involve reducing distractions, limiting extraneous information, or highlighting task-relevant elements and have been associated with improved concentration, situational awareness, and accuracy across domains such as office work, emergency response, and sports (Lindlbauer et al., 2019; Kennard et al., 2020; Stefanidi et al., 2022). Importantly, stress-related differences should arise from the chosen task-support strategy rather than from degraded interface quality or poor interaction design, which can independently increase stress and undermine acceptance and performance (Rauschnabel et al., 2024; Buchner et al., 2022; Jeffri and Rambli, 2021).

Beyond AR, stress-adaptive approaches have been explored in domains such as gaming, aviation, and VR-based training, where adaptive mechanisms have been linked to improved user experience, performance, and learning outcomes (Loewe and Nadj, 2020; Chiossi et al., 2022; Lehmann et al., 2013; Zechner et al., 2023). Common techniques include automation (Rusnock and Geiger, 2016), biofeedback (Zechner et al., 2023; Yu et al., 2017), human–robot collaboration (Teo et al., 2018), and dynamic task difficulty adjustment (Chiossi et al., 2022).

While this body of work demonstrates the potential of stress-adaptive systems, it predominantly emphasizes technical solutions to regulate users' stress, driven by the assumption that moderate stress levels are generally beneficial. In contrast, Situated Action Theory suggests that perception and behavior are contingent on context, including both application design and users' current states (Suchman, 1987; Nardi, 1996). From this perspective, variations in guidance levels may not only affect stress but also shape how users perceive and respond to an application. Understanding how stress and guidance jointly influence perception and behavior remains underexplored but can inform user acceptance (Elliott et al., 2021; Cheng and Huang, 2022; Yang et al., 2020) and future research on context-adaptive AR.

2.4. Summary

- Stress is a complex construct that influences both performance and motivation. Prior research suggests that performance benefits from a moderate stress level (Ewing et al., 2016; Zsidó, 2023; Yerkes and Dodson, 1908; Hancock and Ganey, 2003).
- While prior work demonstrates the feasibility and value of stress-adaptive AR (Lindlbauer et al., 2019; Lindlbauer, 2022; Stefanidi et al., 2022; Kennard et al., 2020; Qin and Bulbul, 2023), it remains underexplored how different guidance levels shape the relationship between stress, motivation, and usage intentions.
- Existing research largely focuses on achieving moderate stress levels through adaptation (Lindlbauer et al., 2019; Stefanidi et al., 2022; Kennard et al., 2020). However, Situated Action Theory (Suchman, 1987; Nardi, 1996) suggests that perception and behavior are contingent on context, including both application design and users' stress states.
- Given the complexity of stress and the potential role of situated affordances, exploring how stress and guidance jointly influence user perception and behavior is underexplored but beneficial to inform future research on the design and implementation of context-adaptive AR.

3. Research approach & questions

As discussed, stress is related to performance, yet their relationship remains complex. Building on prior work, we hypothesize that the *level of guidance* moderates the impact of user stress on performance as well as on perceptions of enjoyment and practicability. To investigate this, we assigned participants to either a high- or low-stress condition using two distinct psychological interventions (see Sections 4.3.1 and Section 4.3.2), acknowledging the inherent challenges in precisely quantifying stress.

In addition, we developed two AR applications for assembling a brick house that differ in their level of guidance. These conditions are referred to as high and low guidance (see Section 4.4). The aim of this design was to examine how stress and guidance jointly shape user motivation, intentions, and performance. We deliberately reduced complexity by using two distinct stress levels and two guidance conditions to isolate direct and moderation effects. This approach further enables an

initial examination of whether situated affordances alter how acceptance and performance emerge, providing an empirical baseline for hypothesis generation in future research on adaptive AR applications. Based on this rationale and the explorative nature of our research, we address the following research questions:

RQ1: What are the individual impacts of stress and varying guidance levels on the users' performance, motivation, and reuse intentions?
RQ2: Which relationships among stress, performance, motivation, and reuse intentions are moderated by the level of guidance?
RQ3: How do different guidance levels (i.e., situated affordances) shape the pathways to performance and acceptance?

4. Method

4.1. Study design

As discussed, we designed a 2×2 between-subjects lab study to address the research questions. Our study manipulates two independent variables: the stress level (high vs. low) and the level of guidance (high vs. low). Performance (task completion time) and reuse intention were the primary dependent variables. At the beginning, participants were randomly assigned to one of the four conditions.

For the stress intervention, participants either completed a short guided meditation or underwent a stress-inducing intervention (see Sections 4.3.1 & 4.3.2). After the respective intervention, participants performed an AR-supported assembly task, where they assembled a brick house while wearing an AR headset. The AR application either provided high guidance (step-by-step instructions for each brick) or low guidance (instructions for larger construction steps). Performance was measured during the task; see details in Section 4.4).

During the experiment, all participants filled out three questionnaires: before the intervention, after the intervention, and after the AR task, assessing subjective experiences and states.

4.2. Self-reported measurements / questionnaires

The first questionnaire, before the intervention, consists of two parts: a mood questionnaire on a semantic differential, following Allen and Janiszewski (1989) and a one-question stress state scale (SNRS-11), following Karvounides et al. (2016). The mood questionnaire was used to control for participants' prior moods. The SNRS-11 was used again after the intervention as the only question in the second questionnaire to control for the successful induction or reduction of stress.

The third questionnaire was answered after the AR task was completed and consisted of a more detailed stress assessment with the Short Stress State Questionnaire (SSSQ) which was adjusted and translated based on Helton and Näswall (2015) and the raw NASA-TLX (Hart, 2006) to assess cognitive workload. Furthermore, participants answered the System Usability Scale (SUS) (Gao et al., 2020), and questions about the reuse intention, utilitarian motivation (performance expectancy), and effort expectancy, as well as hedonic motivation of the *Unified Theory of Acceptance and Use of Technology 2* (Harborth and Pape, 2018). At the end, there were several questions on the familiarity of the participant with AR and their demographic data.

An attention check was embedded within the SSSQ to evaluate response quality. Specifically, participants were instructed to select the response option "2." Noncompliance led to exclusion from the final dataset. All measures are provided in the supplementary material.

4.3. Study condition: stress interventions

We designed two groups with substantially different stress levels. In the high-stress group, participants underwent the Trier Social Stress Test (TSST), a well-established method for inducing stress (Kirschbaum et al., 1993; Allen et al., 2017), while participants in the control group engaged in a ten-minute mindfulness meditation.

Although we considered continuous or physiological stress measurement, we prioritized a simpler design focused on contrasting two pre-task stress-induction conditions. The interventions produced clearly distinguishable stress levels immediately after the manipulation, and prior work suggests that TSST-related stress responses can persist beyond the intervention window (Kudielka et al., 2007). We therefore did not collect continuous stress measures for our primary comparisons.

4.3.1. Low stress

We used a guided meditation because prior work indicates benefits for performance and cognitive control (Larson et al., 2013). In addition, it served as a standardized pre-task activity intended to minimize external influences and promote a comparable cognitive state in the low-stress condition. For the meditation stimulus, we consulted experts in the field of meditation and psychology, who helped us choose an open-access meditation class on Spotify,[2] lasting 12 min. During the meditation, the experimenter left the participant unobserved.

4.3.2. High stress

The intervention for inducing high stress consisted of a combination of four stress-inducing methods over approximately 13 min. We chose these methods to raise stress levels on multiple levels, including social stress, cognitive stress based on conflicting information and logical demands, and sensory stress.

Trier Social Stress Test (TSST). The Trier Social Stress Test (TSST) is a procedure that can induce stress in human subjects (Kirschbaum et al., 1993). It is designed to exploit the vulnerability of the stress response to socially evaluative situations. Since the TSST is a given set of instructions rather than a typical prespecified test, there are different versions (Allen et al., 2017). We used the following structure: The participant sits opposite a jury of two people. With the help of the biology book *Encyclopedia of Energy* (Cleveland, 2004) and a paper to write notes, the participant was given five minutes to prepare a three-minute-long presentation on photosynthesis. We specifically chose this topic, as we expected that participants would have a basic, yet limited, knowledge. After each minute that passes, the jury tells the participant the remaining time. For the presentation, the participant was required to stand up. If the presentation was shorter than 3 min, the jury filled up time with questions. The jury interrupted the participant and ended the presentation if it was longer.

Incongruent Stimuli Test (Stroop Test). Next, the participant's cognitive load was increased through the Stroop test (Stroop, 1935). The participant sat back down and performed the test on a tablet.[3] On the tablet, the participant sees text on the display, including four blocks in the respective colors red, green, blue, and yellow, and with the matching text label. The user was presented with 60 words in four colors (red, green, blue, and yellow), and they had to click as quickly as possible on the matching block, which displays the color that the displayed text has, not the displayed word itself. Since there is a mismatch between literal and color perception, cognitive workload can increase (Renaud and Blondin, 1997). The test takes a maximum of two minutes, including an explanation.

Serial Subtraction Task. Finally, participants had to perform a serial subtraction task. This test consists of a series of simple mental arithmetic problems. The participant was told the initial number *1367*, which they could also write down on a notepad. Subsequently, no more written notes may be made. The participant

[2] https://open.spotify.com/episode/2GztVpeSxMlHNX5d8UvTzN?si=92593cab42ef4a59, accessed December 22, 2025.

[3] https://www.brain-fit.com/html/farbenwort.html, accessed December 22, 2025.

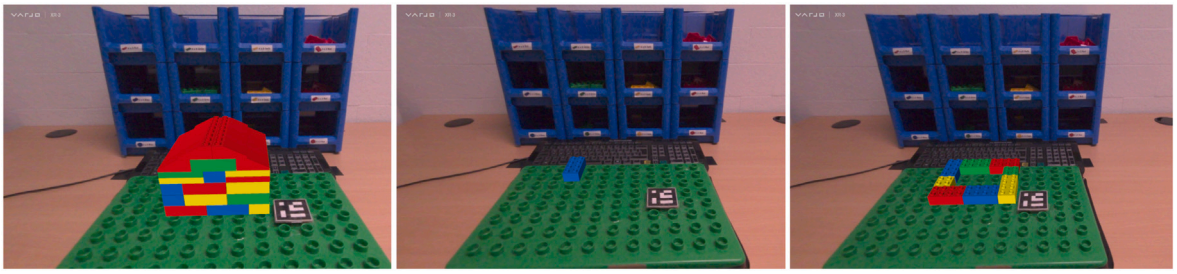


Fig. 1. (a) Augmented Whole House, (b) First Step of the High-Guidance Condition, (c) First Step of the Low-Guidance Condition.

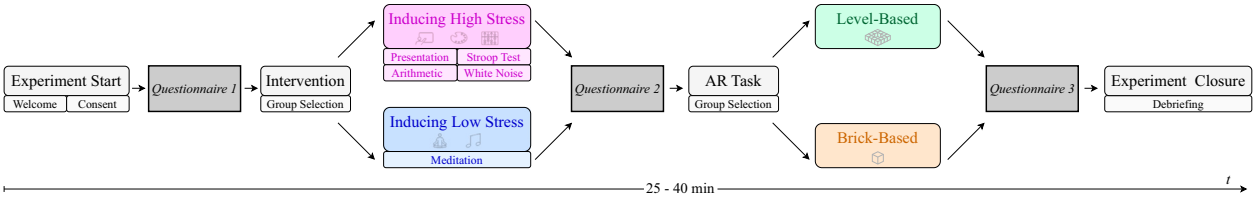


Fig. 2. Visualization of the study procedure (each participant had exactly one intervention and one guidance condition for the AR application).

has to subtract the number *13* and tell the result to the jury. If the jury does not react, the participant must again subtract *13* from this number and report the result to the jury. This continues until the participant reaches the number 0 or below. If there was a mistake, the jury informs the participant and he/she must start again from the initial number *1367*. As a standard part of the Trier Social Stress Tests, this arithmetic task was used to increase the effectiveness of the stress induction by combining different stressors (Kolotylova et al., 2009). The test lasts 3 min.

White Noise. During all high-stress tasks, white noise was played in the background, which added another sensory dimension and can increase the participants' stress level (Buczyński and Kedziora, 1983; Kolotylova et al., 2009).

4.4. Study condition: guidance levels

We developed two AR applications in Unity, using a Varjo XR-3 as a passthrough AR HMD. The primary goal of the two applications was to guide participants through assembling a house of 52 differently colored and shaped interlocking plastic bricks. The main feature that distinguishes the two applications is the granularity of the guidance provided (Fig. 1). In the high guidance condition, the application presented one brick per step, specifying the required brick (shape and color) and its placement. In the low guidance condition, the application presented one construction level per step, showing multiple bricks simultaneously and allowing participants to choose the placement order within that level. Accordingly, the high-guidance version comprised 52 steps, whereas the low-guidance version comprised seven steps. In both conditions, participants assembled the same house.

When the application started, participants pressed the forward button (right arrow key, marked in green) on the keyboard for the first time. The house to be built virtually appeared on the baseplate. The time measurement started afterward with the first building step. To complete the steps, participants searched for the respective brick(s) and placed them on the construction or baseplate. After each step, participants continued by clicking the right arrow key. This procedure was repeated until the participant had built the whole house and the text "End" appeared above the house. At that moment, the time measurement and application stopped, and the participant removed the headset.

We purposely avoided inducing further stress within the application, as we would rather not interfere with the interventions. This allowed us to understand the effects of the guidance level based on different stress levels. A more stress-inducing application, i.e., by displaying a timer, would have complicated the stress analysis.

4.5. Procedure

The study procedure involved multiple parts, lasting between 25 and 40 min, as shown in Fig. 2. The study took place in two separate rooms: `Room A` for the intervention and `Room B` for the AR application. Room A was equipped with desks and seating for the participant and, in the high-stress condition, two experimenters. Room B contained the assembly setup, including storage boxes with bricks, a baseplate, and the AR head-mounted display. In Room A, the study was initiated. After giving consent, participants completed the first questionnaire (see Section 4.2) and watched a three-minute explanatory video about the upcoming AR application. We randomly assigned participants to either the `Induced Low Stress` (see Section 4.3.1) or the `Induced High Stress` intervention (see Section 4.3.2). Both interventions lasted approximately 13 min. After the respective intervention, participants completed Questionnaire 2 and, following that, changed rooms.

In the second room (room B), the experimenter started after a short calibration of the headset (~ 30 s), either the `high-guidance` or `low-guidance` AR condition (see Section 4.4), in which users had to assemble a house with interlocking plastic bricks using AR assistance. The experimenter told the participants to assemble the house as quickly and correctly as possible. After the participants had finished assembling the house, they were asked to answer Questionnaire 3.

As the procedure was based on established procedures (i.e., TSST) and a non-invasive laboratory study, a formal ethics committee or IRB approval was not legally required for our jurisdiction in Germany. Nonetheless, we adhered to established ethical standards: participants provided informed consent prior to the study, were informed about potential increases in stress, could withdraw at any time without penalty, and were debriefed by the experimenter after the study, including the purpose of the study and the interventions as well as clarifying any open questions.

We separated the stress induction from the AR application to ensure higher reliability and enhance participants' comfort. By conducting the intervention in vivo before participants experienced the AR environment, we aimed to achieve a more accurate baseline of stress levels. Previous studies have indicated that stress tests performed in AR can yield less reliable outcomes than those conducted in real-world scenarios (Fallon et al., 2021; Linares et al., 2020). Additionally,

Table 1
Distribution and number of participants in the groups, based on gender.

		Induced Low Stress	*Induced High Stress*	
High-Guidance	Female	8	7	61
	Male	23	23	
Low-Guidance	Female	4	4	62
	Male	27	27	
		62	61	123

this approach allowed participants to wear the HMD for a shorter duration—approximately 10 min—enhancing their comfort compared to wearing it for around 30 min.

5. Results

5.1. Summary of results

- As expected, the intervention effectively created two distinct pre-task stress levels (high and low).
- Stressed participants completed the task more quickly. The high-guidance condition was associated with higher utilitarian motivation and increased worry.
- The guidance level moderated the effect of pre-task stress on hedonic motivation.
- A multigroup analysis with structural equation modeling shows that the guidance level affects the pathways to performance and acceptance.

5.2. Participants

After removing two participants because of a failed attention check and another one because of motion sickness, we analyzed the results for 123 participants (23 [18.7%] female, 100 [81.3%] male, age [18, 48]: M = 24.84). We had between 30 and 31 participants for each condition (see Table 1). Most participants were students (72.4%) who knew AR (M = 5.73) but did not frequently engage with it (M = 2.48; both measured on a 7-point scale).

5.3. Intervention control

Before conducting the comparative analyses, we examined the distributions of all relevant variables in the full sample and separately for each group. Various constructs, including among others, engagement and distress (dimensions of the SSSQ), the time taken, hedonic motivation, and reuse intention, are not distributed normally according to the Shapiro-Wilk test. Nonetheless, we decided to proceed with all following analyses for multiple reasons. First, the unequal *t*-test as well as univariate and multivariate analyses of variance ((M)ANOVA) are robust against violations of the assumption that the data are normally distributed (Wilcox, 2011; Finch, 2005; Blanca Mena et al., 2017). Second, we did not really expect any normal distributions, as the combination of our intervention and the different guidance conditions likely led to a small sample size in the comparison between groups and distortions in the distribution. Third, the nature of this study is exploratory rather than confirmatory.

We next conducted several unequal variance t-tests according to Rasch et al. (2011) to assess the effectiveness of the stress manipulation. First, we compared stress levels before the manipulation. As expected, we found no statistical differences (high stress: M = 4.36, SD = 2.11; low stress: M = 4.19, SD = 2.09; t(120.92) = 0.44, p = .66), indicating comparable groups. Next, we compared stress levels after the manipulation. For the high-stress group (M = 5.98, SD = 2.05), stress levels were significantly higher (t(112.26) = 9.05, p < .001) than for the low-stress group (M = 3.0, SD = 1.57), indicating an effective manipulation where stress levels significantly increased only in the high-stress group (from 4.36 to 5.98, p < .001) and significantly decreased in the low-stress group (from 4.19 to 3.00, p < .001). The stress level after the AR task, measured for the three dimensions of the SSSQ (engagement, worry, and distress), did not show any significant differences between the two applications (see Fig. 3).

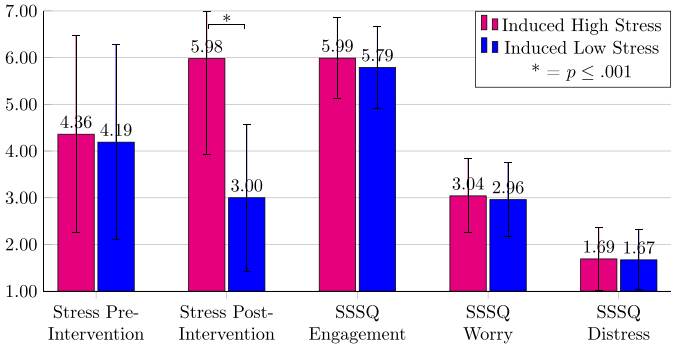


Fig. 3. Mean comparison including std. dev. between the stress measures before and after the intervention (SNRS-11) as well as after the AR task (3 dimensions of the Short Stress State Questionnaire, SSSQ) for both AR conditions.

5.4. Outcome and perception comparisons between groups (RQ1)

Our first research question (RQ1) asked what impact the manipulated variables (induced high and low stress, as well as the high/low guidance condition of the application) had on the time users needed to solve the task and their perceptions of the application. First, we looked at the mean values for different groups based on the stress interventions and guidance conditions. This included the factors' usability, time taken, the three dimensions of the SSSQ, hedonic and utilitarian motivation, as well as effort expectancy. Comparing the mean values with unequal variance t-tests yielded that the time needed to complete the task was significantly lower (t(120.39) = 3.18, p = .002) for the high-stress group (M = 253.59 s, SD = 55.69) than for the low-stress group (M = 286.98 s, SD = 60.79). Additionally, there was a significant difference (t(115.93) = 2.18, p = .031) concerning the utilitarian motivation between both AR applications. The utilitarian motivation was higher for the high-guidance (M = 3.70, SD = 1.14) than for the low-guidance condition (M = 3.19, SD = 1.44). While the three dimensions of the SSSQ did not show any significant difference between both stress groups, the mean value of worry was significantly higher (t(121.00) = 2.07, p = .040) for the high-guidance condition (M = 3.15, SD = 0.81) in comparison to the low-guidance condition (M = 2.85, SD = 0.83). Despite these, no other significant differences were found.

Using a two-way multivariate analysis of variance (MANOVA), further analysis showed for all dependent variables a significant difference between both guidance conditions (F(9, 111) = 2.32, p = .02) and a not significant difference between the stress and control group (F(9, 111) = 1.71, p = .095). Additionally, no significant difference was found for the interaction between guidance and stress conditions (F(9, 111) = 1.31, p = .24). Looking post-hoc at the univariate analyses of variance (ANOVA) yielded comparable results to the unequal t-tests. It is important to mention that we excluded one extreme outlier from the calculations. Furthermore, besides the violated assumption of normal distribution, the dependent variables also show a weak linearity. Nonetheless, these issues are unproblematic because MANOVA is generally robust to such violations, especially with a large sample size, which can mitigate the impact on the overall results (Finch, 2005).

5.5. Exploring the moderation effects of the level of guidance (RQ2)

The second research question revolves around whether an interrelation, specifically a moderation effect, exists between the users' stress level and the level of guidance regarding any outcome variables. A moderation effect occurs if the strength or direction of a relationship between two variables (X→Y) varies based on the magnitude of a third variable

(Z, "moderator variable"). In other words, we investigated whether the influence of stress on any of those outcome variables differs concerning the level of guidance, for example, if one guidance condition leads to an increase in the outcome variable while the other guidance condition decreases the outcome variable with increasing stress levels.

To model and empirically test this, an interaction term between the moderator (Z; in this case, the level of guidance) and the independent variable (X; in this case, a binary variable based on the intervention) is created (guidance × stress) and included in the regression equation while controlling for the moderator's direct effect. A moderation is established if the interaction term's b-coefficient is statistically significant. We employed the established PROCESS macro in SPSS (Hayes, 2017) to estimate the moderation (bootstrapping with 5000 resamples).

While testing moderation effects for all outcome variables (utilitarian and hedonic motivation, effort, reuse intention, usability, performance measured as time needed, and all dimensions of the SSSQ), we found no significant interaction between stress level and guidance condition, except for the prediction of hedonic motivation ($B = 0.30$, $p = .001$). This interaction effect significantly increased the explanatory power ($\Delta R^2 = 0.07$). Having established the moderation, we inspected the role of stress in more detail. We found that stress decreases hedonic motivation in the high-guidance condition ($B = -0.22$, $p < .001$). However, the low-guidance condition tends to be unrelated ($B = 0.07$, $p = .266$). In other words, users experiencing stress in the AR scenario with less freedom tend to perceive the experience as unpleasant. However, consumers in a scenario with much freedom tend to evaluate the application as equally pleasant, no matter how stressed they feel.

We repeated all tests for moderation effects while using perceived stress values (post-intervention stress as measured by the SNRS-11) instead of the binary variable, with similar results. Fig. 4 shows the interaction effect, specifically, the influence of stress on hedonic motivation depending on the level of guidance.

Following Park and Yi (2023), the interaction pattern in our data could resemble what a homologizer would conceptually produce. Specifically, the relationship between stress and hedonic motivation is stronger in the high-guidance condition, whereas a weaker, non-significant relationship was observed in the low-guidance condition. To examine whether this pattern reflects actual variance heterogeneity, we conducted Levene tests for all outcome variables. The results indicated no significant variance differences across guidance conditions in the dependent variables relevant to the interaction interpretation (all $p > .070$).

Consequently, although the guidance manipulation does not statistically function as a homologizer, the observed significant interaction for the relationship between stress and hedonic motivation indicates that different guidance levels change how stress affects hedonic motivation, with potential implications for performance. In other words, whether stress affects motivation is contingent on the level of guidance, indicating, in line with Situated Action Theory, that perceptions depend

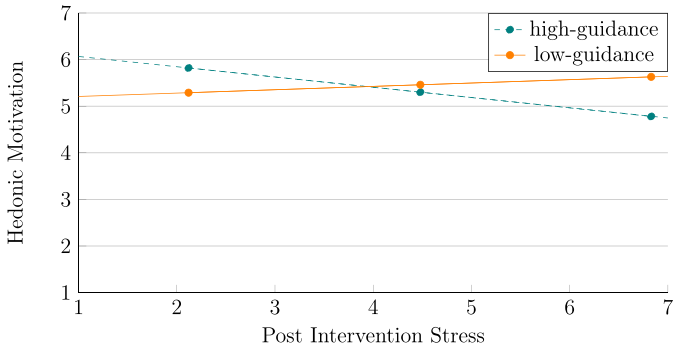


Fig. 4. Change in hedonic motivation with increasing stress levels based on the type of application.

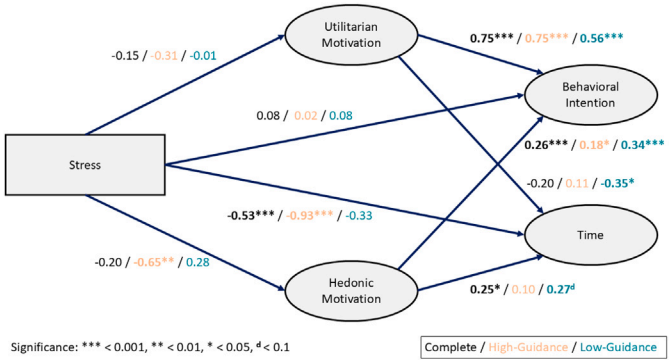


Fig. 5. Paths based on a complete and multigroup analysis with SmartPLS4.

on situative affordances. This, on the one hand, represents an interesting direction for future investigation and can serve as a basis for generating hypotheses. On the other hand, within this study, a more detailed exploration of how stress, motivation, and performance interplay within each guidance condition may reveal further insights.

5.6. Exploratory synthesis of pre-task stress and guidance effects (RQ3)

To contextualize the observed results and answer RQ3, we examine how pre-task stress and guidance conditions jointly shape the relationships among the studied variables. We synthesize these patterns into an exploratory, application-specific explanatory model.

For this model, we consider reuse intention and task completion time as the focal outcomes. Based on the technology adoption literature (Tamilmani et al., 2021; Venkatesh et al., 2012) and the observed relationships among pre-task stress, guidance level, hedonic motivation, utilitarian motivation, and outcomes, we specify hedonic and utilitarian motivation as mediators. We first estimated the model on the full sample and then conducted a multigroup analysis by guidance condition. Due to the robustness to small sample sizes and non-normally distributed data, we used SmartPLS4 for partial least squares structural equation modeling (Ringle et al., 2022). Fig. 5 shows the resulting paths.

The multigroup models reveal distinct patterns across guidance conditions. In the low-guidance condition, hedonic and utilitarian motivation predict reuse intention and task efficiency, with limited sensitivity to pre-task stress. In the high-guidance condition, motivation does not predict efficiency. Instead, pre-task stress is associated with faster completion and relates to reuse intention via reduced hedonic motivation. Together, these patterns suggest that the two guidance conditions create different internal dynamics between stress, motivation, and performance. In other words, the level of guidance shapes how pre-task stress relates to efficiency and acceptance, providing a richer understanding of how stress might interact with guidance. The displayed model is not yet intended to validate a causal structure, as moderation results were mostly non-significant, but it illustrates that the pathways towards performance and acceptance are indeed contingent on the level of guidance, offering a basis for hypothesis generation in future stress-adaptive and pervasive AR research.

6. Discussion

This study contributes to a broader understanding of how stress, guidance design, and motivational processes jointly shape performance and acceptance in AR. Drawing on a 2 × 2 experiment comparing two guidance levels under varying pre-task stress, the findings indicate that stress effects are contingent on situational affordances and give rise to trade-offs between efficiency and acceptance. These patterns suggest that design choices play a critical role in shaping how user states translate into behavioral and attitudinal outcomes. In the following, we discuss how these contingent effects and trade-offs can be interpreted

from a theoretical perspective and what they imply for AR research more generally. Although the system examined here was not adaptive, the identified patterns are relevant for future research on stress-adaptive and pervasive AR by providing a foundation for hypothesis generation and theory development, which we subsequently highlight.

6.1. Theoretical contributions of the findings

Building on our results, we identify two main theoretical contributions:

6.1.1. Contingent effects of stress and guidance

While we observed direct effects of pre-task stress and guidance on motivation, acceptance, and performance, their interplay indicated more nuanced mechanisms. Specifically, guidance level reconfigured the pathway to performance: Under low guidance, performance primarily followed a motivational pathway, with hedonic and utilitarian motivation as the key predictors. Under high guidance, performance instead followed a stress pathway, making pre-task stress the dominant predictor.

Low Guidance → Motivational Pathway

High Guidance → Stress Pathway

Consistent with prior work (Ewing et al., 2016; Zsidó, 2023; Ganem et al., 2022), our findings suggest that stress can enhance performance, but only when guidance is appropriately aligned, in our case, at a high level of guidance. When guidance was low, pre-task stress was less predictive. In this case, our results align with previous research on the importance of utilitarian and hedonic motivation (Elliott et al., 2021; Cheng and Huang, 2022; Yang et al., 2020).

One plausible explanation for why motivation emerged as the primary driver under low guidance is that participants could more freely choose which bricks to place. Such choice and volition may increase perceived autonomy, which Self-Determination Theory identifies as a key condition for sustaining high-quality motivation (Deci and Ryan, 2012). This autonomy-supportive setup might therefore strengthen the quality of hedonic and utilitarian motivation and, in turn, make motivation a stronger predictor of performance and acceptance outcomes in the low-guidance condition.

By contrast, high guidance likely constrained participants' sense of autonomy by prescribing actions more tightly. Reduced autonomy can diminish intrinsic motivation and may increase disengagement. Under these circumstances, higher stress may have functioned less as a detriment and more as a beneficial stress increase in line with Motivation Intensity Theory and the Valence–Arousal Model, as well as the Yerkes–Dodson framework (Ewing et al., 2016; Zsidó, 2023; Yerkes and Dodson, 1908; Ganem et al., 2022), consequently boosting the performance.

Overall, our results reinforce prior evidence but introduce an important contingency in line with the Situated Action perspective (Nardi, 1996; Suchman, 1987): the stress–performance and motivation–performance relationships in our assembly task depend on the level of guidance.

6.1.2. The hedonic trade-off

Beyond reaffirming that both hedonic and utilitarian motivation are relevant for understanding technology acceptance and performance (Tamilmani et al., 2019; Elliott et al., 2021; Cheng and Huang, 2022), our results illustrate the tension described by Tamilmani et al. (2019) as a "battle" between affective and cognitive drivers of acceptance and performance. Notably, this tension is visible in our data across both guidance levels, with hedonic motivation emerging as a central channel through which a performance-acceptance trade-off unfolds.

Under low guidance, higher hedonic motivation was positively associated with reuse intention yet negatively associated with efficiency, suggesting that the affective appeal that supports acceptance can coincide with reduced task efficiency. Under high guidance, higher pre-task stress was associated with faster completion, but it was also associated with reduced hedonic motivation, which in turn was related to lower reuse intention. Thus, across both guidance levels, improving efficiency and sustaining acceptance did not necessarily co-occur: either hedonic motivation conflicted directly with efficiency (low guidance), or efficiency gains associated with stress coincided with reduced hedonic motivation and thereby reduced acceptance (high guidance). For example, in time-critical contexts (e.g., emergency response), designers may intentionally privilege cognitive-oriented reactions such as usefulness, comprehension, and control over affective reactions such as enjoyment or curiosity, whereas in voluntary or leisure contexts, the reverse prioritization may be more appropriate.

Notably, similar to El Halabieh et al. (2017), we did not observe direct stress effects on acceptance; instead, they emerged indirectly via hedonic motivation (depending on guidance level). This suggests that future studies on acute user states such as stress should model mediation pathways explicitly.

6.2. Implications for context-adaptive and pervasive AR

Whereas RQ1 and RQ2 focused on the observed effects within our study, RQ3 concerns what these findings imply for stress-aware, context-adaptive, and pervasive AR. Importantly, our study compared two static guidance levels rather than implementing real-time adaptation. Accordingly, the results should not be treated as validated evidence for stress-adaptive or pervasive AR design. Instead, we interpret them as foundational patterns that can inform future research and help to create new hypotheses on adaptation logics to advance theory development.

A central challenge for adaptive systems that react to physiological signals is not only sensing and translating physiological signals reliably, but also determining how to adapt in ways that improve desired outcomes (Fairclough, 2009). A common and intuitive assumption (c.f., Kennard et al., 2020; Lindlbauer et al., 2019) is that adaptive applications should regulate physiological reactions toward an optimal zone (e.g., moderate stress), consistent with perspectives such as the Yerkes-Dodson law, the Valence-Arousal Model and the Motivation Intensity Theory (Ewing et al., 2016; Zsidó, 2023; Ganem et al., 2022; Hancock and Ganey, 2003). However, our results motivate a complementary possibility: adaptation may not primarily function as a linear regulator of stress, but may instead change the process through which performance and acceptance emerge.

In our study, the two guidance designs can be interpreted as different task contexts: increasing guidance may reduce degrees of freedom and cognitive demands, whereas reducing guidance may increase autonomy and challenge. Rather than one guidance level simply being better for high versus low stress, the observed patterns suggest that guidance can shift which factors are most predictive for performance and acceptance (motivational vs. stress-related pathway). This aligns with a Situated Action perspective in which context shapes how action unfolds (Suchman, 1987; Nardi, 1996). From this viewpoint, guidance level is not merely an output of adaptation; it is itself a contextual factor that can reconfigure problem-solving and thereby change which user states and mediators become consequential.

This interpretation extends beyond our data, but it offers a potentially useful lens for future context-adaptive (and especially stress-aware) AR research: adaptive guidance (and other potential adaptation strategies) may operate by reconfiguring task-solving processes, not only by shifting outcome levels.

Call for Research: We therefore call for future work to examine adaptations as a process-shaping mechanism. Concretely, future studies should:

1. **Implement dynamic stress-adaptive application:** Develop a continuous adaptive guidance AR application and evaluate whether the mechanisms linking user state to outcomes

(e.g., stress- vs. motivation-related predictors) change across adaptation states.
2. **Collect process evidence for Situated Action in AR:** Complement outcome measures with interaction traces and/or process measures (e.g., step-level behaviors, gaze/attention proxies, think-aloud or post-hoc elicitation) to examine how guidance shapes problem-solving.
3. **Expand to multi-context-adaptive designs:** Implement and evaluate mechanisms for applications that adapt to multiple different context-factors (e.g., environmental and human factors), following a pervasive AR vision (Grubert et al., 2016).

6.3. Implications for practitioners

Although our study examined only two static guidance levels in a lab-based assembly task, the findings suggest two practical considerations for designers of guidance-based AR systems. First, practitioners should make objectives explicit before selecting or tuning guidance strategies. If the primary goal is efficiency (e.g., time-critical or safety-relevant tasks), more directive guidance may be appropriate even if it reduces hedonic motivation and, consequently, reuse intention. Conversely, if repeated voluntary use is central (e.g., training, leisure, or consumer-facing experiences), preserving hedonic motivation and perceived autonomy may warrant less directive guidance, even if efficiency is not maximized.

Second, our results caution against one-size-fits-all assumptions such as "more guidance is always better under stress." Instead, guidance strategies should be evaluated regarding the targeted outcome (efficiency vs. acceptance), the task context, and the anticipated user state, ideally through iterative testing that examines performance and acceptance-related measures. Overall, practitioners should treat guidance as a design lever and evaluate it against efficiency and acceptance.

6.4. Limitations & future work

This study intentionally examined a simplified setting (two static guidance levels following a pre-task stress induction or reduction) to isolate how stress and guidance configurations interplay and affect motivation and performance. Because stress is complex and highly subjective, it is challenging to measure and directly compare exact stress levels across individuals. Instead, we assigned participants to two groups that differed significantly in their stress levels. Furthermore, we implemented only two substantially different AR applications, rather than exploring a broader spectrum. This decision was motivated by the goal of creating a clear contrast in our experiment. Using different guidance levels between groups, we focused our research questions on identifying general effects rather than finding the optimal guidance level. With this approach, we could reduce the complexity and understand the fundamental effects and trends of how users respond to different levels of guidance in an application at different stress levels. Notably, limiting the guidance conditions does not exclude the potential for exploring a broader range of possible adjustments in future research, which could provide valuable insights and optimizations for different contexts.

For interpreting our findings, the following two limitations are important to consider. First, our sample has an unequal gender distribution (18.7 % female participants), which may constrain generalizability despite potential relevance to certain workforces (e.g., manufacturing; Pal et al., 2023). Second, while the pre-task interventions affected stress before the task, post-task stress differences were not observed between conditions. Notably, post-task stress was measured on the SSSQ, while pre-task stress was measured by the SNRS-11. Still, there is no evidence of sustained stress throughout task execution. Nonetheless, we were able to find effects of the pre-task stress levels on the outcomes. Thus we argue that our findings provide a valuable foundation for broader investigations.

Future research should be twofold. First, following our call for research to test and extend our proposed situated lens in relation to context-adaptive and pervasive AR developments in Section 6.2. Beyond this, based on the limitations and the observed insights, future research should extend our design along three dimensions:

1. **Design and task scope:** Move beyond binary guidance, binary stress levels, and a single assembly task to multiple guidance granularities, interaction modalities, continuous stress levels, and task types to identify whether the observed patterns remain consistent and whether new patterns or evidence emerge.
2. **Broader outcomes and mediators:** Incorporate additional variables that are critical in applied settings, such as situational awareness (Stefanidi et al., 2022), engagement (Rauschnabel et al., 2024), and trust in human-agent interaction (Gupta et al., 2019, 2020).
3. **Continuous Stress Measurement:** Measure stress dynamics during task performance (e.g., continuous physiological sensing) to establish when and how stress fluctuations relate to performance and acceptance.

7. Conclusion

Advances in sensor technologies (Qin and Bulbul, 2023), physiological computing (Fairclough, 2009), and pervasive AR (Grubert et al., 2016) are enabling AR systems that can respond to users' momentary states. Yet, it remains insufficiently understood how concrete application designs, such as the level of guidance, shape motivation, acceptance, and performance under stress.

This paper contributes evidence from a controlled 2×2 study showing that guidance level is a consequential design factor: it conditions how pre-task stress and motivational responses relate to performance and acceptance outcomes and indicates that efficiency and continued use may not be jointly optimizable. These findings motivate a Situated Action lens for future context-adaptive AR, where adaptations are examined not only for their outcome shifts but also for how they reconfigure task-solving processes. Future work should implement and evaluate real-time adaptive guidance in more diverse tasks and contexts to test and extend these hypotheses and pave the way for pervasive AR systems.

CRediT authorship contribution statement

Dominik O.W. Hirschberg: Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Oliver Hein:** Writing – original draft, Visualization, Software, Methodology, Investigation, Conceptualization. **Florian Alt:** Writing – review & editing, Supervision, Resources, Conceptualization. **Philipp A. Rauschnabel:** Writing – review & editing, Validation, Supervision, Resources, Conceptualization.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used ChatGPT and DeepL Write to enhance readability, clarity, and optimize grammar. 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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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.

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Appendix A. Supplementary data

Supplementary data for this article can be found online at doi:10.1016/j.ijhcs.2026.103848.

Data availability

Data will be made available on request.

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