Journal of Public Health
https://doi.org/10.1007/s10389-026-02781-5

ORIGINAL ARTICLE

Routine knowledge work: mental workload and performance during work in long-distance trains and activity-based work environments

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Received: 30 January 2026 / Accepted: 16 April 2026

Abstract

Aim This research examines the performance and mental workload of knowledge workers in various work environments, with a specific focus on long-distance trains and activity-based work settings. As mobile work becomes increasingly prevalent in Europe, understanding the implications of such settings on worker productivity and well-being is essential.

Subject and methods Experiment 1 compares routine task performance and perceived mental workload between a stationary office and a long-distance train environment. Experiment 2 extends this inquiry by examining the effects of an activity-based work environment, where workers can choose their workspaces based on the task at hand. A total of 57 participants aged between 20 and 62 years were included in the analysis of Experiment 1. The analysis of Experiment 2 included 29 re-recruited participants from Experiment 1, also aged between 20 and 62.

Results Results indicate that performance is significantly worse on trains, attributed to increased processing time rather than error rates, alongside higher mental workload. Findings reveal that performance and mental workload improve in the flexible setting compared to both the single office and the train.

Conclusion The study highlights the importance of adapting work environments to promote productivity and health among mobile knowledge workers, advocating for the tailored selection of tasks and consideration of individual employee needs when implementing mobile work strategies. These results underscore the importance of aligning work environments with task demands in mobile work contexts. Organizations should encourage the strategic selection of workspaces and tasks, while considering individual employee needs, to promote productivity and health among mobile knowledge workers.

Keywords Mobile work · Mental workload · Knowledge work · Work performance · Activity-based work · Work environment design · Cognitive ergonomics · Transportation environments

Introduction

The work landscape in Europe and the USA has changed significantly in recent years. An increasing number of knowledge workers are no longer exclusively working at fixed locations in offices (Castle 2021; Wulff Pabilonia and Redmond 2024). More than half of employees work at least occasionally outside a stationary office setting (Hammermann 2019). This shift towards mobile work environments is particularly noticeable among commuters and business travelers, who increasingly use the time on long-distance trains for mobile work (Haller and Dauth 2018). After a slump in business travel during the COVID-19 pandemic, it is now steadily increasing again. This is due, in part, to the advantages of face-to-face meetings, particularly in customer service, compared to digital contact (Business

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Published online: 05 May 2026

Traveller 2022). In this context, companies are increasingly refraining from flights and switching to long-distance trains (Gluschitsch 2023).

Since the effects on performance and mental workload of this environment are unclear, in this study, Experiment 1 aims to investigate how routine work tasks can be accomplished on long-distance trains compared to those in traditional stationary offices.

With the increasing spread of mobile work in the field of knowledge work, the “original” stationary knowledge work is also changing (Reindl et al. 2022). Companies are employing new space concepts (Brunia et al. 2016), such as the activity-based work environment, where the work environment is adapted to the task at hand (Reindl et al. 2022). The effects of this work environment on performance and stress are still unclear. To achieve effective knowledge work in both mobile and stationary settings, and to ensure it is both ergonomic and motivating, Experiment 2 examines the activity-based work environment as an additional experimental condition.

For the experiments reported in this article, ethical approval was obtained in advance. All participants consented to the anonymized publication of their data.

Both the terms “knowledge work” and “mobile work” are used in different ways. Therefore, the following presents the definition of the terms used here and their combination into mobile knowledge work. According to Backhaus et al. (2021, p. 2), mobile work describes a “sporadic, not necessarily all-day work with PC or portable screen devices (e.g., laptop, tablet), which is not tied to the office in the company, nor the home workplace. It can be carried out with electronic or non-electronic work tools.” In this way, mobile work is neither telework nor mobile telework, as it does not involve a fixed workplace. Fixed legal regulations are only in place for the area of telework (Hammermann 2019), which is why mobile work is based mainly on individual coordination between employers and employees. This leads to challenges in terms of occupational safety and insurance (Piel 2020). The location of mobile work can be chosen by employees themselves or agreed upon with employers (BMAS 2026). According to Tegtmeier (2021), knowledge workers are either viewed as a highly specialized, highly qualified group or, in a broader definition, identified by their content-related activities and roles. In an experiment on digital stress in Germany, people employed in knowledge work are defined as those “whose primary activities are closely related to the processing of information” (Gimpel et al. 2019, p. 40). Möller (2022) describes knowledge workers as highly qualified individuals who predominantly apply theoretical and analytical knowledge in their work.

Research on knowledge work in public transportation and activity-based work environments remains scarce. The studies conducted so far have shown that when working in public places, such as on long-distance trains, the restricted privacy and physical conditions of employees, including the lack of ergonomic design in the seated workstation and unwanted noise, are perceived as hindrances. Additionally, there is a lack of exchange with coworkers and a reduced sense of team feeling, which is described as unpleasant (Koroma et al. 2014). Despite the restrictions on privacy, however, work in activity-based work environments is predominantly described as pleasant by employees. Possible reasons for this are the spatial separation of work and private life, along with simultaneous opportunities for social interaction (Keller et al. 2017; Tegtmeier et al. 2022).

Particularly relevant for healthy work is the stress and the associated mental workload caused by the work environment and the work itself. The concept of stress and strain, as described by Rohmert (1984), states that strain is the result of stress. Stresses are external influences that act on humans, while strain is the subjective reaction to these stresses (Manzey 1997). Strain results from a combination of stresses and individual prerequisites, such as physical abilities or age. Every human being reacts individually to this strain. Laurig et al. (1971) vividly present this concept in a model in which human characteristics act like the spring constant of a stress spring, amplifying or reducing the strain. Strain is additionally influenced by external conditions that indirectly influence stress. These are caused by influences from the work environment, such as temperature and noise, and affect humans (Rolo et al. 2010). Strain has both physical and mental components, such as mental workload. In the present study, the mental workload is mainly considered, as it has direct effects on the health of knowledge workers (Metz and Rothe 2017).

The train environment imposes continuous extra-aural noise (45–85 dB) that taxes attention and working memory, while confined seating and limited personal space constrain posture and ergonomics (Sharma et al. 2022). Frequent interruptions—such as onboard announcements and staff interactions—and abrupt acceleration or braking further fragment task sequences, leading to slower response times and increased error rates in routine activities (Jafari et al. 2019). Activity-based workspaces mirror these stressors through shifting acoustic profiles, variable workstation density, and unpredictable social encounters, all of which increase cognitive load. According to cognitive load theory, such fluctuations prolong completion times for habitual tasks by disrupting established workflows, and they disproportionately affect the divergent thinking processes essential to creative problem-solving (Eismann et al. 2022).

To measure mental workload, different methods can be used, which can be divided into three categories (Rubio et al. 2004). Firstly, the subjectively perceived mental workload can be directly queried from the affected person (Meshkati et al. 1995). Additionally, there are other approaches to capturing mental workload via physically measurable indicators such as eye parameters (Charles and Nixon 2019). Finally, performance parameters can be determined through either the primary or a secondary work task, thus allowing conclusions to be drawn about mental workload (Meshkati et al. 1995). Since the subjective measurement allows for a detailed comparison of the strain situation between individual measurements (Rubio et al. 2004), this form of measurement is used in these field studies, together with an evaluation of the primary performance. The measurement of physiological parameters for determining the mental workload would be associated with the disturbing influence of measurement instruments (primarily due to the working environment conditions on long-distance trains). Therefore, this form of measurement was dispensed with.

Routine tasks are characterized by repetition, automatability, and programmability, and thus are based on describable declarative factual knowledge (Salaberry 2018). Examples can be found in the reproduction and merging of factual knowledge, as is required, for example, in invoice creation or appointment scheduling (Oeste-Reiß et al. 2021).

As an example of a routine task, a ticket system was used in which fictitious customer inquiries were categorized. Specifically, a computer program was created in Opensesame (Mathôt et al. 2012) which resembles a ticket system in structure and function. The participants were given the task of reading appearing tickets and correctly assigning them to one of nine departments by clicking on a labeled folder. This assignment was made according to urgency, affiliation of the sender to a group of people, and postal code. The participants were assigned the goal of processing at least 350 tickets within the 2-h processing time. The individual ticket, in turn, had to be assigned within 30 s. These 30 s were displayed in the form of a countdown. Through this and the communication of their performance via a feedback page after 30 tickets, participants were motivated to work at their maximum performance. Some tickets were not clearly assignable. In this case, participants contacted a call center that had been set up, in which a confederate person correctly identified the allocation of the ticket. The program could be interrupted by the participants for making calls and for small breaks. Due to the repeated measurements between the conditions of long-distance train, single office, and activity-based work environment, three scenarios were constructed. The participants put themselves in the position of an employee of a telecommunications company, a mail-order company, or an energy supplier. For each scenario, 420 tickets were created (14 blocks with 30 tickets). The tickets were distributed across nine different departments and had different text difficulties. The tickets were written in such a way that they clearly fulfilled the categories of "easy" (50% of the tickets), "medium" (35% of the tickets), and "difficult" (15% of the tickets) based on the Hamburger Verständlichkeitsmodell (Hamburg comprehensibility model; Langer et al. 1981, 2011).

Experiment 1

Method

To answer the questions raised in the introduction, a study design was developed. This involved examining participants in routine tasks, which are repetitive tasks consistently performed on a daily basis, in various work environments to assess their performance and the psychologically perceived mental workload. Mobile work on the train may place different demands on work relative to working in a stationary office. The aim of Experiment 1 was to explore how well routine work tasks could be performed on long-distance trains compared to a stationary single office. Therefore, the experiment was conducted in two environments: a long-distance train and a single office. Special attention should be paid to the physical and psychological stresses that arise from mobile work and their influence on the performance achieved. Knowledge work takes place not only on the train and in a single office, but also in various settings.

The stationary office environment was established in the laboratory of the Institute of Human and Industrial Engineering (IFAB) on the Karlsruhe Institute of Technology (KIT) campus. For this purpose, workstations were set up in single offices for the participants. Each workstation was equipped with a table and a chair. As work material, the participants were provided with a laptop (Lenovo ThinkPad L15 Gen 2 20×4), a computer mouse (Conceptronic DJEBBEL 7), and a smartphone (Samsung Galaxy A12) at their disposal.

Due to the duration of the journey, the Intercity Express (ICE) route from the Karlsruhe main station to Kassel Wilhelmshöhe was suitable for conducting Experiment 1 on the train. For the experiment on the train, seats in the ICE large room of the second class with a fixed table were reserved for implementing the experiment. The journey takes about 2.5 h without changing trains. This allowed for a buffer of time before and after the 2-h task processing, which was necessary for packing and unpacking the laptop, taking seats, and receiving final instructions from the test management.

During a preliminary survey, the first demographic data of the participants were collected, and a pre-selection was made to ensure that all participants had prior experience in knowledge work and the associated digital support instruments. Additionally, the participants' mobility behavior was assessed at this point. A total of 117 people participated in the unpaid preliminary survey. Of these, 12 people were excluded because either concentration weakness or poor German language skills were indicated. Finally, 46 people were no longer considered because the necessary number of participants had already been reached. Due to the complexity of the field experiment, participants were informed about the course of the experiment in a 15–20-min online introduction prior to the first day of the experiment. They gained brief insight into the course of the day in the lab (single office) and on the ICE, as well as into the tasks to be processed. The within-subject study design with repeated measurements (2×1) for Experiment 1 is shown in Fig. 1.

During the processing of the routine task, the mental workload experienced by the participants was queried automatically every 10 min using a digitalized SEA scale (Eilers et al. 1986). The scale appeared in the work program, and the value could be set using a slider.

The SEA scale is a method for measuring subjective perception of psychological stress, which is a one-dimensional scale for recording subjectively experienced effort. It measures the experienced effort using a value scale from 0 to 220, which is labeled at certain points for orientation. The multiple querying of the scale, for example, over the survey phase of an experiment, makes the perceived subjective mental workload continuously measurable. An advantage of this scale is its low time expenditure, which makes it particularly attractive when used repeatedly.

Participants

An a priori power analysis with a medium effect size resulted in a required sample size of 54 participants. Ultimately, 59 people participated in the field experiment. Due to inconsistent data, two participants were excluded from the data analysis of the routine task performance. The 57 participants included were aged between 20 and 62 years. The average age was 29.18 years ($SD = 10.4$). Of the participants, 23 were female and 34 were male. The participants were compensated €200 for participating in the experiment. The analyzed sample was relatively young, with an average age of 29.18 years. The age distribution of the sample was not balanced. Despite the high compensation of €200 for participation, only 13 participants over 30 years of age could be recruited. This research complied with the tenets of the Declaration of Helsinki and was approved by the Institutional Review Board at Karlsruhe Institute of Technology. Informed consent was obtained from each participant.

In the evaluation of mental workload during the routine, an additional two participants were excluded from the data analysis because they did not answer the SEA scales sufficiently. Ultimately, a total of 55 participants, aged between 20 and 62 years, were included. The mean age of this sample was 28.9 years ($SD = 10.47$); there were 33 male and 22 female participants.

Results

The performance in the routine task was determined according to correctly assigned tickets. The performance on the routine task on the long-distance train was significantly worse than in the single office ($t(56) = -3.39$, $p < 0.001$, $d = 0.45$). These findings are shown in Fig. 2. The error rate of the assigned tickets does not differ significantly between the single office ($M = 9.03\%$, $SD = 5.26$) and long-distance train experimental conditions ($M = 9.64\%$, $SD = 4.04$) ($t(56) = 0.78$, $p = 0.44$). The difference in performance therefore results from a longer processing time per ticket.

The mental workload measured by the SEA scale during the processing of the routine task is significantly higher

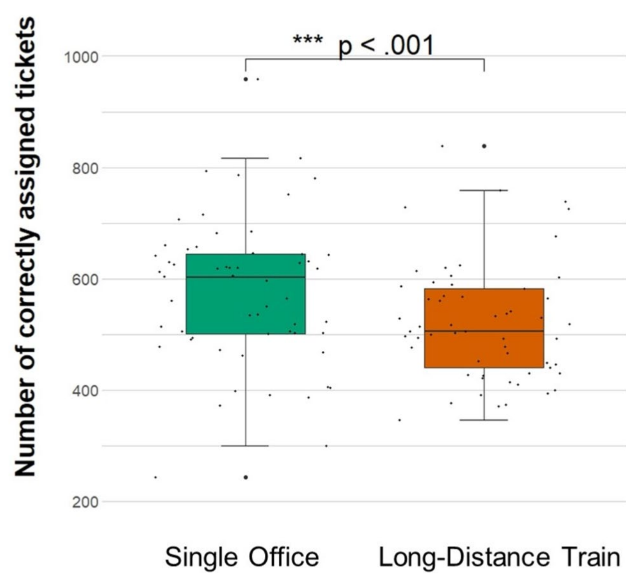

Fig. 2 Results of the performance during the routine task in Experiment 1

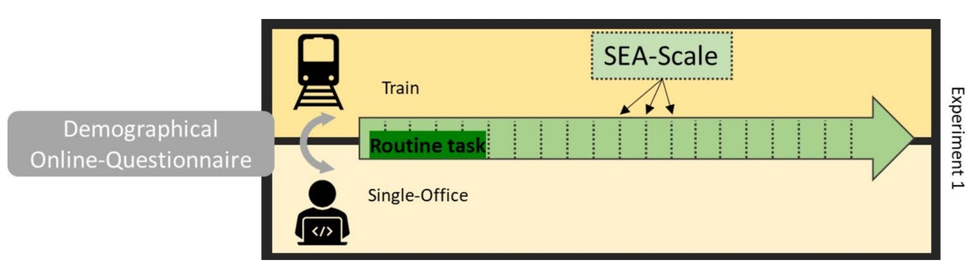

Fig. 1 Study design of Experiment 1

on the long-distance train ($Mdn = 86.94$, $W = 548$, $p = 0.03$, $r = 0.25$) than in the single office ($Mdn = 67.24$) (Fig. 3).

Conclusion

The results of Experiment 1 suggest a negative influence of the train work environment on performance during the routine task as well as mental workload.

Experiment 2

Method

Knowledge work takes place not only on trains and in single offices, but also in various other settings. Increasingly, companies are also considering new space concepts, such as activity-based work environments (Reindl et al. 2022). In companies with a high mobile work quota, this form of work environment becomes especially interesting (Iffländer 2022). In activity-based work environments or needs-based work landscapes, there are no fixed workplaces; instead, employees adapt the work environment to suit their tasks (Reindl et al. 2022). This results in irregular coming and going. All these elements distinguish this work environment from an open-plan office. The influence of the activity-based work environment on the performance and perceived mental workload of employees was addressed in a second experiment. To answer the questions raised, a within-subject study design with repeated measurements (3 × 1) shown in Fig. 4 was developed. This involved, analogous to Experiment 1, examining participants in various tasks across different work environments in terms of their performance and the psychologically perceived mental workload. Experiment 2 can be understood as an extension of Experiment 1, which is why many elements were taken directly from Experiment 1.

An activity-based work environment is characterized by the ability of people working there to freely choose between different work scenarios (van Meel 2020). For example, there are quiet zones for individual work, as well as conference rooms for group work and discussions. There are individual workstations, as well as rooms for exchange and retreat. The IFAB laboratory rooms were converted into such an activity-based work environment. This included two rooms with a total of seven individual workstations, each consisting of a desk (six sitting desks and one sit-stand desk) and an office chair.

Furthermore, the premises included a conference room, a lounge with sofas, and a small kitchenette. The rooms were stocked with plants for a more pleasant working atmosphere. The work environment differed, among other things, from the previously examined condition in the static single office in that participants worked here simultaneously and together in the workrooms provided.

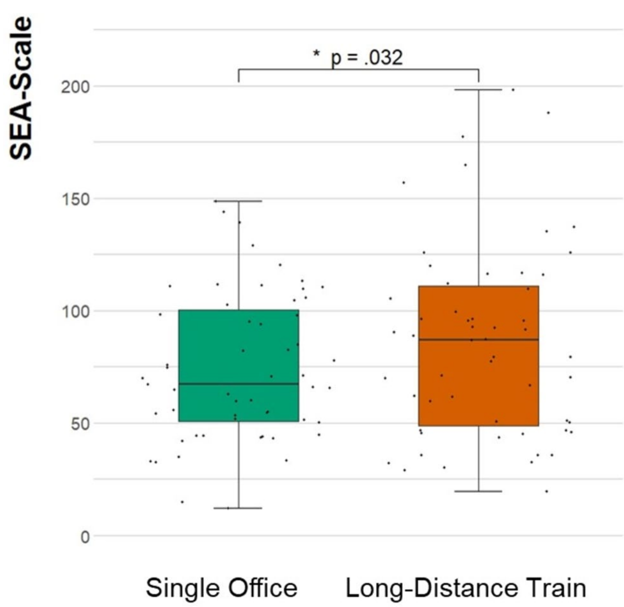

Fig. 3 Results of the measurement of mental workload during the routine task in Experiment 1

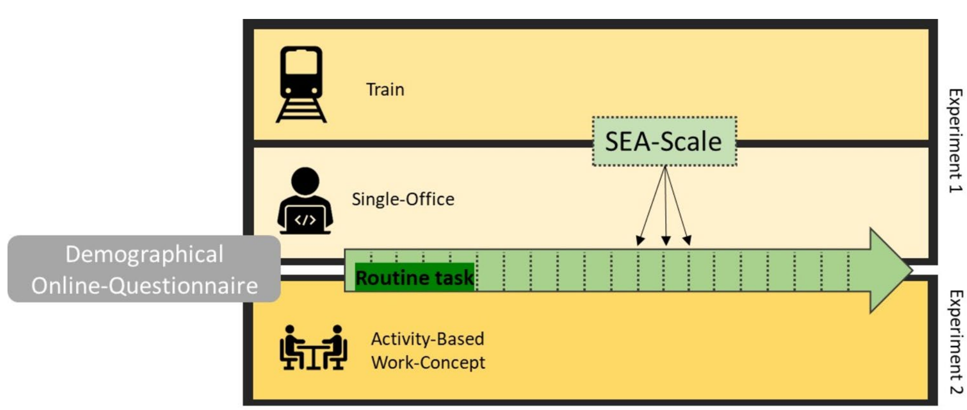

Fig. 4 Study design of Experiment 2

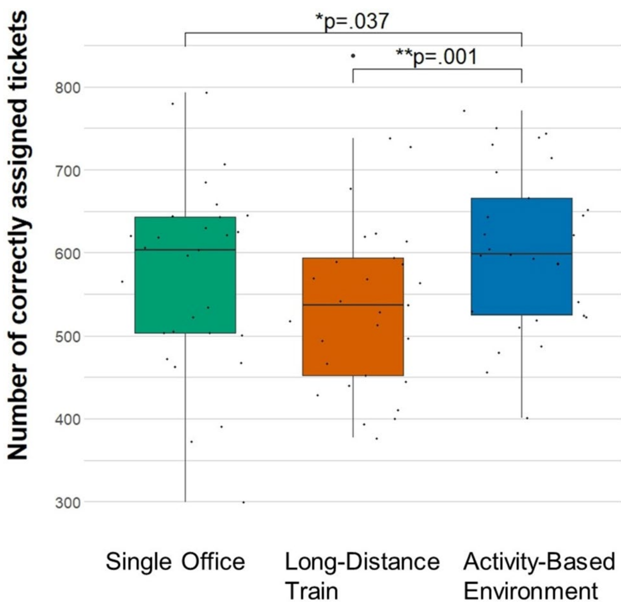

Fig. 5 Results of the performance during the routine task in Experiment 2

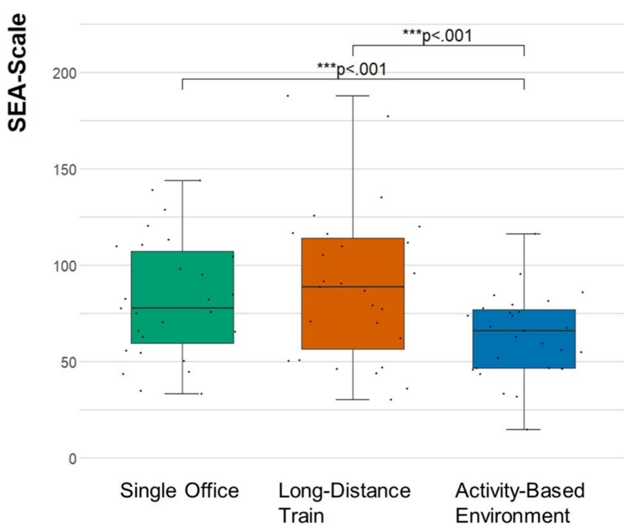

Fig. 6 Results for the measurement of mental workload in Experiment 2

Participants

For this experiment, all former participants in Experiment 1 were contacted again and asked to participate. The resulting sample thus contained only participants who were already familiar with the experimental procedure from Experiment 1. An a priori power analysis with a medium effect size resulted in a required sample size of 24 people. Thirty people aged between 20 and 62 years participated in the field study. The participants were compensated €80 for participating in the experiment. Twenty-nine participants aged between 20 and 62 years (15 male, 14 female, mean age 31.9 [SD = 12.51]) were included in the data analysis of the performance of the routine task. The data set for one participant was removed because they failed to follow the instructions given by the experimenter. A total of 27 participants, ranging in age from 20 to 62 years (14 male, 13 female, mean age 31.52 [SD = 12.89]), were included in the evaluation of mental workload during the routine task. Two additional data sets had to be removed from the evaluation because the participants did not provide sufficiently complete answers to the SEA scale.

Results

The performance of the routine task was based on correctly assigned tickets during working time in the ticket system. The task performance in the activity-based work environment was significantly higher than that in the single office ($t(28) = 1.85$, $p = 0.037$, $d = 0.34$) (Fig. 5). The performance during on the long-distance train was significantly worse than that in the activity-based work environment ($t(28) = 3.33$, $p = 0.001$, $d = 0.62$). One data set was excluded from the evaluation because the participant stopped processing the routine task on the long-distance train towards the end of the task. The error rate of the assigned tickets was significantly better in the activity-based work environment in comparison with both the single office ($t(28) = 0.28$, $p < 0.001$, $d = 0.86$) and the long-distance train ($t(28) = 5.28$, $p < 0.001$, $d = 0.98$). The performance difference thus seems to be at least partly due to a more error-free performance in the activity-based work environment.

The measured mental workload during the processing of the routine task was significantly lower in the activity-based work environment ($Mdn = 65.92$, $W = 315$, $p < 0.001$, $r = 0.58$) than in the single office ($Mdn = 77.89$). Additionally, a comparison of the measured mental workload in the activity-based work environment and on the long-distance train ($Mdn = 88.89$) revealed a significantly higher mental workload on the long-distance train ($W = 322$, $p < 0.001$, $r = 0.62$) (Fig. 6).

Conclusion

The results of Experiment 2 suggest a positive influence of the activity-based work environment on performance during the routine task as well as on mental workload.

Discussion

The measured performance during routine knowledge work was significantly worse on the train than in a single office. The performance did not suffer from an increased error rate, but from a longer processing time for the same content. Therefore, it must be assumed that more time needs to be planned and allocated for the same routine knowledge work when working on the train. In addition, a significantly higher mental workload was measured during routine knowledge work on the train. Therefore, it can be expected that frequent performance of routine knowledge work on public long-distance trains poses an increased risk of health complaints. The results of Experiment 2 show that there is no need for interventions during routine knowledge work in the examined activity-based work environment. The measured environmental conditions indicate a suitable work environment. This is to be understood under the premise that quiet work areas are actually used for concentrated work, and only occasional, brief private conversations are held. The comparison of mental workload during tasks and the performance of these tasks also shows no indication of a necessary intervention, both in comparison with the work environment on the train and in comparison with the single office. However, when interpreting the results from Experiment 2, it should be noted that the newly designed work environment in which the experiment was conducted may have had a positive influence on the participants' performance and mental workload. Additionally, there was no mixed task permutation during the experiment, and participants were familiar with the task concept. Furthermore, the measured noise level reported shows that the conditions for knowledge work were improved in Experiment 2.

The results of Experiment 1 show that design criteria for both employers and employees are necessary for mobile knowledge work on trains to ensure duty of care and health. Mainly due to the unpredictability of the work environment on the train, the topic should receive more attention. The results presented here are intended to contribute to improving the situation of mobile knowledge work on long-distance trains. A notable innovation is the specific planning and selection of work tasks for processing on the train prior to the travel application. Future work should investigate the extent to which a work task tailored explicitly to the work environment on the train influences the stress situation and employee performance. A more concrete investigation of the experiences of different age classes of knowledge workers on trains would be another interesting question for the future, as the initially targeted age distribution of the participants in three age classes could not be implemented in the experiment presented here. Generally speaking, working in a train environment is unpredictable and thus cannot be standardized. Employees should not be exposed to such conditions without proper training or adequate preparation. Additionally, it is beneficial if employees have the freedom from their employer to independently adapt work content according to the prevailing situation on the train.

In summary, the results of these studies allow a differentiated view of mobile knowledge work in different environments. In particular, the finding that executing tasks on long-distance trains should be viewed with caution, in terms of both performance and mental workload, points to potential challenges and limitations of this approach. Accordingly, mobile work on the train is not a permanent suitable replacement for a single office. In contrast, there is a clear recommendation for mobile work in activity-based work environments. This finding highlights the positive impact of an environment tailored to the specific task on the productivity and well-being of employees. Activity-based work environments appear to offer an atmosphere that supports the individual requirements of knowledge work and promotes employee flexibility. Overall, the study results highlight the importance of a differentiated view of the work environment for mobile knowledge work. It is recommended to focus specifically on the individual requirements of tasks, as well as on the needs and stress limits of employees, when implementing mobile work concepts. This can effectively exploit the advantages of mobility, while potential disadvantages, especially in public transport, should be consciously included in planning and implementation.

Author contributions The research was mainly planned, implemented, and analyzed by the main author. The manuscript was mainly written by the main author. All authors have significantly contributed to the research and preparation of this manuscript and have approved its final version.

Funding Open Access funding enabled and organized by Projekt DEAL. This research was supported by the Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (Grant No. F2455). Members of the Bundesanstalt für Arbeitsschutz und Arbeitsmedizin contributed to the formulation of the research questions, study design, and methodology, and reviewed the manuscript prior to submission.

Data availability As the transfer of data during data collection by the test subjects was not agreed to in the data protection agreement, data sharing is no longer possible at this time.

Declarations

Declaration of originality We, the authors, hereby declare the following:

Originality and authorship This manuscript is our original work and has not been published or submitted elsewhere. This manuscript is requested to be published as a reprint. The research in this paper has been previously published as a report in German (https://doi.org/10.21934/baua:bericht20240821).

Public health and welfare implications The authors acknowledge the potential implications of this work for public health and general welfare and affirm that all necessary disclosures have been made.

Informed consent This study was conducted in accordance with the ethical standards of the Declaration of Helsinki. Ethical approval for this research was obtained from the Ethical Committee of the Karlsruhe Institute of Technology (https://www.ethik.kit.edu/index.php) on December 10, 2020. The committee does not issue approval numbers. Written informed consent was obtained from all participants on the day of their first examination prior to participation in the study.

Competing interests The authors declare no financial or nonfinancial conflicts of interest.

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