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Experimental Design to Measure the Effect of Room Acoustics on Prospective Memory of Hospital Nurses: A protocol

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ABSTRACT

A prominent cognitive aspect of a hospital nurse's job is to form, imprint and retrieve intentions for prospective memory (PM) tasks. During the verbal change of shift report and visual inspection of patient files, generally performed in the nurses' station at the start of a shift, important PM intentions are formed and imprinted. The correct retrieval of these intentions during the course of a shift is important for both patient safety and satisfaction. The nurses' station can be a hectic environment with multiple conversations at the same time. While research has shown that the acoustic environment, speech in particular, has a significant influence on several cognitive tasks, its effect on PM is not known. The acoustic environment of a nurses' station potentially influences the forming and imprinting of PM intentions. The current paper presents the design of an ecologically valid experiment with the goal of measuring the effect of realistic background speech and room acoustic conditions on the forming and imprinting of prospective memory intentions. While the experimental design is closely linked to a hospital situation, understanding the effect of acoustic conditions on PM might also be valuable in other domains.

Keywords: Cognitive performance, Hospitals, Nursing, Room Acoustics, Experimental design

1. BACKGROUND

Nurses working in a hospital ward share a great responsibility: the wellbeing of their patients. The sound environment they work in should facilitate them through minimalizing the risk of care omissions. Most importantly this regards patient safety and patient satisfaction, but it also touches upon job satisfaction. The effect of the sound environment on cognitive performance has been demonstrated in numerous studies, for reviews see (1,2). There is, however, a difficulty in translating these results to applied settings, as the effect of sound on performance is different for different cognitive abilities (3), and dependent on the difficulty of the task (4). Furthermore, both the nature of the sound environment (the room acoustics of the space in which the sound is produced and the exact location from which the sound is originating) and the nature of the sounds that are produced have to be taken into account (3). Therefore, in order to determine whether and which aspects of the sound environment influence the task performance of a nurse we need to take a closer look at the nursing job and the ward environment.

A nurse working in a hospital ward has to remember to perform several activities at the right moment. Typical examples are to administer antibiotics at a specific time, to call a family member of a patient once they wake up or turning off a nebulizer after 10 minutes of use. Forgetting to execute such tasks can in some occasions be a risk for a patient's health or safety, in other occasions it could have an effect on the patient's satisfaction with the received care. Remembering to perform a previously planned action requires prospective memory (PM) (5,6), a cognitive ability of which the effect of sound on its performance, to our knowledge, has not yet been reported in literature.

A PM task comprises three aspects that can be distinguished. First, an intention has to be formed to perform a future action. Second, this intention has to be encoded and third, the intention has to be retrieved at the right moment, the window of opportunity. Most research on PM focusses on the maintenance of the intention during the delay between forming and retrieving, and on factors

influencing successfully retrieving the intention, such as age or brain damage (7,8). In a typical PM paradigm experiment, participants are instructed to work on a single simple ongoing task, such as watching a video or processing written text from a screen. They are instructed to perform a PM task, for example to hit a key on the keyboard, either at a specific time (time-based PM task), or when a certain event occurs (event-based PM task). The event in the event-based PM task could be encountering a specific word on a screen during a reading task, or seeing an animal in the case of the video task. The instructions for these simple PM tasks are presented prior to starting the ongoing task and do not require any active planning from the participant. Only a limited amount of studies were found that do take into account the forming and encoding of PM intentions, their results however do suggest that the quality of the planning phase is important for PM performance (9,10).

Based on an observation study by the authors a division of activities in a nurses' shift was made. Typically, the first 15-30 minutes of a shift were spent reading patient files and receiving a verbal change of shift report from a colleague. In this time period an important cognitive task is to form and encode intentions for PM tasks. No intentions have to be retrieved yet.

We argue that intentions which are not formed, or not properly formed are less likely to be executed, and intentions which are not sufficiently encoded are less likely to be retrieved. The remainder of the shift is spent executing routine nursing tasks (medication round, ADL(activities of daily living) care and visiting round) during which intentions for specific PM tasks have to be retrieved and intentions for new PM tasks are formed.

The first part generally takes place in a nurses' station or an office where nurses walk in and out, chat, discuss patients and exchange change of shift reports (occasionally multiple verbal reports between different people at the same time). Additionally, a nurses' station can be quite reverberant due to large glass surfaces to allow a view of the ward. Based on the observation by the authors, background speech is the most prominent sound source in the nurses' station and will therefore be a focus of the current study, as well as room acoustic parameters.

Background speech has a significant effect on various cognitive tasks such as serial recall (11), proof reading (12) and mental arithmetics (11,13), but the effect on PM performance is unknown. While there is much debate concerning the mechanisms responsible for the different effects -in a very recent study, Bell and colleagues (14) present results contradicting the main assumption of the duplex-mechanism account which has, until now, received the most support- our main interest is to investigate whether realistic interventions regarding the sound environment influence a nurse's work, regardless of the mechanisms that are responsible. Moreover, reading patient files to form and encode intentions is a complex task in which several coginitive abilities are employed. It requires semantic abilities, taps into memory and has a planning component but the relative contribution of specific processes in unclear.

Considering speech as the most important sound source in a nurses' station, we ask ourselves whether the presence of speech, and the room acoustic design, which influences not only speech intelligibility, but also the overall sound level and perception of the soundscape, influences the forming and encoding of PM intentions. Increasing sound absorption in the space would increase speech intelligibility, but, especially in the case of more people simultaneously speaking also reduce the overall sound level.

Based on the observation mentioned before, the expected importance of the planning phase for PM performance and the evidence in literature on the influence of the sound environment on cognitive performance, the following hypotheses were formulated.

1. The sound environment in a nurses' station influences the forming of PM intentions.
2. The sound environment in a nurses' station influences the encoding of PM intentions.

This paper describes the design of an ecologically valid laboratory study in which the experimental task resembles the cognitive task of a nurse and the sound conditions are exemplary for a typical nursing ward. The main parameters of the sound environment that are taken into account in this protocol are the amount of sound absorbing materials and the presence of background speech.

The results of a first pilot study, intended to validate the resemblance of the experimental task and sound conditions to the actual working environment of a nurse, are pending and could lead to adaptations of the proposed method.

2. EXPERIMENTAL DESIGN

2.1 Study Design

The objective of the proposed experiment is to determine whether background speech and room acoustic parameters in a nurses' station have an effect on the forming and encoding of prospective memory intentions for care activities of nurses working in a hospital ward. The forming and encoding of PM intentions are the dependent variables and will be measured. A full within-subjects design will be used with the sound environment in which the task is performed as the most critical independent variable. Other within-subjects variables are the type of PM task (event-based or time-based) and the presentation of patient info (visual or aural). The experiment consists of two phases that represent the two parts of a nurses' shift that were described in paragraph 1. In the first phase, the experimental task resembles the nurses' activities at the start of a shift, reading patient files and receiving a verbal transfer report. Participants are subjected to different realistic sound conditions during this first phase in which the forming of intentions is logged and measured. The second phase is designed to measure whether the formed intentions are retrieved at the correct moment and therefore properly encoded. In this phase, no experimental sound conditions will be used. A withinsubjects design will be used in which the sound conditions and corresponding task scenarios are counter balanced.

Experimental Phase 1: Reading & Verbal Transfer

This part of the experiment was designed with the aim to have a close resemblance to reality, both for the experimental task and the sound environment. Screenshots of electronic medical records (EMR) are used to create a scenario of 'currently' admitted patients in the ward. The participating nurse is asked to browse through the patient files and plan their shift accordingly. Additional to the visually presented patient information, a verbal change of shift transfer that refers to the patients in each scenario is announced at some point during the first part.

The amount of patients that are within a nurse's care depends on several factors such as the severity of their condition, hospital management and perhaps even cultural differences. While in the observation, one nurse was responsible for up to five patients, the scenarios for the current experiment are consisting of three patients who are admitted in adjacent rooms in an orthopedic ward. The reason for this is that not being able to actually see and talk to the patients introduces an extra difficulty. The first author is allowed access to a scrambled electronic patient file system that is used in a Dutch hospital for educational purposes. Screenshots were taken of a ward overview that showed all 'currently' admitted patients on a date in the past. For each patient, screenshots of the available information in the system up to the selected date were taken. Even though the personal information on the screenshots was scrambled, all patient and staff names are removed from the screenshots and replaced with random names. Using Matlab 2019a, a user interface is developed that allows navigating through the screenshots in a controlled setting. Figure 1 shows an example of the interface. This screenshot provides an overview of protocols and to-be-performed actions of one patient. As mentioned, all staff names have been removed, the (scrambled) name of the patient was replaced with a random name and an avatar was created for the patient to provide some visual recognition later on in the experiment. Since the interface was built from a screenshot, the original buttons do not function. Purple buttons(providing a high contrast with the screenshot) were added to allow the participants to navigate through the different screenshots.

The amount of possible intentions to be formed is similar for each set of patient files, but it is expected that the amount of intentions that is actually formed varies across participants. The difference between the amount of possible intentions in each scenario, and the amount of actually formed intentions by the participants is the measure of formed intentions.

PM intentions that can be formed based on the EMR can be time based and event based. An example of a time-based task is to administer antibiotics at 9.00, an example of an event-based task is to discuss a rash on a patient's skin when visiting the patient with the doctor. Another distinction that can be made are regular PM tasks and irregular PM tasks. A regular PM task is conducted every day for every patient. This includes, amongst others, writing your (participant) name on the information board when entering the room in the morning and asking for pain scores on a visual analogue scale. Irregular tasks are specific for a patient, such as taking a patient's temperature, administering antibiotics or performing a bladder scan. As the regular tasks are performed every shift and can be seen as part of a routine, they are less likely to be influenced by the sound environment in which intentions are formed. Therefore, in this experiment the PM tasks that have to be formed and encoded are limited to the

irregular PM tasks. This is made very clear in the instructions at the start of the experiment and is taken into account in the design of the second part of the experiment. A maximum of fifteen PM tasks can be formed in each experimental patient scenario that is created by the EMR screenshots. These include five time-based PM tasks and ten event-based PM tasks. Participating nurses are instructed to think out loud during this part of the experiment, allowing the researcher to record and log the intentions that are formed.

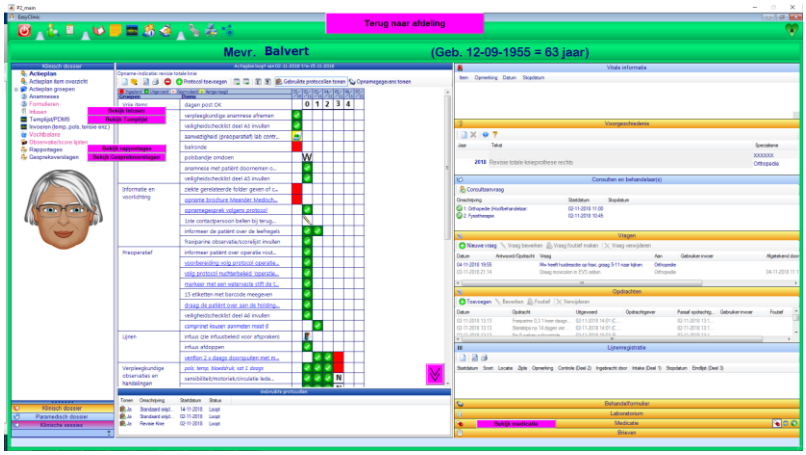

Figure 1 – Example of the user interface created for experimental phase 1.

Experimental Phase 2: Virtual Shift

The aim of this second part of the experiment is to measure whether the formed intentions are properly encoded and thus retrieved in the right window of opportunity. To this end, an existing PM laboratory task called Virtual Week was transformed into a task called Virtual Shift. Virtual Week is a board game, designed by Rendell and Craik (16) with the aim to develop a procedure that explicitly measures PM performance with a close resemblance to every-day life. In the game, participants roll a die and move around on the board according the outcome. The position on the board corresponds to the time of day, and one circuit on the board represents the waking hours of one day. To complete the game, seven circuits (seven days) would have to be finished. While moving around on the board the participants encounter 'event cards' that represent typical daily activities such as meals or a shopping trip. After picking up an event card, the participant is required to make a choice about that event. In the case of a meal, the required choice could be the drink they have with the meal. Each virtual day, 10 event cards are picked up. Before the start of the game, and before each new circuit, instructions for PM tasks are given to the participants. The PM tasks are to be executed at a specific time (marked on the board), or when a certain event occurs. Examples are to take antibiotics at 9.00 am and to return a book to the library when going for groceries (event card). Virtual Week has proven to be a valid measure of PM performance for various situations (17,18).

For the purpose of the current experiment, Virtual Week is transformed into a game called Virtual Shift. Rather than a day, one circuit of the board corresponds to one hour of a nurses' shift, and the event cards are typical events that occur during a nurses' shift. An important aspect of Virtual Shift is that the events are linked to the intentions to be formed in the patient scenarios that are used in the first part of the experiment. The consecutive events can be seen as a narrative for the participants' shift. They inform the participant that they are starting their medication round, when they enter a patient's room and also include the regular PM tasks that are performed every day for each patient. The events can be, but do not have to be linked to a to be performed PM task. An example of an event, translated to English (Virtual Shift is in Dutch) is shown below. For each PM task, only one timeslot, or one event provides the correct window of opportunity.

"You are entering room 2, in which mrs Balvert resides, to administer medication. You introduce yourself and write your name on the whiteboard in the room. Then you ask about her sleep quality and whether she is in pain. Mrs. Balvert tells you that she has slept OK and that, as yesterday, she is in pain but that she can cope with the help of pain medication." The choice to make regarding this event is either to ask her whether she wants to try reducing the pain medication or to stick to the current dose. This is an example of an event that does link to a PM task, as in the EMR for this patient the participant could have read that this patient's temperature needs to be measured three times a day. In the

instructions of the experiment it was made clear that these type of measurements were conducted during the medication round. After choosing one of the provided options, it is up to the participant to perform the task of taking the patient's temperature before rolling the die again.

Using the programming language Python, a digital version of the board game was developed. Figure 2 shows the layout of the digital cardboard. With a mouse click participants can roll the die causing a marker to move around the board shown on a computer screen. Whenever the marker lands on, or passes a yellow square, a pop up screen with a description of the event and the options occurs. By clicking one of the options, the pop up screen disappears. The time corresponding to the token's position on the board is always visible in the corner of the screen. If, based on an event or the time, a PM task has to be executed, the participant has to click the button labeled 'execute task' to launch another pop-up screen that allows the participant to type the task they want to conduct. The time (position of the marker on the board) of each performed task is logged and used to calculate PM performance.

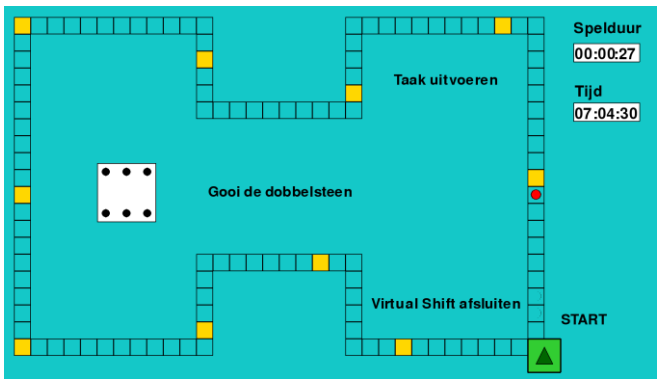

Figure 2 – Layout of the Virtual Shift board game. The red token corresponds to the virtual time, indicated on the board with 'Tijd'.

2.2 Study Population

Experienced nurses who are familiar with the EMR system will be asked to participate.

2.3 Sample Size Calculation

With this experiment we aim to detect a medium effect size of 0.25 for the most critical comparison between the three sound conditions with a power of 0.8. An a-priori power calculation was performed using G*Power software (19). The calculation was made for an ANOVA with repeated measures, within factors. The experimental design consists of one group that undergoes three measurements. Conservative estimates were made of 0.5 for the correlation among repeated measures and a nonsphericity correction of 0.5. The required sample size is 44 participants.

2.4 Sound Conditions

Three extreme conditions which can be considered realistic are modelled using Odeon 12.12 combined. The first condition represents a nurses' station of 20 m^2 with an absorptive ceiling and absorbing elements on the wall which is modelled after an existing nurses' station. Figure 3 shows the model of the room and the position of the sources that were used. The receiver location (1 in Figure 3) is located behind a desk in the room. The ambient sound environment is the result of the sound from the ventilation (L7 in Figure 3), the adjacent ward (which is separated from the nurses' station by a glass wall (M6,19 and M6,21 in Figure 3)) and one person who is working on a computer but not speaking (P5 in Figure 3). This condition is referred to as 'dry, no speech'. The second condition is similar to the first condition with the addition of background speech (P1 and P2 in Figure 3), 'dry, speech'. In the third condition, background speech is also present, and the ceiling and wall properties are such that a more reverberant environment is created, 'reverberant, speech'. Standard material properties from the Odeon library, are linked to the surfaces in the model to create realistic room acoustics (see Table 1). The acoustic properties of the ceiling, and a 1 m strip on the walls just below the ceiling are used to create the difference between room acoustic conditions. In the reverberant condition, these surfaces are modelled as plastered concrete while in the dry condition these surfaces are covered with mineral wool.

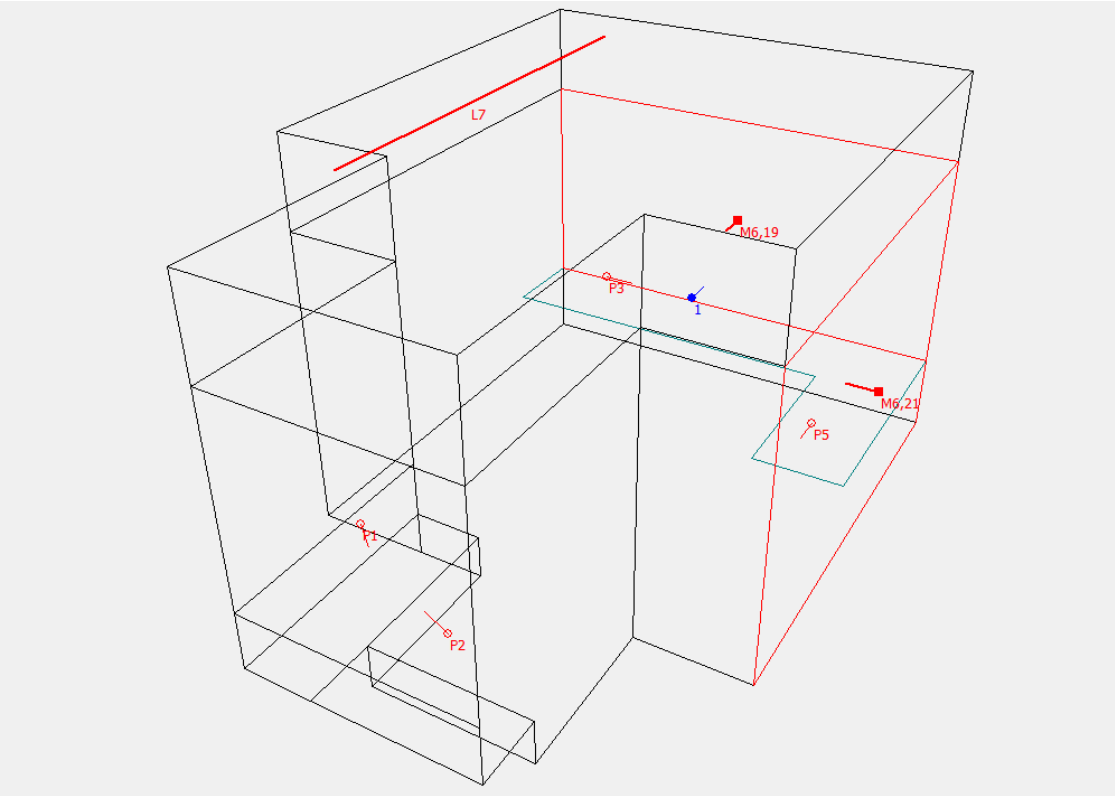

Figure 3 – Nurses' station model in Odeon

The speech signals that are used in the speech scenario's and the verbal change of shift report are to be recorded in a semi-anechoic room using a headset. Volunteers (co-workers at the university) are asked to read from a script that is written for each patient scenario. In both speech scenarios the background speech script consists of a change of shift report between two colleagues and some personal chatting. The source and receiver positions are marked in Figure 3. The information about the patients that are discussed is not relevant for the participant. Since the nursing population in the Netherlands mainly consists of females, all recorded voices are female. An additional recording is made for the change of shift report that addresses the participant.

Table 1- Material properties in Odeon model

Surface	Material code Odeon	Area
Floor	6000 – Linoleum or vinyl stuck to concrete	17.96 m^2
Lower part walls	4002 – Painted plaster surface	15.6 m^2
Glass walls	10003 - Double glazing, 2-3mm glass, 10 mm gap	14.3 m^2
Seat covers	11005 – Empty chairs, upholstered with leather cover	4.04 m^2
Wooden panels below seats	3062 – Plywood on battens fixed to solid backing	1.36 m^2
Wooden closets	3021- 6mm wood fibre board on laths, cavity >100mm deep	10.8 m^2
Desk	10- 10% absorbent	4,4 m^2
Upper part walls & Ceiling (dry)	12004- 50 mm mineral wool (40kg/m^3), glued to wall	32.8m^2
Upper part walls & Ceiling (reverberant)	4002 – Painted plaster surface	32.8m^2

2.5 Procedure

Each participant goes through the experimental procedure four times, one practice round and three experimental sound conditions. They are seated behind a desk in an enclosed, sound insulated office, wearing headphones. There are two computer screens on the desk, a main screen right in front of the participant and a second screen on the right. The main screen is connected to a keyboard. In the first phase of the experimental task the participant sees a user interface with written instructions on the main computer screen. After reading the instructions for the first time, the participant is asked to sign an informed consent form and click on a 'start' button on the user interface. In the consecutive experimental conditions, the instructions are still part of the procedure. When the start button is clicked, the audio file corresponding to the scenario starts to play and the ward overview of the EMR is shown on the screen. It shows all the patients who are 'currently' admitted to the ward, three of which are within the participants' care. The task of the participants is to read the patient files as if they were starting their shift and had to care for these patients. They are instructed to think out loud while reading the files. Intentions for actions to be performed are measured and counted by a researcher who is sitting in the back of the room. To allow offline analysis an audio recording is made. At some point during the reading task they are interrupted with a verbal shift transfer from a fictional colleague (embedded in the audio file with background sounds) which contains additional PM tasks to be performed. No repetition of the PM tasks in the EMR are included in the report. Thinking aloud is not required during the verbal change of shift report, and the assumption is made that all PM tasks received verbally lead to forming an intention. The audio stream of the verbal shift transfer is synchronized with a video on the second computer screen. The whole process of reading and the shift transfer takes a minimum of 10 minutes and a maximum of 15 minutes, depending on the reading speed of the participant. When the participant has finished reading the files, a button to continue to the next part of the experiment can be clicked. A short break during which the participant leaves the room is held between the first and the second part of the experiment.

In the second part of the experiment no headphones are used. The participant returns to the office after the short break and commences the game 'Virtual Shift'. After three circuits on the board game, the final 'event' that pops up informs the participants that they have finished their shift. After the game the participants are asked to answer a short questionnaire about the sound environment and the experimental task. After each scenario a short break outside the room is held. It is expected that one scenario lasts approximately 30 minutes, and the full experiment including instructions will take two hours.

3. ANALYSIS

The first part of the experiment is expected to provide information on the amount of intentions that are formed by the participant. The second part of the experiment is expected to provide information on the amount of correctly retrieved and therefore properly encoded intentions. The maximum amount of formed PM intentions is 15, the maximum amount of retrieved PM intentions is dependent on the amount of formed intentions by each individual participant. Therefore, there is a high correlation between the two dependent measures. To answer the main research question, whether and which aspects of the sound environment influence the forming and encoding of PM intentions, separate single-factor ANOVAs are planned for both dependent measures. The independent measure is the sound condition which has three levels. Based on the results, planned comparisons will be performed to further analyze the contribution of the two aspects of the sound environment that were included in the experiment; the presence of background speech and the room acoustic design of the nurses' station in a situation with background speech. Furthermore, we aim to analyze interaction effects for the type of PM task (time based or event based) and the presentation mode in phase one (aural or visual).

4. FINAL REMARKS

The intention of this paper was to characterize the different experimental design aspects from different disciplines that we combined in the proposed protocol while keeping the resemblance of the task, sound conditions and the sound-task interaction as high as possible. Initially, a pilot study with experienced nurses is planned. In this pilot study a small group of participants will perform the experiment in all three conditions followed by an interview on their experience. Furthermore, the results of this pilot study will be used to validate the amount and difficulty of the PM tasks that can be formed based on the EMR. The content of the EMR files will be adapted to create three scenarios with

an equal amount of intentions to be formed.

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